PROJECT MANAGEMENT FOR ENGINEERING, BUSINESS AND TECHNOLOGY

JOHN M. NICHOLAS AND HERMAN STEYN

SIXTH EDITION

"An excellent book which provides comprehensive coverage of project management theory and practice with insights from technology-based case studies, practical examples and exercises. An essential core text for project management students in engineering and technology disciplines."

—**Jane Britton,** *University College London, UK*

"As a Professor who has taught Project Engineering for the last 14 years, I have also performed large scale Project Engineering throughout my first career (over 20 years) in Aerospace, Defense and Information Technology. When deciding on a textbook for my graduate Project Engineering class, I looked long and hard. I wasn't finding what I was looking for and was going to write my own, until I found *Project Management for Engineering, Business and Technology*. This is the textbook I would have written. It is robust, complete and easy to follow. The graphics, charts and figures are all very descriptive and real. . . . I highly recommend this textbook for anyone teaching Engineering, Business or Technology Project Management/Engineering. I also recommend it as a 'keeper' for students who will be guiding projects in the future."

—**Mark Calabrese,** *University of Central Florida, USA*

"This book has long been a comprehensive but accessible publication that provides valuable insights into the strategic and day-to-day management of projects both large and small. There are numerous publications in this field but Nicholas and Steyn have found the balance between the needs of experienced practitioners looking for ways to improve project outcomes, and the needs of students who are new to the project management field. The concepts are clearly and logically laid out, and the language is appropriate for a wide range of audiences. It continues to be a benchmark in a crowded field of publications offering both practical and strategic insights into the art and craft of project management."

—**Barrie Todhunter,** *University of Southern Queensland, Australia*

"I have absolutely no hesitation in recommending this book as a standard resource for teaching students in a university set up and/or for working executives in a project environment. The book is also a good resource as a study material for certification courses."

—**Krishna Moorthy,** *Ex-Dean, Larsen & Toubro Institute of Project Management, India*

"*Project Management for Engineering, Business and Technology* is one of the most comprehensive textbooks in the field. Nicholas and Steyn explain the matter in a readable and easy-to-understand way, illustrated with interesting examples. The authors combine the 'hard matter' of project management with relevant behavioural aspects. Overall, a useful work for anyone new to the field or as reference for the more advanced project manager."

—**Martijn Leijten,** *Delft University of Technology, The Netherlands*

"A very comprehensive text. An excellent mix of materials to enable students to learn techniques and engage in discussion of scenarios."

—**Richard Kamm,** *University of Bath, UK*

Project Management for Engineering, Business and Technology

Project Management for Engineering, Business and Technology is a highly regarded textbook that addresses project management across all industries. First covering the essential background, from origins and philosophy to methodology, the bulk of the book is dedicated to concepts and techniques for practical application. Coverage includes project initiation and proposals, scope and task definition, scheduling, budgeting, risk analysis, control, project selection and portfolio management, program management, project organization, and all-important "people" aspects—project leadership, team building, conflict resolution, and stress management.

The systems development cycle is used as a framework to discuss project management in a variety of situations, making this the go-to book for managing virtually any kind of project, program, or task force. The authors focus on the ultimate purpose of project management—to unify and integrate the interests, resources, and work efforts of many stakeholders, as well as the planning, scheduling, and budgeting needed to accomplish overall project goals.

This sixth edition features:

- updates throughout to cover the latest developments in project management methodologies;
- a new chapter on project procurement management and contracts;
- an expansion of case study coverage throughout, including those on the topic of sustainability and climate change, as well as cases and examples from across the globe, including India, Africa, Asia, and Australia; and
- extensive instructor support materials, including an instructor's manual, PowerPoint slides, answers to chapter review questions, and a test bank of questions.

Taking a technical yet accessible approach, this book is an ideal resource and reference for all advanced undergraduate and graduate students in project management courses, as well as for practicing project managers across all industry sectors.

John M. Nicholas is Professor of Operations and Project Management at Loyola University Chicago, USA. He is an active teacher, writer, and researcher in the areas of project management and lean production and has led or participated in projects with organizations such as Lockheed Martin Corporation, Bank of America, and Argonne National Laboratory.

Herman Steyn is Professor of Project Management in the Graduate School of Technology Management, University of Pretoria, South Africa. He has also managed a variety of large- and small-scale engineering projects and is the author of widely cited papers on project management.

Project Management for Engineering, Business and Technology

SIXTH EDITION

John M. Nicholas
Loyola University Chicago

Herman Steyn
University of Pretoria

Routledge
Taylor & Francis Group
LONDON AND NEW YORK

Sixth edition published 2021
by Routledge
2 Park Square, Milton Park, Abingdon, Oxon, OX14 4RN

and by Routledge
52 Vanderbilt Avenue, New York, NY 10017

Routledge is an imprint of the Taylor & Francis Group, an informa business

Third edition published by Elsevier Inc. 2008
Fourth edition published by Routledge 2012
Fifth edition published by Routledge 2017

British Library Cataloguing-in-Publication Data
A catalogue record for this book is available from the British Library

Library of Congress Cataloging-in-Publication Data
Names: Nicholas, John M., 1945– author. | Steyn, Herman, author.
Title: Project management for engineering, business and technology /
  John M. Nicholas, Loyola University Chicago, Herman Steyn,
  University of Pretoria.
Description: Sixth edition. | Abingdon, Oxon ; New York, NY : Routledge, 2020. |
  Includes bibliographical references and index.
Identifiers: LCCN 2020009827 (print) | LCCN 2020009828 (ebook) | ISBN 9780367277307 (hardback) |
  ISBN 9780367277345 (paperback) | ISBN 9780429297588 (ebook)
Subjects: LCSH: Project management.
Classification: LCC HD69.P75 N53 2020 (print) | LCC HD69.P75 (ebook) |
  DDC 658.4/04—dc23
LC record available at https://lccn.loc.gov/2020009827
LC ebook record available at https://lccn.loc.gov/2020009828

ISBN: 978-0-367-27730-7 (hbk)
ISBN: 978-0-367-27734-5 (pbk)
ISBN: 978-0-429-29758-8 (ebk)

Typeset in Joanna MT
by Apex CoVantage, LLC

Visit the companion website: www.routledge.com/cw/nicholas

To Sharry, Julia, Joshua, and Abigail
J.M.N.

To Karen and Janine
H.S.

Brief Contents

Taylor & Francis
Taylor & Francis Group
http://taylorandfrancis.com

Contents

Preface

When people see or use something impressive—a bridge arching high over a canyon, a space probe touching down on a distant planet, an animated game so realistic you think you're there, or a nifty phone/camera/computer the size of your hand—they sometimes wonder, "How did they do that?" By *they*, of course, they are referring to the creators, designers, and builders, the people who created—thought up and made—those things. Seldom do they wonder about the *leaders* and *managers*, the people who organized and lead the efforts that brought those astounding things from concept to reality and without whom most neat ideas would never have been achieved. This book is about them—the managers of projects, the mostly unsung heroes of engineering, business, and technology who stand outside the public eye but ultimately are responsible for practically everything that requires collective human effort.

The projects is but one of many people involved in the creation of society's products, systems, and artifacts, yet it is he or she who gets the others involved and organizes and directs their efforts so everything comes out right. Occasionally, the manager and the creator happen to be the same: Burt Rutan, Woody Allen, and Gutzon Borglum are examples; their life work—in aerospace, motion pictures, and monumental sculptures, respectively—represent not only creative or technological genius but leadership and managerial talent as well.

In the last several decades, businesses have expanded from domestic, nationalistic enterprises and markets into multinational, global enterprises and markets. As a result, from a business perspective, there is more of everything to contend with—more ideas, competitors, resources, constraints, and, certainly, more people doing and wanting things. Technology is advancing and products and processes are evolving at a more rapid pace; as a result, the life cycles of most things in society are getting shorter. This "more of everything" has had a direct impact on the conduct of projects—including projects to develop products, systems, or processes that compete in local, domestic, and international markets; projects to create and implement new ways of meeting demand for energy, recreation, housing, communication, transportation, and food; and projects to answer basic questions in science and resolve grave problems such as disease, pollution, climate change, and the aftermath of natural disasters. All of this project activity has spurred a growing interest in improved ways to plan, organize, and guide projects to better meet the needs of customers, markets, and society within the bounds of limited time and resources.

Associated with this interest is the growing need to educate and train project managers. In the past—and still today—project managers were chosen for some demonstrated exceptional capability, although not necessarily managerial. If you were a good engineer, systems analyst, researcher, architect, or accountant, eventually you would become a project manager. Somewhere along the way, presumably, you would pick up the "other" necessary skills. The flaw in this reasoning is that project management encompasses a broad range of skills—managerial, leadership, interpersonal—that are much different from and independent of skills associated with technical competency. And there is no reason to presume that the project environment alone will provide the opportunity for someone to "pick up" these other necessary skills.

As a text and handbook, this book is about the "right" way to manage projects. It is intended for advanced undergraduate and graduate university students and practicing managers in engineering, business, and technology. It is a book about principles *and* practice, meaning that the topics in it are practical and meant to be applied. It covers the big picture of project management—origins, applications, and philosophy, as well as the nitty-gritty, how-to steps. It describes the usual project management topics of schedules, budgets, and controls but also the human side of project management, including leadership and conflict.

Why a book on project management in engineering *and* business *and* technology? In our experience, technology specialists such as engineers, programmers, architects, chemists, and so on involved in "engineering/technology projects" often have little or no management or leadership training. This book, which includes many engineering and technology examples, provides somewhat broad exposure to business concepts and management specifics to help these specialists get started as managers and leaders.

What about those people involved in product-development, marketing, process-improvement, and related projects commonly thought of as "business projects"? Just as technology specialists seldom receive formal management training, students and practitioners of business rarely get formal exposure to practices common in technology projects. For them, this book describes not only how "business" projects are conducted but also the necessary steps in the conception and execution of engineering, system development, construction, and other "technology" projects. Of course, every technology project is *also* a business project: it is conducted in a business context and involves business issues such as customer satisfaction, resource utilization, deadlines, costs, and profits.

Virtually all projects—engineering, technology, and business—originate and are conducted in a similar way, in this book conceptualized using a methodology called the systems development cycle (SDC). The SDC serves as a general framework for discussing the principles and practices of project management and illustrating commonalities and differences among a wide variety of projects.

This book is an outgrowth of the authors' combined several decades of experience teaching project management at Loyola University Chicago and University of Pretoria to business and engineering students, preceded by several years' experience in business and technology projects, including for aircraft design and flight tests, large-scale process facility construction, and software application development and process improvement. This practical experience gave us an appreciation not only for the business-management side of project management but also for the human-interpersonal side as well. We have seen the benefits of good communication, trust, and teamwork, as well as the costs of poor leadership, emotional stress, and group conflict. In our experience, the most successful projects are those where leadership, trust, communication, and teamwork flourished, regardless of the formal planning and control methods and systems in place. This book largely reflects these personal experiences. Of course, comprehensive coverage of project management required that we look much beyond our own experience and draw upon the published works of many others and the wisdom and suggestions of colleagues and reviewers.

In this sixth edition, we have revised and added material to incorporate new topics of interest, current examples, and the growing body of literature in project management. Among significant changes are a new chapter on project procurement management (Chapter 12) and completely reorganized chapters on project execution and closeout (Chapter 5) and project monitoring and control (Chapter 13). The Introduction includes updated tables that relate sections of the book to the project management knowledge areas and methodologies of PMI, PMBOK, IPMA, APM, and PRINCE2. Also newly included are examples recognizing the role of project management in addressing sustainability and climate change (Chapters 3, 11, and 19). Books tend to grow in size with each new edition; to combat that, all chapters have been rewritten to make everything more readable and concise. Despite the inclusion of new material, we've held the page count to roughly the same as it was in the previous edition.

Our goal in writing this book is to provide students and practicing managers the most practical, current, and interesting text possible. We appreciate hearing your comments and suggestions. Please send them to us at jnichol@luc.edu and herman.steyn@up.ac.za.

Acknowledgments

Like most projects, writing a book reflects the contributions of many people. We want to acknowledge and give special thanks to those who contributed the most. First, thanks to our research assistants. Research assistants in general do a lot of work—academic as well as gofer, and without their toiling efforts, most professors would accomplish far less. We were fortunate to have had the assistance of several such bright and capable people, particularly Elisa Denney, Hollyce James, Diane Petrozzo, Miguel Velasco, Gaurav Monga, Cary Morgan, Louis Schwartzman, and Brian Whelan.

Special thanks to current and former colleagues at Loyola University Chicago and the University of Pretoria. In Chicago, thanks to Dr. Gezinus Hidding for his enthusiasm and contributions to the field of project management and to Drs. Enrique Venta, Harold Dyck, Samuel Ramenofsky, and Donald Meyer, and to Elaine Strnad, Paul Flugel, John Edison, Sharon Tylus, and Debbie Gillespie for their suggestions and support for this and earlier editions. In Pretoria, thanks to Dr. Tinus Pretorius and Dr. Elma van der Lingen for encouraging education and research in project management at the Graduate School of Technology Management and for supporting the work on this book. I (Herman) also want to express appreciation to Dr. Taryn Bond-Barnard, Dr. Giel Bekker, Corro van Waveren, Philip Viljoen, Sarel Lotz, Anneli Delport, Dr. Jorg Lalk, Dr. Pieter Pretorius, Dr. Krige Visser, Dr. Michael Carruthers, Dr. Marie-Louise Barry, and Dr. Suzaan Pretorius for their direct and indirect contributions to this book and for all I have learned from them. I (John) want to acknowledge the influence of three of my professors, Dr. Charles Thompson and Dr. Gustave Rath at Northwestern University and Dr. Dick Evans at the University of Illinois, whose philosophies and teachings helped shaped this book. I also want to thank Chris Phares and Bob Zimmerman, dear friends and project managers extraordinaire, for ongoing sharing of their wisdom on the meaning and significance of project leadership.

Special thanks also to our wives, Sharry and Karen. Sharry provided numerous suggestions for the first edition and helped reduce the amount of "techno-jargon" in the book; she managed the home front and freed up time so that I (John) could pursue and complete this project. Karen provided wifely support and encouragement; as in the case of so many other projects I (Herman) have been involved in, my contribution to this project would never have materialized had not it been for her support.

Thanks also to Sophia Levine, Emmie Shand, Marie Louise Roberts, and the folks at Routledge and Taylor and Francis for their ongoing support throughout preparation of this sixth edition.

Other colleagues, students, and friends, some mentioned in the endnotes throughout the book, provided support, encouragement, and reference materials; to them also, we say thank you. Despite the assistance of so many people and our own best efforts, there are still likely to be omissions or errors. We had final say and accept responsibility for them.

John M. Nicholas
Herman Steyn

About the authors

JOHN M. NICHOLAS is Professor of Operations Management and Project Management in the Quinlan School of Business at Loyola University Chicago. He is an active teacher, writer, and researcher in project management and production management and conducts executive seminars and consuls on project management and process improvement. John is the author of numerous academic and technical publications and five books, including *Lean Production for Competitive Advantage* (2018) and *The Portal to Lean Production* (2006). He has held the positions of team lead and engineer on military and commercial aircraft development projects at Lockheed-Martin Corporation, team lead and business analyst on operations projects at Bank America, and researcher on energy-environmental research projects at Argonne National Laboratory. He has a BS in aeronautical and astronautical engineering and an MBA in operations research from the University of Illinois, Urbana-Champaign, and a PhD in industrial engineering and applied behavioral science from Northwestern University.

HERMAN STEYN is Professor of Project Management in the Graduate School of Technology Management, University of Pretoria, South Africa. He has been involved in projects in industry since 1975; has managed a variety of large and small engineering projects (system, product, and process development) in the minerals, defense, and nuclear industries; and has also managed programs and project portfolios. In 1996, he was appointed in his current position at the University of Pretoria, where he initiated a masters' program in project management. Besides supervising project management research and teaching graduate project management courses, Herman has conducted more than 200 seminars and workshops on project management. He has a bachelor's degree and graduate diploma in metallurgical engineering, an MBA, and a PhD in engineering management.

Taylor & Francis
Taylor & Francis Group
http://taylorandfrancis.com

Introduction

I.1 In the beginning. . .

Sometime during the third millennium BC, workers on the Great Pyramid of Khufu set the last stone in place. They must have felt jubilant, for this event represented a milestone of sorts in one of humanity's grandest undertakings. Although much of the ancient Egyptians' technology is still a mystery, the enormity and quality of the finished product remains a marvel. Despite the lack of sophisticated machinery, they were able to raise and fit some 2,300,000 stone blocks, weighing 2 to 70 tons apiece, into a structure the height of a modern 40-story building. Each facing stone was set against the next with an accuracy of 0.04 inch (1 mm), and the base, which covers 13 acres (52,600 m^2), deviates less than 1 inch (25 mm) from level (Figure I.1).[1]

Equally staggering was the number of workers involved. To quarry the stones and transport them down the Nile, 20,000–30,000 laborers were levied. In addition, skilled masons and attendants were employed in preparing and laying the blocks and erecting or dismantling the construction ramps. Public works were essential to keep the working population employed and fed, and it is estimated that no less than 150,000 women and children also had to be housed and fed.[2] But just as mind-boggling was the managerial ability exercised by the Egyptians throughout the estimated 20-year duration of the pyramid construction. Francis Barber, a nineteenth-century pyramid scholar, concluded that:

> It must have taken the organizational capacity of a genius to plan all the work, to lay it out, to provide for emergencies and accidents, to see that the men in the quarries, on the boats and sleds, and in the mason's and smithies shops were all continuously and usefully employed, that the means of transportation was ample . . . that the water supply was ample . . . and that the sick reliefs were on hand.[3]

Some have suggested the pyramid was built by slaves, but research indicates that such a massive undertaking could only have been accomplished by a highly skilled, motivated, and well-fed workforce, eager to participate in such an historic and honorable endeavor.

Building the Great Pyramid is what we today would call a large-scale project. It stands among numerous projects from early recorded history that required massive human works, complex and thorough planning, and managerial competency. For the Great Pyramid's construction, we know that the pharaoh Khufu chose his vizier, Hemiunu, to manage and lead the project.

Figure I.1

The Great Pyramid of Khufu, center back, an early (circa 2500 BC) large-scale project.

Source: Photo courtesy of iStock.

Also worthy of note are the managerial and leadership accomplishments of Moses. The Biblical account of the exodus of the Hebrews from the bondage of the Egyptians gives some perspective on the preparation, organization, and execution of this tremendous undertaking. Supposedly Moses did a magnificent job of personnel selection, training, organization, and delegation of authority.[4] The famed ruler Solomon also was the “manager” of great projects. He transformed the battered ruins of many ancient cities and crude shantytowns into powerful fortifications. With his wealth and the help of Phoenician artisans, Solomon built the Temple in Jerusalem. Seven years went into the construction of the Temple, after which Solomon took 13 years more to build a palace for himself. He employed a workforce of 30,000 Israelites to fell trees and import timber from the forests of Lebanon.[5] That was almost 3,000 years ago.

With later civilizations, notably the Greeks and Romans, projects requiring extensive planning and organizing escalated. To facilitate their military campaigns and commercial interests, the Romans constructed networks of highways and roads throughout Europe, Asia Minor, Palestine, and northern Africa so that all roads would “lead to Rome.” The civilizations of Renaissance Europe and the Middle and Far East undertook river engineering, construction of aqueducts, canals, dams, locks, and port and harbor facilities. With the spread of modern religions, construction of temples, monasteries, mosques, and massive urban cathedrals was added to the list of projects.

With the advent of industrialization and electricity, projects for the construction of railroads, electrical and hydro-electrical power facilities and infrastructures, subways, and factories became commonplace. In recent times, development of large systems for communications, defense, transportation, research, and information technology have spurred different, more complex kinds of project activity.

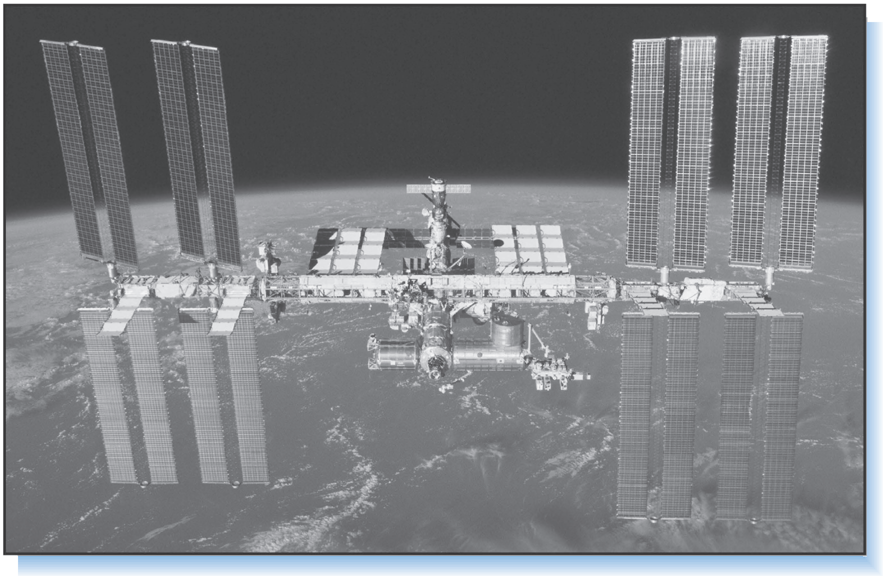


Figure I.2
The International Space Station, a modern large-scale project.
Source: Photo courtesy of NASA.

As long as people do things, there will be projects. Many projects of the future will be similar to those in the past. Others will be different either in terms of increased scale of effort or more advanced technology. Representative of the latter are two recent projects, the English Channel tunnel (Chunnel) and the International Space Station. The Chunnel required tremendous resources and took a decade to complete. The International Space Station (Figure I.2) required development of new technologies and the efforts of the US, Russian, European, Canadian, and Japanese space agencies.

I.2 What is a project?

From these examples, it is clear that humankind has been involved in project activities for a long time. But why are these considered "projects" while other human activities, such as planting and harvesting a crop, stocking a warehouse, issuing payroll checks, or manufacturing a product, are not?

What is a project? This is a question we will cover in much detail later. As an introduction, though, listed subsequently are some characteristics that warrant classifying an activity as a project.[6]

1. A project has a defined *goal—a purpose* with *well-defined end-items, deliverables*, or *results* to achieve specific *benefits*.
2. It is *unique*; it requires doing something differently than was done previously. It is a one-time activity, never to be exactly repeated again.
3. It is a *temporary* organization formed to accomplish the project goal in a limited time frame.
4. It utilizes people and other resources *from different organizations and functions*.
5. Given that each project is unique, it carries *unfamiliarity* and risk.

The examples described earlier are for familiar kinds of projects such as construction (pyramids) and technology development (space station). In general, the list of activities that qualify as projects is long and includes many that are commonplace. Weddings, remodeling a home, and moving to another house are projects; so are company audits, major litigations, corporate relocations, and motion picture productions; and so are efforts to develop new products and implement new systems. Military campaigns also qualify as projects; they are temporary, unique efforts directed toward a specific goal. The Normandy Invasion in World War II on June 6, 1944 is an example:

> The technical ingenuity and organizational skill that made the landings possible was staggering. The invasion armada included nearly 5,000 ships of all descriptions protected by another 900 warships. The plan called for landing 150,000 troops and 1500 tanks on the Normandy coast *in the first 48 hours*.[7]

Most artistic endeavors are projects, too. Composing a song or symphony, writing a novel, or making a sculpture are one-person projects. Some artistic projects also require the skills of engineers and builders, for example, Mount Rushmore, the Statue of Liberty, and the Eiffel Tower.

Many efforts at saving human life and recovering from man-made or natural disasters become projects. Examples are the massive cleanup following the Soviet nuclear accident at Chernobyl; rescue and recovery operations following disastrous earthquakes in Chile, Haiti, China, Pakistan, Mexico, Turkey, Italy, and elsewhere; the Indian Ocean tsunami of 2004; the Ebola outbreak in western Africa in 2014; and the COVID-2019 pandemic. Ongoing efforts to stem climate change and mitigate its global effects will of necessity spur innumerable projects.

Figure I.3 shows diverse project endeavors and examples of well-known projects and where the projects fall with respect to complexity and uncertainty. Complexity is measured by the magnitude of the effort—the number of groups and organizations involved and the diversity of skills or expertise needed to accomplish the work. Time and resource commitments tend to increase with complexity.

Uncertainty is measured roughly by the difficulty in predicting the final outcome in terms of the dimensions of *time*, *cost*, and *technical performance*. In most projects, there is some uncertainty in one or two dimensions (e.g. weddings); in complex projects, there is uncertainty in all three (e.g. the space station).

Generally, the more often something is done, the less uncertainty there is in doing it. This is simply because people learn by doing and so improve their efforts—the "learning curve" concept. Projects that are very similar to previous ones and about which there is abundant knowledge have lower uncertainty. These are found in the lower portion of Figure I.3 (e.g. weddings, highways, dams, system implementation). Projects with high uncertainty are in the upper portion of the figure.

When the uncertainty of a project drops to nearly zero, and when the project effort is repeated a large number of times, then the work is usually no longer considered a project. For example, building a skyscraper is definitely a project, but mass construction of prefabricated homes more closely resembles a scheduled, repetitive operation than a project. The first flight to the South Pole by Admiral Byrd was a project, but modern daily supply flights to bases there are not. Early human missions to Mars will be projects, but future chartered tourist trips to hotels and excursions on Mars will not be. They will just be run-of-the-mill scheduled operations.

The cost curve in Figure I.3 indicates that a project's expense tends to increase roughly in proportion to its complexity and uncertainty. Cost, represented in terms of time or economic value, is at the level of tens or hundreds of labor hours for projects with low complexity and uncertainty but increases to millions and billions of hours for projects with the greatest complexity and uncertainty.

In all cases, projects are conducted by organizations that, after the project is completed, go on to do something else (construction companies) or are disbanded (Admiral Byrd's crew, the Mars exploration team). In contrast, repetitive, high-certainty activities (prefabricated housing, supply flights, and tourist trips to Antarctica or Mars) are performed by permanent organizations that do the same thing repeatedly, with few changes in operations other than scheduling. Because projects are not repetitive, they must be managed differently.

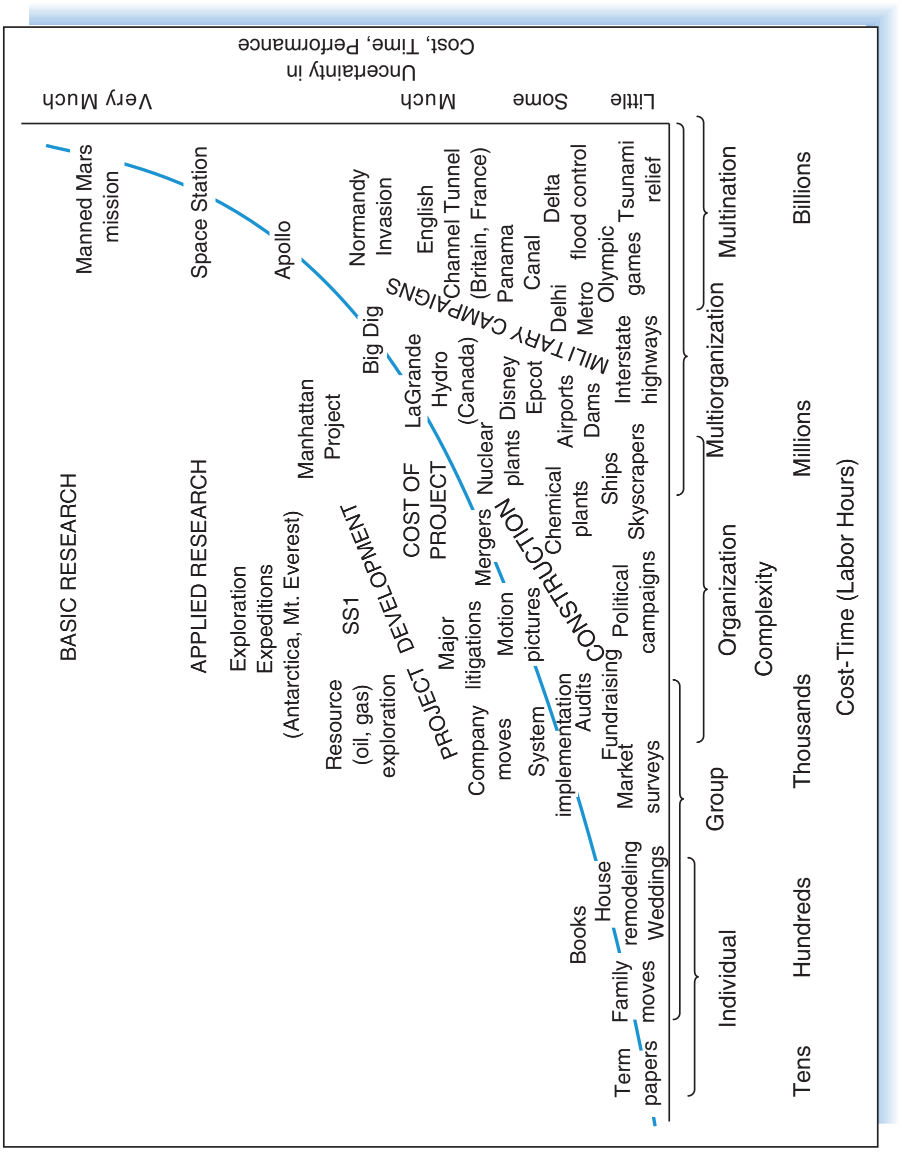


Figure I.3
A typology of projects.

I.3 All projects are not the same[8]

Besides Figure I.3, another way to illustrate the diversity in projects is with the so-called NTCP model or Diamond model, which classifies projects and their end results or products into four dimensions, each with three or four possible levels. The dimensions and levels are:

- *Novelty*: Represents how new the project end-item or product is to customers and potential users and how well defined its initial product requirements are. It has three levels:
    - *Derivative*—the project end-item or product is an extension or improvement of an existing product or system, for example, new features to an existing car model
    - *Platform*—the end-item or product is a new generation of an existing product line in a well-established market, for example, a new car model
    - *Breakthrough*—the end-item or product is new to the world, for example, the first mobile telephone, the first commercially available flying car.
- *Technology*: Represents the project's technological uncertainty and whether it is new or mature. It addresses the question of how much new technology is required to create, build, manufacture, and enable the use of the product and how much technical competency is needed by the project manager and the team. It has four levels:
    - *Low-tech*—involves only well-established technologies
    - *Medium-tech*—uses mainly existing technologies but also limited use of some new technology or new features, for example, automotive and appliances industries
    - *High-tech*—uses technologies that are mostly new to the firm but already exist and are available at project initiation; typical of many defense and computer projects; is synonymous with "high-risk"
    - *Super-high-tech*—relies on new technologies that do not exist at project initiation. The project goal is well defined, but the solution is not; is synonymous with "very high-risk," for example, landing humans on Mars.
- *Complexity*: Represents the complexity of the product and the project organization; has three levels:
    - *Assembly*—the project involves combining a collection of elements, components, and modules into a single unit or entity that performs a single function, for example, developing a new coffee machine or creating a department to manage a single function (such as payroll)
    - *System*—involves a complex collection of interactive elements and subsystems that jointly perform multiple functions to meet specific operational needs, for example, creating a new car, new computer, or entirely new business;
    - *Array*—the project involves a large variety of dispersed systems (a system of systems, or "super system") that function together to achieve a common purpose, for example, national communications network, mass transit infrastructure, regional power generation and distribution network, an entire corporation.
- *Pace*: Refers to time available for the project—the urgency or criticality of meeting project's completion targets; has four levels:
    - *Regular*—no urgency; time is not critical to immediate success
    - *Fast/competitive*—complete project in adequate time to address market opportunities, create a strategic positioning, or form a new business unit, for example, launching a new drug, introducing a new product line
    - *Time-critical*—complete project by a specific deadline; missing the deadline means project failure, for example, Y2K projects, construction of facilities for the Olympic Games, launch of space probe to a comet
    - *Blitz*—a crisis project; the criterion for success is solving a problem as fast as possible, for example, rescue the survivors of a tsunami or develop a vaccine in a pandemic.

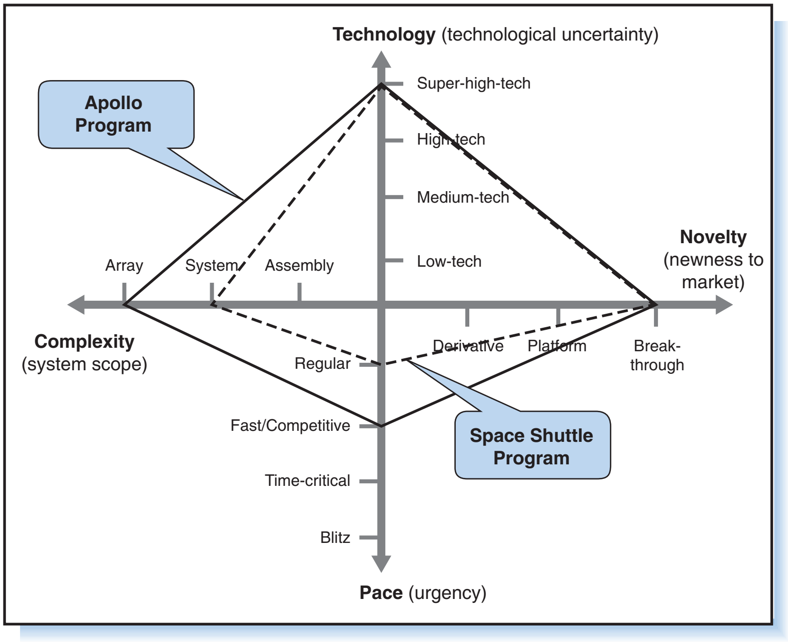


Figure I.4
Shenhar and Dvir's NTCP diamond model contrasting the Apollo and space shuttle programs.

Source: Shenhar A. and Dvir D. *Reinventing Project Management: The Diamond Approach to Successful Growth and Innovation*. Cambridge, MA: Harvard Business School Press; 2007.

All projects can be characterized according to the four dimensions. In Figure I.4, each of the dimensions is represented by a quadrant on the graph. The diamond-shaped profiles show the four dimensions for two examples, the Apollo lunar program and the space shuttle program.

I.4 Project management: the need

Although mankind has been involved in projects since the beginning of recorded history, obviously the nature of projects and the environment have changed. Many modern projects involve technical complexity and challenges in terms of assembling and directing large temporary organizations while subject to constrained resources, limited time schedules, and environmental uncertainty. An example is the NASA Pathfinder Mission to land and operate a rover vehicle on the surface of Mars. Such a project was unparalleled not only in terms of technical difficulty and organizational complexity but also for the requirements imposed on it. In ancient times, requirements were more flexible. When Renaissance builders ran out of funds during construction of a cathedral, they stopped the work until more funds could be raised (one reason cathedrals took decades or centuries to complete). When a king ran out of money while building a fortress or palace, he could just levy more taxes. In cases where additional money or workers could not be found or the project delayed, then the scale of effort or quality of workmanship was reduced.

More common, however, project requirements are not flexible. Khufu's Great Pyramid had to be completed before the pharaoh died to serve as his tomb and portal to the afterlife, and tens of thousands of skilled artisans and laborers were recruited so as to meet that deadline (pun intended). The Mars Pathfinder project was challenged with developing and landing a vehicle on Mars in less than 3 years' time and on a $150 million budget—less than half the time and 1/20th the cost of the last probe NASA had landed on Mars. The project involved advanced research and explored new areas of science and engineering. Technical performance requirements could not be compromised.

Beyond large-scale engineering efforts, constraints and uncertainty are common in everyday business and technology projects where organizations strive to develop and implement new products, processes, and systems and to adapt to changing requirements in a changing world. Consider Dalian Company's development of "Product J," a product development project that exemplifies companies everywhere in the struggle to remain competitive. Product J is a promising but radically new idea. To move the idea from a concept to a real product will require the involvement of engineers and technicians from several Dalian divisions and suppliers. Product J will require meeting tough technical challenges, launching the product ahead of the competition, and doing it for an affordable cost.

Another example is Shah Alam Hospital's installation of a new employee benefits plan. The project would involve developing new policies, training staff workers, familiarizing 10,000 employees with the plan, and installing new software and a database and require participation from personnel in human resources, financial services, and information systems, plus experts from two consulting firms. It typifies "change" projects everywhere—projects initiated in response to changing needs and with the goal of transforming the organization's way of doing things.

Finally, consider that virtually every company has or will have a website. Behind each site are multiple projects to develop or enhance the website and to integrate electronic business technology into the company's mainstream marketing and supply-chain operations. Such projects are also examples of organizations' need to change, in this case to keep pace with advances in information technology and business processes.

Activities such as these defy traditional management approaches for planning, organization, and control. They are representative of activities that require the use of project management to meet technological or market-related performance goals in spite of limited time and resources.

I.5 Project goal: time, cost, and performance

The goal of every project can be conceptualized in terms of hitting a target that floats in three-dimensional space—the dimensions of *cost*, *time*, and *performance* (Figure 1.5). Cost is the specified or budgeted cost for the project. Time is the scheduled period over which the work is to be done. Performance is what the project end-item, deliverables, or final result must do; it includes whatever the project customer, user, and other stakeholders consider necessary or important. The target represents a goal to deliver a certain something to somebody by a certain date and for a certain cost. The purpose of project management is to hit the project target goal.[9]

But technological complexity, changing markets, and an uncontrollable environment make hitting the target difficult. Time, cost, and technical performance are interrelated, and exclusive emphasis on any one will likely undermine the others. In trying to meet schedules and performance requirements, costs increase; conversely, in trying to contain costs, work performance erodes and schedules slip. In earlier times, one or two aspects of the goal could be allowed to slide so that the "most fixed" could be met. Many projects, such as the Pathfinder, Dalian Company, and Shah Alam Hospital examples, do not have this luxury. Project management offers a way to maintain focus on all three dimensions and to control the tradeoffs among them.

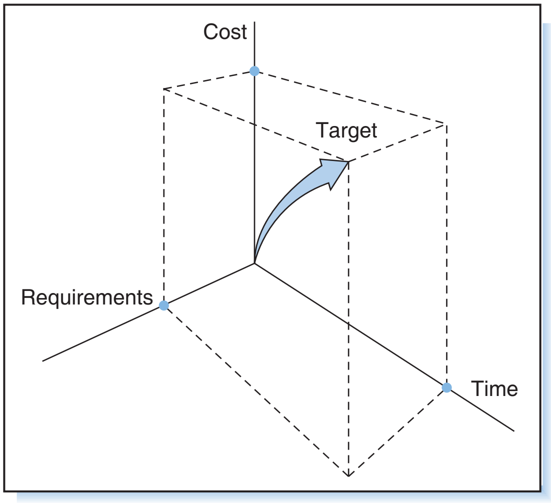


Figure I.5
Three-dimensional project goal.
Source: Adapted from Rosenau M. *Successful Project Management*. Belmont, CA: Lifetime Learning Publications; 1981, p. 16.

I.6 Project management: the person, the team, the methodology

Three features distinguish project management from traditional forms of management: the person, the team, and the methodology.

The most prominent feature of project management is the role of the project manager—the individual who has overall responsibility to *plan*, *direct*, and *integrate* the efforts of everyone associated with the project to achieve the project goal. In the role of project manager, one person is held accountable for the project and is dedicated to achieving its goals. The project manager coordinates the efforts of every functional area and organization in the project and oversees the planning and control of costs, schedules, and work tasks. As we will discuss, numerous other parties (stakeholders) are also involved in and crucial to project management; nonetheless, the role of project manager is a key feature distinguishing project- from non-project management.

Doing a project is a team effort, and project management means bringing individuals and groups together to form the team and directing them toward the common goal. The team will often consist of people and groups from different functional areas and organizations. Depending on the project, the size and composition of the team may fluctuate; usually the team disbands after the project is completed.

The project manager and project team typically perform work in phases according to a "project management methodology." This methodology provides for *integrative planning and control* of projects, which, says Archibald, refers to the pulling together of all important elements of information related to (1) the products or results of the project, (2) the time, and (3) the cost, in funds, manpower, or other key resources . . . for all (or as many as practical) phases of the project. [It] requires continual revision of future plans, comparison of actual results with plans, and projection of total time and cost at *completion* through interrelated evaluation of all elements of information.[10]

As a project proceeds from one phase to the next, the project manager relies on the methodology to (1) identify the project tasks, (2) identify the required resources and costs, (3) establish priorities, (4) plan and update schedules, (5) monitor and control end-item quality and performance, and (6) measure project performance.[11]

I.7 Project management standards of knowledge and competencies

Project management has become a recognized vocation supported by several professional organizations around the world. These organizations have advanced project management by establishing standards, guidelines, and certifications. Among the more well-known of these organizations are the International Project Management Association (IPMA), Association for Project Management (APM) Group, and Project Management Institute (PMI). PMI is based in the United States and is the largest of these organizations; IPMA, based in the Netherlands, is an international group of national project management associations in Europe, Africa, Asia, and North and South America; APM is based in the United Kingdom.

These professional organizations have published accepted best practices of project management as standards or "bodies of knowledge" (BOKs) and competencies for the profession.[12] Although none of the standards covers everything about project management, they have become recognized norms about what minimally a project management professional should know. The organizations also offer levels of qualification and certification that include, for example, PMI's Project Management Professional (PMP) certification, APM's APM Professional (APMP), and IPMA's Certified Project Management Associate (CPMA). PMI's and APM's certifications are "BOK-based"; IPMA's certifications are "competency-based." Another certification popular in Europe is based upon PRojects IN Controlled Environments, Version 2 (PRINCE2), a project management methodology originated by the UK Office of Government Commerce.[13]

For readers interested in professional certification, Tables I.1 through I.4 in the Appendix to the chapter show the correspondence between the knowledge areas, competencies expected, and methods from PMI, IPMA, APM, and PRINCE and chapters in this book most relevant to them.

I.8 About this book

Philosophy and objectives

As a philosophy and an approach, project management is broader and more sophisticated than traditional management of repetitive activities. It has roots in many disciplines, including management science, systems theory, accounting, operations management, organizational design, law, and applied behavioral science. What has evolved, and will continue to evolve, are a philosophy, approach, and set of practices, the *sum total* of which make up project management. Some managers fail to understand this, believing that application of techniques alone, such as "Gantt charts," "critical path," or "matrix management" (all explained later) makes for successful project management. Project management is much more than these.

C.P. Snow wrote an essay entitled "Two Cultures" about the cultural gap that separates scientists from the rest of society.[14] Managers and management scholars also tend to separate the world into either of two perspectives: (1) the "quantitativists" tend to view projects in terms of costs, dates, and economic variables; (2) the "behaviorists" view projects in terms of peoples' behavior, skills and attitudes, and systems of organization.

The intent of this book is to give a balanced view that emphasizes both the behaviorist and quantitativist views of project management. The philosophy of this book is that for managers to "do" project management, they need familiarity with four topical areas: system methodology; systems development process; management methods, procedures, and systems; and organization and human behavior; correspondingly, the objectives of this book are to cover in depth:

1. The principles and philosophy that guide project management practice.
2. The logical sequence of stages in the life of a project.
3. The methods, procedures, and systems for defining, planning, scheduling, controlling, and organizing project activities.
4. The organizational, managerial, and human behavioral issues in project management.

In recent years, the scope of project management has grown to encompass more than the management of individual projects, recognizing that project success involves more than managerial skills and talent; hence, a final objective of the book is to cover:

5. Responsibilities of the *organization* for assuring effective project management and successful projects.

Organization of this book

Beyond this introductory chapter, the book is divided into five main parts. The first part is devoted to the basic concepts of project management. It describes project management principles, systems methodologies, and the systems approach—the philosophy that underlies project management. It also covers the origins and concepts of project management, situations where it is needed, and examples of applications. The second part describes the logical process in the creation and life of a system. Called the systems development cycle, it is the sequence of phases through which all human-made systems move from birth to death. The cycle is described in terms of its relation to projects and project management. The third part is devoted to methods and procedures for planning, scheduling, cost estimating, budgeting, risk management, procurement, controlling, and terminating a project. The topics of resource planning, computer and web-based project management, and project evaluation are also covered. The fourth part is devoted to project organizations, teams, and the people in projects. It covers forms of project organization, roles and responsibilities of project managers and team members, leadership styles, and methods for managing teamwork and conflict. The last part covers topics that lie beyond the project manager but are crucial for project success and, more broadly, the success of the organizations and communities that sponsor and undertake projects. It also covers a topic that spans most other topics in this book but requires special attention: managing international projects.

The five stated objectives of this book are roughly divided among the book's five parts:

1. Basic concepts and systems philosophy: Chapters 1 and 2.
2. Systems development and project life cycle: Chapters 3 through 5.
3. Systems and procedures for planning and control: Chapters 6 through 14.
4. Organizations, management, and human behavior: Chapters 15 through 17.
5. The corporate context and international project management: Chapters 18 through 20.

Three Appendices provide in-depth examples of topics covered throughout the book: request for proposal (Appendix A), project proposal (Appendix B), and project execution plan (Appendix C).

I.9 Study project

The best way to learn about project management is to actually participate in it or, failing that, to witness it. At the end of every chapter in this book are two kinds of questions: the first kind are the usual chapter review questions; the second are called "Questions About the Study Project." The latter are intended to be applied to a particular project of the reader's choosing. This will be called the "study project." The purpose of these questions and the study project is to help the reader relate concepts from each chapter to real-life situations.

The study project questions can be used in two ways:

1. For readers who currently work in projects as managers or project team members, the questions can be related to their current work. They serve to increase the reader's awareness of key issues surrounding the project and to guide managers in the conduct of project management.
2. For readers who currently are full- or part-time students, the questions can be applied to "real-life" projects they are permitted to observe and research. Many business firms and government agencies are happy to allow student groups to interview managers and collect information about their projects. Though secondhand, this is nonetheless an excellent way to learn about project management practice (and mismanagement).

Assignment

Select a project to investigate. It should be a "real" project; that is, a project that has a real purpose and is not contrived just so you can investigate it. It can be a current project or one already completed; whichever, it must be a project for which you can readily get information.

If you are not currently involved in a project as a team member, then you must find one for which you have permission to collect data and interview people as an "outsider." The project should include a project team (minimum of five people) with a project leader and be at least 2 or 3 months in duration. It should also have a specific goal in terms of a target completion date, a budget limit, and a specified end-item result or product. In general, larger projects afford better opportunity to observe the concepts of project management than smaller ones.

If you are studying a project as an outsider, it is also a good idea to do it in a team with three to six people and an appointed team leader. This, in essence, becomes your *project team*—a team organized for the purpose of studying a project. You can then readily apply many of the planning, organizing, team-building, and other procedures discussed throughout the book as practice and to see how they work. This "hands-on" experience with your own team, combined with what you learn from the project you are studying, will give you a fairly accurate picture about problems encountered and management techniques used in real-life project management.

APPENDIX: RELATION BETWEEN PROFESSIONAL STANDARDS AND CHAPTERS OF THIS BOOK

Table I.1 PMI knowledge areas and process groups, *PMBOK GUIDE, 6th Edition*, 2017.

PMBOK GUIDE, 6th Edition, 2017	Chapters Addressing these Areas	
	Most Relevant	Related
Part 1		
1. Introduction	0, 1	16, 17
2. The environment in which projects operate	15, 18	5, 13
3. The role of the project manager	16, 17	12
4. Project integration management*	5, 6, 7, 13	13, 18

Table I.1 (*Continued*)

PMBOK GUIDE, 6th Edition, 2017	Chapters Addressing these Areas	
	Most Relevant	Related
5. Project scope management*	4, 5, 6	2, 14, 20
6. Project schedule management*	6, 7, 8, 13	14, 20
7. Project cost management*	9, 13	20
8. Project quality management*	10	2, 13, 14
9. Project resource management*	7, 12, 17	8, 13, 15, 16, 20
10. Project communications management*	13	12, 14, 20
11. Project risk management*	11	8, 13, 19, 20
12. Project procurement management*	12	13, 20
13. Project stakeholder engagement*	16	1, 2, 3, 12, 17, 20
*PMBOK Knowledge area		
Part 2		
Introduction	1, 3, 16, 18, 19	
Initiating process group	3, 4	
Planning process group	6, 7, 8, 9	10, 11, 14, 20
Executing process group	5	14, 20
Monitoring and controlling process group	13	11, 14, 20
Closing process group	5	

Table I.2 IPMA Individual Competence Baseline 4th Version, 2015.

IPMA ICB4	Chapters Addressing these Competencies	
	Most Relevant	Related
1. *Introduction (Note: An introduction to the ICB standard)*	–	
2. *Purposes and intended users*	–	
3. *The individual competence baseline*	–	
4. *Individuals working in project management*		
4.1 Managing projects	1, 3–6, 13, 14	2, 7–12, 15–20
4.2 Competences overview	–	
4.3 ***Perspective***		
4.3.1 Strategy	3, 19	4
4.3.2 Governance, structures and processes		15, 18, 19
4.3.3 Compliance, standards and regulation		18, 20
4.3.4 Power and interest	16	17
4.3.5 Culture and values	17	20
4.4 ***People***		
4.4.1 Self-reflection and self-management		17
4.4.2 Personal integrity and reliability	16	17
4.4.3 Personal communication	13	20
4.4.4 Relations and engagement	16, 17	
4.4.5 Leadership	17	18
4.4.6 Teamwork	17	15
4.4.7 Conflict and crisis	17	

Table I.2 (*Continued*)

IPMA ICB4	Chapters Addressing these Competencies	
	Most Relevant	Related
4.4.8 Resourcefulness		2, 6
4.4.9 Negotiation	12	17
4.4.10 Results orientation	13	4–12
4.5 ***Practice***		
4.5.1 Project design	2–4	17–20
4.5.2 Requirements and objectives	2–4, 10, 16	19
4.5.3 Scope	6	2, 4, 10
4.5.4 Time	3, 6, 7, 8	14
4.5.5 Organizations and information	13, 15	6, 18
4.5.6 Quality	10	2, 4
4.5.7 Finance	9, 13	
4.5.8 Resources	6–8	12, 18
4.5.9 Procurement	12	
4.5.10 Plan and control	2–4, 6–9, 13	10–12, 14
4.5.11 Risk and opportunity	11	19
4.5.12 Stakeholders	16	13
4.5.13 Change and transformation		17
5. Individuals working in programme management	18	
6. Individuals working in portfolio management	19	

Table I.3 APM Body of Knowledge, 7th Edition, 2019.

APM Body of Knowledge	Chapters Addressing these Areas	
	Most Relevant	Related
Chapter 1 *Setting up for success*		
1.1 Implementing strategy	19	15, 16
1.2 Life-cycle options and choices	3	2, 4, 5
1.3 Establishing governance and oversight	3	10, 15, 19
Chapter 2 *Preparing for change*		
2.1 Shaping the early life cycle	3, 12	18, 19
2.2 Assurance, learning and maturity	3, 18	10
2.3 Transition into use	3, 5	19
Chapter 3 *People and behaviours*		
3.1 Engaging stakeholders	16, 17	6, 13
3.2 Leading teams	17	16
3.3 Working professionally	16	13, 17
Chapter 4 *Planning and managing deployment*		
4.1 Defining outputs	2, 4, 6, 10, 11	
4.2 Integrated planning	6, 7, 8, 9, 11, 12	
4.3 Controlling deployment	13, 10, 11, 12	

Table I.4 Managing Successful Projects with PRINCE2, 6th Edition, 2017.

PRINCE2	Chapters Addressing Principles, Themes, Processes	
	Most Relevant	Related
1. Introduction		
2. Project management with PRINCE2	1, 16	13, 14, 17, 18
3. Principles	3, 16, 19	18
4. Tailoring and adopting PRINCE2	3, 14	18
5. Introduction to PRINCE2 themes	3, 6, 10, 11, 13, 15,	
6. Business case	3	19
7. Organization	15, 16	3, 13, 14, 17
8. Quality	10	2, 13, 14
9. Plans	6, 7, 8, 9	10, 11, 14, 20
10. Risk	11	8, 13, 19, 20
11. Change	4	10
12. Progress	13	14, 20
13. Introduction to processes	3	
14. Starting a project	3, 4	19
15. Directing a project	3, 5, 13	
16. Initiating a project	3, 4, 6	11, 19
17. Controlling a stage	13	3, 11, 14, 20
18. Managing product delivery	5, 13	14, 20
19. Managing a stage boundary	3	11
20. Closing a project	5	
21. Considerations for organizational adoption	18	

Review Questions

1. Look at websites, newspapers, magazines, or television for examples of projects. Surprisingly, a great number of newsworthy topics relate to current and future projects or to the outcome of past projects. Prepare a list of these topics.
2. Prepare a list of activities that are not projects. What distinguishes them from project activities? Which activities are difficult to classify as projects or non-projects?
3. Because this is an introductory chapter, not very much has been said about why projects must be managed differently from ordinary "operations" and what constitutes project management—the subject of this book. Now is a good time to speculate about these: Why do you think projects and non-projects need to be managed differently? What do you think are some additional or special considerations necessary for managing projects?

CASE I.1 THE DENVER AIRPORT[15]

When the Denver Airport project was initiated in 1989, the planned 4-year timeframe seemed adequate. However, despite abundant political backing and adequate funding, the project suffered a 16-month delay and a $1.5 billion cost overrun. The NTCP model can be used in retrospect to explain the root cause of much of the project's unsatisfactory performance. With 20–20 hindsight, one may argue that a relatively simple NTCP analysis of the project and its subprojects at an early stage (and adjustment of management style accordingly) might have improved project performance.

To enable aircraft turnaround around in less than 30 minutes as requested by United Airlines, one of the airport's largest tenants, an automated baggage sorting and handling system was selected over the traditional manual handling system. In December 1991, BAE Automatic Systems was contracted to design and implement the system in an estimated 2.5-year timeframe. By August 1994, the system, already 11 months late, was still not functioning properly and was severely hampering airport operations. Management decided as a backup to build an alternative, more traditional baggage system at an additional $50 million cost, and only United would use the BAE system at its own terminal concourse. In January 1995, a full-scale practice run of the BAE system was executed successfully, and in February 1995, the airport was opened—16 months late.

Building the airport was mostly a typical large construction project; in terms of NTCP, it would be classified as follows: novelty—platform; technology—low-tech; complexity—array; pace—fast/competitive. The snag in the project was the BAE automatic baggage-handling system: it was new technology and thus riskier than the rest of the project, a risk that was not considered. It was the first of its kind (the technology had been used before but only on a much smaller scale) and required several design cycles and intensive testing. In terms of technology, it should have been considered high-tech. As discussed later in the book, high-risk projects need to be managed differently from low-risk projects. The NTCP profiles of the total project and the baggage-handling system are illustrated in Figure I.6.

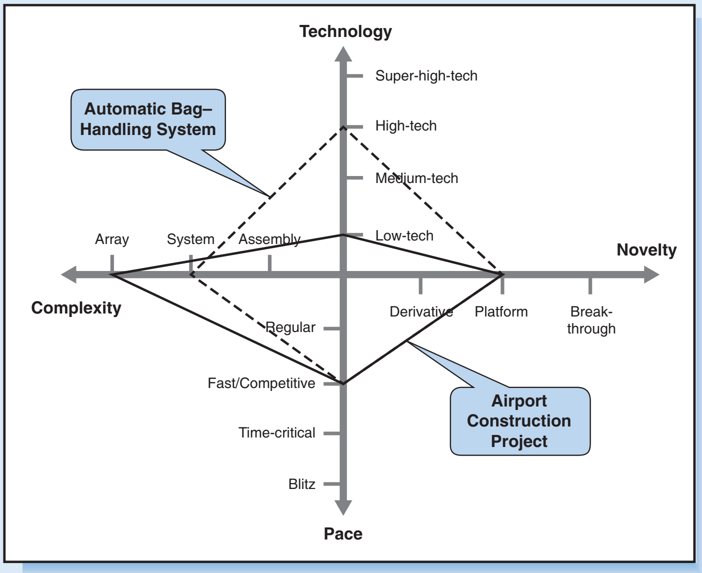


Figure I.6
"Diamond" profiles for the Denver Airport and for the baggage-handling system.

Source: Shenhar A. and Dvir D. *Reinventing Project Management: The Diamond Approach to Successful Growth and Innovation*. Cambridge, MA: Harvard Business School Press; 2007.

Questions About the Case

1. In what ways should high-tech projects be managed differently from low-tech ones?
2. BAE Automatic Systems is a reputable high-technology corporation and was familiar with building automated baggage-handling systems. What might have convinced them to accept a schedule of 2.5 years for designing and construction of the baggage-handling system?
3. If an NTCP analysis had been done and the profile of the baggage-handling system identified, what should the project manager have done to help ensure project success?
4. Explain how the NTCP model makes provision for 144 different types of projects.

Notes

1. Tompkins P. *Secrets of the Great Pyramids*. New York, NY: Harper & Row; 1976, pp. 233–234; Poirier R. *The Fifteen Wonders of the World*. New York, NY: Random House; 1961, pp. 54–67; Smith C. *How the Great Pyramid Was Built*. Washington, DC: Smithsonian; 2004. The last reference is noteworthy for its engineering and project management perspective.
2. Tompkins. *Secrets of the Great Pyramids*, pp. 227–228.
3. Barber F. *The Mechanical Triumphs of the Ancient Egyptians*. London, UK: Tribner; 1900.
4. George C.S. *The History of Management Thought*. Upper Saddle River, NJ: Prentice Hall; 1968, p. 11.
5. Potok C. *Wanderings*. New York, NY: Fawcett Crest; 1978, pp. 154–162.
6. See Archibald R.D. *Managing High-Technology Projects*. New York, NY: Wiley; 1976, p. 19; Meredith J. and Mantel S. *Project Management: A Managerial Approach*, 3rd edn. New York, NY: Wiley; 1995, pp. 8–9; Roman D. *Managing Projects: A Systems Approach*. New York, NY: Elsevier; 1986.
7. See Terraine J. *The Mighty Continent*. London, UK: BBC; 1974, pp. 241–242.
8. This section is adapted from: Shenhar A. and Dvir D. *Reinventing Project Management: The Diamond Approach to Successful Growth and Innovation*. Cambridge, MA: Harvard Business School Press; 2007. Since publication of the book, the NTCP model has been revised: "Breakthrough" has been split into New-to-Market and New-to-World; to "Complexity," the level of Component has been added below Assembly.
9. See Rosenau M.D. *Successful Project Management*. Belmont, CA: Lifetime Learning; 1981, pp. 15–19.
10. Archibald. *Managing High-Technology Projects*, pp. 6–7.
11. Kerzner H. *Project Management: A Systems Approach to Planning, Organizing, and Controlling*, 12th edn. Hoboken, NJ: John Wiley & Sons; 2017.
12. *APM Body of Knowledge,* 6th edn. Association for Project Management; 2013; *IPMA Competence Baseline: ICB*. International Project Management Association. Available for download at http://ipma.ch/certification/competence/ipma-competence-baseline/, accessed December 30, 2014; Project Management Institute. *A Guide to the Project Management Body of Knowledge (PMBOK Guide)*, 6th edn. Project Management Institute; 2017.
13. Managing Successful Projects with PRINCE2, 2009 ed. Office of Government Commerce. Available for download at www.prince2.com/downloads, accessed December 30, 2014. Currently distributed by Axelos. https://www.axelos.com/best-practice-solutions/prince2, accessed May 14, 2020.
14. Snow C.P. *The Two Cultures and a Second Look*. Cambridge, UK: Cambridge University Press; 1969.
15. Shenhar and Dvir. *Reinventing Project Management*.

Part I

Philosophy and concepts

The two chapters in this section describe the philosophy and concepts that differentiate project management from traditional, non-project management. The first chapter introduces features associated with project management and project management variations. Project management is an application of what has been called the systems approach to management; the second chapter describes the principles, terminology, and methodology of that approach. The two chapters set the stage for more detailed coverage in later sections.

Chapter 1

What is project management?

The projects mentioned in the Introduction—the Great Pyramid of Egypt, the International Space Station, the Chunnel, and the development of "Product J"—have something in common with each other and with every other undertaking of human organizations: they all require, in a word, *management*. Although the resources, work tasks, and goals of these projects vary greatly, none of them could have happened without management. This chapter contrasts project management and non-project management and looks at the variety of ways and places where project management is used.

1.1 Functions of management[1]

The role of management is to plan, organize, and integrate resources and tasks to achieve goals. Although the specific responsibilities of managers vary greatly, all managers—whether corporate presidents, agency directors, line managers, school administrators, movie producers, or project managers—have this same role.

The activities of managers, including project managers, can be classified into the five functions identified in Figure 1.1. First is deciding what has to be done and how it will be done. This is the *planning* function, which involves setting a goal and establishing the means for achieving it consistent with higher-level organizational goals, resources, and constraints in the environment.

Second and related to planning is arranging for the work to be done; this is the *organizing* function. This involves (1) hiring, training, and gathering people into a team with specified authority, responsibility, and accountability relationships; (2) acquiring and allocating materials, capital, and other resources; and (3) creating an organization structure with policies, procedures, and communication channels.

Third is directing and motivating people to attain the goal. This is the *leadership* function.

Fourth is monitoring work performance with respect to the goal and taking necessary action whenever work deviates from the goal; this is the *control* function.

All four functions are aimed at the goal, which implies a fifth function: assessing how well each of the functions is doing and whether the functions or the goals need to be *changed*.

On a day-by-day basis, rarely do managers perform all the functions. Although planning logically precedes the others, there is always a need to organize activities, direct people, and evaluate work, regardless of sequence. Managers constantly face change, which means that plans, activities, performance standards, and leadership styles must also change.

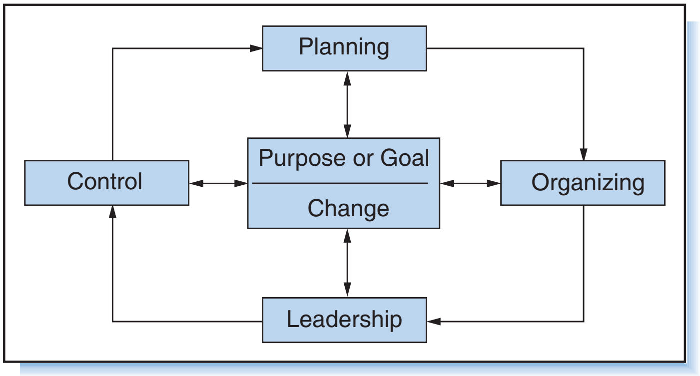


Figure 1.1
The functions of management.

Different managers' jobs carry different responsibilities depending on the functional area and managerial level of the job. Some managers devote most of their time to planning and organizing, others to controlling, and others to directing and motivating. At some time or another, project managers perform all these functions.

1.2 Features of project management

Project management is a systems *approach* to management. A system is a collection of interrelated components or elements that in combination serve a purpose and work toward a goal. A project can be thought of as a system: it is a collection of elements—work tasks, resources, and stakeholders (individuals, teams, organizations)—aimed at achieving a goal. The focus of the systems approach is to optimize the overall *system* (not its individual elements) so as to achieve the goal. The approach starts by defining the goal, identifying elements of the system that contribute to or detract from meeting the goal, and then managing the elements to best achieve the goal. It involves all the functions of management—planning, organizing, leadership, and so on.

As described in the Introduction, projects differ from non-projects. Non-project activities such as mass production of products or delivery of routine services are routine and seldom change. They tend to involve the same people doing the same procedures, day-in, day-out. There is little uncertainty or risk involved. In contrast, every project is unique and unfamiliar in some sense and requires people or teams from different functions or organizations. This creates uncertainty and risk and makes it harder to achieve the goal. So the question is: How do you manage such a thing as a project? The answer: Use project management.

The key features of project management are:[2]

1. A single person, the project manager, heads the project organization and works outside of the normal chain of command. The project organization reflects the cross-functional, goal-oriented, temporary nature of the project.
2. Because each project requires a unique variety of skills and resources, project work is typically performed by people from different functional areas or outside contractors.
3. The project manager is responsible for integrating work done by people from the different functional areas or outside contractors.
4. The project manager works with functional managers or contractors who might be responsible for the individual work tasks and personnel within the project.
5. A project might have two chains of command, one functional and one project, so people working in a project report to both a project manager and a functional manager.

6. Decision-making, accountability, outcomes, and rewards are shared between the project team and supporting functional units and outside contractors.
7. Although the project organization is temporary, usually the functional or subcontracting units from which it is formed are permanent. When a project ends, the project organization is disbanded and people return to their functional or subcontracting units.

Because projects require the coordinated efforts of different individuals and units from within and outside the organization, managers and workers in different units and at different levels work directly with each other. Formal lines of communication and authority are frequently bypassed, and a *horizontal hierarchy* is created. This horizontal hierarchy enables people in the project organization from different functional areas and outside organizations to work directly with each other as needed.

In non-project organizations, managers tend to be specialized and responsible for a single functional unit or department. A project, however, since it might involve many departments, needs someone from beyond these departments to take responsibility for meeting the project's goals. That person is the project manager. The emphasis on project goals versus the goals of each functional unit is a key feature that distinguishes project managers from functional managers.

Project managers often direct people who are not "under" them but who are "assigned" to them from different areas of the organization as needed. This makes being a project manager more complicated (and difficult) than being a departmental manager. Project managers must know how to use diplomacy, resolve conflicts, and be able to function without the convenience of always having the same team reporting to them.

1.3 Evolution of project management

No single individual or industry can be credited with the idea of project management. It is often associated with the early US missile and space programs of the 1960s, but clearly its origins go back much earlier. Techniques of project management probably were first used in the major construction works of antiquity, such as the Pyramids and the Roman aqueducts, and were later modified for use on other projects such as shipbuilding. Starting in the early twentieth century, managers developed techniques for use in other kinds of projects, such as for designing and testing new products and building and installing specialized machinery. During World War I, a new tool called the *Gantt chart* for scheduling and tracking project-type work was developed (examples in Chapter 6), followed about 40 years later by the *project network diagram* (discussed in Chapter 7).

See Chapters 6 and 7

By the 1950s, the size and complexity of many projects had increased so much that existing management techniques proved inadequate. Repeatedly, large-scale projects for developing aircraft, missiles, communication systems, and naval vessels suffered enormous cost and schedule overruns. To grapple with the problem, two new methods for planning and control were developed, one called PERT, the other called CPM (described in Chapters 7 and 8). A decade later, network-based methods were refined to integrate project cost accounting with project scheduling. These methods came into widespread usage in the 1960s when the US government mandated their usage in projects for the Department of Defense, NASA, and large-scale efforts such as nuclear power plants. In the 1970s, the *earned value* method of project tracking was developed (see Chapter 13); this led to performance measurement systems that simultaneously track work expenditures and work progress.

See Chapters 7 and 8

See Chapter 13

The last 50 years have witnessed the increased computerization of project management. Early project planning and tracking systems cost \$10,000 to \$100,000, but today relatively low-cost software and freeware make possible the use of a variety of planning, scheduling, costing, and controlling tools for virtually any size project.

Associated with the evolution of project management was the emergence of project forms of organization and the role of project manager. Not until World War II was "the project" recognized as a distinct organizational form. In the urgency to develop sophisticated weaponry and organize massive task forces of troops and material, the "pure-project" form of organization evolved (described in Chapter 15), and it was not until the 1960s that companies began to use the term "project manager" as a formal title and role (see Chapter 16).

See Chapters 15 and 16

In recent years, project management has proliferated throughout all industries around the world. The most widespread applications of each are discussed in the following sections.

1.4 Where is project management appropriate?[3]

Fact is, project management is applied everywhere, and there are few industries or situations where it is not. This section identifies conditions and situations where a project-type organization applies or is essential.

Project management can be applied to any "ad hoc" undertaking. As shown in Figure I.3 in the Introduction, "ad hoc" includes activities that range from writing a term paper or remodeling a kitchen, to fundraising and constructing theme parks. Generally, the more unfamiliar or unique the undertaking, the greater the need for project management; the more numerous, interdisciplinary, and interdependent the activities in the undertaking, the greater the need for project management to ensure everything is coordinated, integrated, and completed and nothing is overlooked.

Customers such as major corporations and governments frequently request or mandate formal project management because they believe it offers better cost, schedule, and quality control, and they prefer having a single point of contact—the project manager—with whom to deal.

Criteria

Cleland and King list five criteria for determining when to use project management methods and organization:[4]

1. Unfamiliarity

By definition, a project involves doing different things, doing the same things but differently, or both. For example, whereas continuous minor changes in products such as small improvements in automobile parts can usually be accomplished without project management, modernizing an automotive plant, which calls for non-routine efforts such as upgrading facilities, replacing equipment, retraining employees, and altering procedures, would certainly require project management.

2. Magnitude of the effort

When a job requires substantially more resources (people, capital, equipment, etc.) than are normally employed by a department or organization, project management may be necessary. Examples include relocating a facility, merging two corporations, or developing a new product and placing it on the market. Even when the job lies primarily within the realm of one functional area, the task of coordinating the work with other functional areas might be large. For example, although a corporate software installation project might *seem* to fall entirely within the functional area of information technology, in fact it might require a meshing of the procedures and resources of all departments affected by the installation and involve hundreds of people.

3. Dynamic environment

Industries such as aerospace, biotechnology, computers, electronics, pharmaceuticals, and communications face continual change driven by an environment characterized by high innovation, intense competition, and shifting markets and consumer demands. Project management provides the necessary flexibility to deal with emerging threats and opportunities in such environments.

4. Multifunctional effort

Functional areas tend to be self-serving and work independently. When the effort requires that they must work together, project management builds the necessary relationships between the areas, expedites work, and reconciles conflicts. The project manager coordinates the efforts of internal functional areas and outside contractors.

5. Reputation of the organization

If failure to satisfactorily complete a project would result in financial ruin, loss of market share, damaged reputation, or loss of future contracts, that is a strong case for use of project management. Although project management cannot guarantee success, it does improve the odds.

Example 1.1: Renovating the Statue of Liberty[5]

Ninety-five years after the Statue of Liberty was presented to the American people, its surface and interior structure had become so badly corroded that it was judged structurally unsound. To oversee restoration of the statue and other buildings on nearby Ellis Island, the US Department of Interior established a foundation.

Very little of the restoration work qualified as "standard." It involved highly specialized skills such as erecting scaffolding, constructing a new torch, building windows for the crown, and replacing the interior framework—expertise that tends to be found in smaller firms. As a result, the work was accomplished by a legion of over 50 small businesses, many of whose workers were immigrants or descendants of immigrants whom the statue had welcomed to America.

There were myriad notable features about the job. The scaffolding surrounding the statue never touched it at any point. Constructed of hundreds of thousands of pieces of aluminum, it qualified for the *Guinness Book of World Records* as the largest free-standing scaffolding ever built. To renovate the statue's interior, 1,699 five-foot (1.5-m) bars were painstakingly fashioned from 35,000 pounds (15,900 kg) of stainless steel and then individually installed. Around the crown, 25 windows were replaced. Each was handcrafted and had to be treated as a project unto itself. To fashion an entirely new torch, French artisans practiced an ancient copper shaping technique. The project was truly a marriage of art and engineering.

The 30-month, $31-million project involved thousands of tasks performed by hundreds of people. Most of the tasks were non-routine and interrelated, and all had to be completed within a tight budget and schedule; such a situation calls for project management. (Chapter 16 discusses the company responsible for managing the renovation.)

See Chapter 16

Where is project management not appropriate?

The obverse of all of this is that the more familiar and routine the undertaking, the more stable the environment, the less unique and more standardized the end-item, and the lower the stake in the result, the less the need for project management. Production of standardized industrial and agricultural outputs, for example, is generally more efficiently managed by tried and true operations planning and control procedures than by project management. This is because for standardized, repetitive operations, there is much certainty in the process and outcome; for such operations, standardized, routine procedures for planning, scheduling, and budgeting are well-suited, and project management is unnecessary.

1.5 Management by project: a common approach

Beyond large-scale, infrequent undertakings, project management applies to all kinds of smaller, more frequent activities as well. Whenever an undertaking involves activities that are somewhat unique or unfamiliar and requires cooperation from several parties, project management applies.

For example, consultants in most every industry perform work on a project-by-project basis. Whenever their work calls for coordinated participation of several individuals or groups, project management applies. The more people or groups involved, the greater the applicability.

Similarly, groups that develop or implement new products, systems, or services also work on a project-by-project basis. The larger; riskier; and more complex, costly, innovative, or different the thing being developed or implemented, the greater the applicability of project management.

Further, any group that performs unique work on a *client-by-client* basis (so-called made-to-order, or made-to-engineer) is performing project work. If the work requires coordinated efforts from different parties, project management applies.

Think about these situations for a moment, and you start to realize the many cases where projects happen and project management applies.

Managing any kind of work as a discrete project is referred to as "managing by project," or MBP.[6] With MBP, an undertaking or set of activities is planned and managed as if it were a project. In particular, MBP implies that the undertaking will have well-defined objectives and scope, firm requirements for the end results, a plan of work, a completion date, and a budget for the required resources. A team is formed for the sole purpose of performing the work, and a project manager or team leader is assigned to guide and coordinate the work.

At some time, all organizations do projects. Even in repetitive industries, small projects involving a few individuals are always in progress: new machines are installed, old ones are repaired, the office is remodeled, the cafeteria is renovated. When these or larger project efforts arise, a formalized project group is formed and a project manager appointed.

Example 1.2: Relocation of Goman Publishing Company

Many companies, regardless of size, at some point face the decision to relocate. Relocation requires planning and coordination of numerous tasks involving many individuals, departments, and outside contractors. It is an important event that if done properly can be an exciting and profitable experience, but if done poorly can lead to financial loss or ruin. It is also representative of a situation wherein a company must do something it does not ordinarily do.

Goman Publishing was experiencing rapid growth and expected to outgrow its current facility. The initial task in relocating the company was to decide between two options: buying land and constructing a new building or leasing or buying an existing structure. After deciding to build, the next task was to select a site. The main selection criteria were purchase expense, distance from current location, prestige and size of the new location, and access to major highways. The next task was the relocation planning, which had two major phases: design and construction of the new facility and the physical move, each involving numerous considerations. For example, Goman wanted to retain its current employees, and to maximize the new facility's appeal, it chose to build an indoor employee parking area and a large, well-appointed cafeteria. Among the many move-related considerations were furniture procurement, special handling of computers, hiring movers, informing employees and clients about the move, and maintaining corporate security. Further, the relocation would have to be scheduled to minimize downtime and interruption of operations.

To oversee the project and ensure that construction and the physical move would go as planned, Goman appointed a project manager. The project manager worked with architects and building contractors during the design and construction phases and with representatives from functional departments and moving contractors during the relocation move. Despite the scope and unfamiliarity of the project, Goman was able to complete the construction and physical move on time and on budget.

1.6 Different forms of project-related management

Project management takes different forms with different names, including task force management, team management, matrix management, and program management, all discussed later. These forms all share two features: (1) a *project team* or project organization created uniquely for the purpose of achieving a specific goal and (2) a single person—a *project manager*—assigned responsibility for seeing that the goal is accomplished. Beyond these, features of the forms somewhat differ.

The following section covers "basic" project management, the most commonly understood concept of project management. Subsequent sections cover management forms similar to or variants of project management.

Basic project management

Commonly, the project manager and functional managers in a company are on the same organizational level and report to the same senior-level persons. The project manager has formal authority to plan, direct, organize, and control the project from start to finish. She may work directly with any level and functional area of the organization to accomplish project goals. She reports to the general manager or company owner and keeps him apprised of project status. The project manager sometimes has authority to hire personnel and procure facilities, although more often she has to negotiate with functional managers to "borrow" them.

Basic project management is implemented in two widely used forms—pure project and matrix. In pure project management, a complete, self-contained organization is created; the needed resources belong to the project and do not have to be borrowed. In matrix management, the project team is created from resources borrowed from the functional units. The project must share its resources with other projects and with the functional areas from which they are borrowed. These two project management forms are described further in Chapter 15.

See Chapter 15

Often found in construction and technology industries, basic project management also readily applies to small, nontechnical activities, including in the arts and social sciences. Adams, Barndt, and Martin cite examples:[7]

- Health, Education, and Welfare (HEW) performs social work largely on the basis of grants allocated through state and local agencies. Associated with each grant are time, cost, and performance requirements for the funding agencies. In essence, each grant results in a project to which the concepts of project management can be applied.

- An advertising firm conducting promotional campaigns utilizes the services of the marketing research, accounting, graphics, sales, and other departments. The campaigns are similar to the projects in other industries: they require planning and coordination of the departments as provided by project management.

Program management

The term "program management" is sometimes used interchangeably with project management due to the similarities of programs and projects: both are defined in terms of goals or objectives about what must be accomplished, and both require plans, budgets, and schedules to accomplish goals.

Nonetheless, programs and projects are different; the main distinctions are that a program extends over a *longer time horizon* (sometimes indefinitely) than a project, and it consists of *several parallel or sequential projects* working to meet a program goal. The projects within a program share common goals and resources and, often, are interdependent. As examples, an urban development program may include several projects such as housing rehab, job and skills training, and small business consulting assistance; a Mars exploration program may include several projects for unmanned probes to the red planet and its moons, Phobos and Diemos, followed by manned missions to Mars.

Another distinction is that projects are oriented to producing and delivering a product or service end-item, but afterward, the project organization is dissolved and responsibility is handed off to someone else for operating the end-item. In a program, however, it is the responsibility of program management to ensure the end-item is not only delivered but is integrated with other systems and operational for as long as needed. For example, program management would oversee not only development of a satellite and its booster rocket and launch but also ongoing operation and monitoring of the satellite.

Many concepts for managing projects also apply to managing programs, though with modification to handle the larger scope and magnitude of programs and enable the program manager to oversee and coordinate the projects within the program. The Project Management Institute has published a Standard for Program Management that aligns with its PMBOK; the UK Office of Government has produced one that aligns with PRINCE2.[8] Program management is discussed more in Chapter 18.

See Chapter 18

New venture management

Project management resembles *new venture management*, a type of management used in consumer-oriented firms for developing new products or markets. In new venture management, a team is created to find new products or markets that fit an organization's specialized skills, capabilities, and resources. Once it has defined the product, the team may go on to design and develop it, then determine the means to produce, market, and distribute it.

Product management

Product management refers to a special type of program management whereby a single person is responsible for overseeing all aspects of a product's production scheduling, inventory, distribution, and sales. The product manager coordinates and expedites the product's launch, manufacture, distribution, and support. Like the project manager, the product manager communicates directly with functions inside and outside the organization and coordinates efforts directed at product goals. The product manager is active in managing conflicts and resolving problems that would degrade manufacturing capability, forestall distribution, alter price, harm sales, or in any way affect financing, production, and marketing of the product. For long life-cycle products, the product manager role is filled on a rotating basis.

Project portfolio management

Many organizations group projects and programs into "portfolios," each similar to an investment portfolio, with the goal of maximizing the value of the portfolio in terms of, for example, profit, rate of return, or meeting company strategic goals. The portfolio manager helps the organization make decisions about adding, cancelling, or changing projects or programs in the portfolio based on financial performance, resource utilization, risks, and other factors affecting business value.

Whereas the purpose of project and program management is to *manage* particular projects and programs, the purpose of portfolio management is to make sure the right projects and programs are *selected*, that is, to ensure that they align with the organization's strategic and financial goals and fit within the available limited resources. Portfolio management is not really about managing projects per se but selecting and retaining the *right* projects. Thus, the portfolio manager needs the financial and analytical skills to select and group projects and programs. The PMI created the Standard for Portfolio Management and offers a Certification in Portfolio Management; the UK Office of Government Commerce (OGC) has also created a standard.[9] Portfolio management is covered in Chapter 19.

See Chapter 19

1.7 New product and systems development projects

The development of every new product and system is a project. Examples include development of products such as appliances, pharmaceuticals, information systems, medical equipment, industrial machinery, and computers and systems for defense, aerospace, energy, and telecommunication.

When the development of new products and systems includes new technologies, the early phases of the projects typically require much testing and experimentation. Although the purpose of each project is to create a newly designed product or system, the actual project deliverable could be either the physical product or system or merely the design documentation or instructions specifying how to produce it.

Following are two examples of systems and product development projects.

SpaceShipOne and the X-Prize competition[10]

In April of 2003, SpaceShipOne (SS1) and its mother ship White Knight were rolled out to the public. Simultaneously it was announced that SS1 was entering the $10 million X-Prize competition against 23 other teams from seven countries to be the first manned vehicle to successfully make two trips into space in less than 2 weeks (Figure 1.2). Space is internationally recognized as beginning at 100 km, or about 62 miles (commercial jets fly at about 8 km). The brainchild of celebrated aerospace engineer Burt Rutan and the culmination of almost 8 years of design and development work, it was but the first step in Rutan's broader dream to build vehicles to carry paying passengers into space. Rutan's major challenge was not just winning the prize but designing and building a *complete space launch system*—spacecraft, aerial launch vehicle, rocket motor, and all support subsystems—without having many hundreds of engineers and many millions of dollars in government support to do it. Rutan would try to do it with his own company of 130 people, a handful of subcontractors, and $25 million from billionaire Paul Allen, cofounder of Microsoft.

Figure 1.2
SpaceShipOne beneath its mother ship, White Knight.
Source: Photo: Flight 16P taxi pre launch, photo by D Ramey Logan, http://creativecommons. org/licenses/by-sa/4.0/.

Besides Rutan and Allen, the principal stakeholders in the program included the Ansari Foundation, Sir Richard Branson, and the Federal Aviation Administration (FAA). The Ansari Foundation is the sponsor of the X-Prize competition, and its requirements for the project were for "a non-government-funded program to put three people safely into space twice within 2 weeks with a reusable spacecraft." Sir Richard Branson, founder of the Virgin Group, is the program's customer; his plan is to buy spaceships and the associated technology for his fledgling space airline, Virgin Galactic. Branson has estimated Virgin will be able to turn a profit if it can carry 3,000 customers into suborbit over a 5-year period at about $200,000 a ticket—to include medical checks, 3 days of training, custom-molded seats, and 5 minutes of floating weightless in space. (By comparison, a civilian trip aboard the International Space Station costs about $50 million.) Paying passengers are another stakeholder group. Although none would be aboard SS1, the vehicle was designed with them in mind. For instance, SSI's cabin is designed to provide a "shirtsleeve" environment so passengers would not have to wear spacesuits. The FAA is also a stakeholder; it imposes a long list of requirements necessary for the spaceship to be "certified safe" and commercially viable.

As in most technical projects, a project manager shared oversight with a project engineer. The project engineer was responsible for identifying technical requirements and overseeing design work, system integration, and testing. All this, and what else is left for the project manager to do, will become clear in later chapters.

Development of "Product J" at Dalian Company[11]

The future of Dalian Company depends on its ability to continuously develop and market new products. Dalian specializes in food and drink additives, but it is representative of firms in industries such as pharmaceuticals, food products, biotechnology, computer and entertainment electronics, and communications that must continuously generate new products to survive in a competitive environment.

Dalian Company was concerned about maintaining market share for its "Product H," but it knew that competitors were developing less expensive substitutes for the product. To beat the competition, Dalian had to develop its own substitute, "Product J."

The product development process at Dalian is facilitated by the New Product Development Department, which is responsible for managing and coordinating all internal and externally contracted development projects; its purpose is to ensure that good ideas can be developed and quickly brought to market. The department has three directors, who are the project managers.

For each new product concept, a team is created with representatives from various departments. A director works with the team to direct and assess the project's progress. Functional managers decide what is to be done and how, but the director has final say over project direction. The director always knows the status of the project and reports any problems or delays to upper-level managers who manage project portfolios (i.e. they are portfolio managers). Projects facing big problems or signs of failure are cancelled so resources can be allocated to more promising projects.

Similarly to all new product developments, development of Product J involved the participation of several departments: R&D developed a product prototype and prepared specifications, engineering defined where and in what ways the product would be used, marketing defined the commercial market and determined how to position the product, manufacturing developed a new process for making the product that would be difficult for competitors to copy, finance determined the initial product costing and performed profit/loss forecasts, and legal obtained regulatory approval and performed patent research.

The director for Product J was involved from project conception. She worked with R&D scientists and marketing experts to determine project feasibility and was active in gaining upper management's approval. She worked with scientists and managers to prepare project plans and schedules. When additional labor, equipment, instruments, or raw materials were needed, she wrote requests for funds. When additional people were needed, she wrote personnel requests to upper management. During the project, she scheduled and chaired project review meetings and issued monthly and quarterly progress reports.

1.8 Construction projects

Similar to developing new products and systems, construction projects often have a front-end piece devoted to architectural/engineering design followed by a back-end piece for fabrication and construction. This is typical for almost all construction projects, whether for new commercial and residential buildings, transport infrastructure (roads, bridges, rail systems, harbors, airports), factories, oil and gas installations, dams, mines, and plants for renewable energy and utilities. When undertaken for profit, such projects are classified as "capital expenditure projects." Throughout this book are many examples of construction projects, including Case 9.2, the Chunnel Project; Case 10.1, Big Dig; Case 11.1, Sydney Opera House; Case 11.3, Nelson Mandela Bridge; and Case 20.1, the Mozal Aluminum Smelter. These are large projects; the following illustrates project management in a small project.

See Chapters 9, 10, 11, and 20

Small projects at Delamir Roofing Company

Delamir Roofing Company installs and repairs roofs for factories and businesses. Like other companies associated with the construction industry, it treats each job as a project and assigns a project manager to oversee it.

Involvement of the project manager begins when a request for work is received from a potential customer. The project manager examines the blueprints to determine how much material and labor time will be needed (called "prepping the job") and then prepares a budget and a short proposal. After the contract is signed, the project manager visits the site ahead of the crew to make arrangements and accommodations for work to begin. The project manager has discretion in work crew selection so that the size and skills of the crew will fit the requirements of the job. After work begins, he is responsible not only for supervision of work and delivery of supplies but for maintaining budget records and reporting progress to the home office. The project manager performs the final inspection with the customer and signs off when the job is completed. His overall responsibility is to see that the job is done well.

1.9 Service-sector projects

Project management is employed in a broad range of services, including banking, consulting, insurance, national revenue services, and accounting. The next two examples show how it is used in a corporate audit and in a nonprofit fundraising campaign.

Auditing at CPAone[12]

Large audits conducted by the auditing division at CPAone require the involvement of many people. In the audit of a national corporation, for example, numerous auditors with diverse specialties are needed to investigate all aspects of operations in various geographic areas. Given the number of people and the variety of skills, expertise, and personalities involved, a project manager is needed to oversee the audit. Every audit begins by assigning the client to a partner who is familiar with the client's business. The partner becomes the audit's "project director" and is responsible for the project's initiation, staffing, scheduling, and budgeting.

The project director begins by studying the client's income statement, balance sheet, and other financial statements. If the client has a bad financial reputation, the project director can decide for CPAone to refuse the audit. If the client is accepted, the director prepares a proposal that explains the general approach to be used in the audit, the completion date, and the estimated price.

In determining the general approach for conducting the audit, the project director considers the company's size and number of departments. Auditors are then assigned on a department-by-department basis. The audit team is a pure project team, created anew for every audit, composed of people who have the skills best suited to the needs of the audit. Generally, each audit team has one or two staff accountants and one or two senior accountants. During the audit, the director monitors all work to ensure it adheres to the Book of Auditing Standards and is completed on schedule. Each week the client and project director meet to review progress. When problems cannot be solved immediately, the director may call in people from CPAone's tax or consulting divisions. If the Internal Revenue Service (IRS) requests an examination after the audit is completed, the project director makes sure that the client is represented.

Nonprofit fundraising campaign project: Archdiocese of Boston[13]

The Archdiocese of Boston contracted the American Services Company, a fundraising consulting firm for nonprofit organizations, to manage a 3-year campaign to raise $30 million for education, social and health care services, building renovations, and a clergy retirement fund. American Services appointed a project manager to prepare the campaign strategy and organize and direct the campaign staff. The project manager had to work with three stakeholder groups: donors, the Archdiocese Board of Directors, and campaign volunteers. Potential target donors had to be identified and provided with evidence to show how their financial commitments would benefit the community and the Archdiocese; the board and church leadership had to be kept apprised of campaign planning and progress; and volunteers had to be identified, organized, and motivated.

One of the project manager's first tasks was to conduct a feasibility study to determine whether there was sufficient leadership capability, volunteer willingness, and "donor depth" within the Archdiocese community to achieve the $30 million goal. The study indicated that the goal was achievable, and pastors were invited to a kickoff luncheon, at which time the Cardinal of the Archdiocese introduced the campaign. During the meeting, influential church personnel were signed up, and the process of identifying potential donors and volunteers was started.

The project manager provided guidance for establishing a campaign leadership team and project office, enlisting volunteers, forming campaign committees, and recruiting and training volunteers. In addition to organizational matters, he convened several "reality sessions" with chairpersons to remind them of the importance of the campaign and renew their commitment to the campaign goal and organized frequent meetings with the volunteers to instill a sense of pride and involvement in the campaign.

1.10 Public-sector and governmental projects and programs

The following two examples illustrate how project and program management is performed in large public-sector and joint government/commercial undertakings.

Disaster recovery

The aid, assistance, cleanup, rebuilding, and return-to-normalcy efforts following a disaster involve the labors of numerous organizations. A large disaster such as the December 2004 tsunami in the Indian Ocean impacts many countries and requires the support and coordinated efforts of host governments, non-governmental agencies (NGOs), local business, religious, and community organizations, and international aid, charitable, and funding organizations.

Almost by definition, post-disaster recovery is a program—or several programs—a host of project efforts devoted to the goals of rescuing and providing immediate relief to victims and, ultimately, returning the lives of people in the areas affected back to normal. The programs involve many projects to address the multiple aspects of a recovery, including:[14]

- Immediate rescue of victims
- Food and medical care
- Temporary shelter and housing
- Clothing, blankets, and other immediate physical needs
- Social, moral, and spiritual assistance.

Ideally, disaster recovery is treated as an organized, coordinated effort that enables quick assessment of the scope of the situation, identification and organization of needed and available resources, and effective deployment of those resources. For all of that to happen requires leadership, usually in the person of someone with exceptionally strong organization and leadership abilities—in effect, a *program leader*. In the chaos and frenzy immediately following a disaster, however, it is often not clear who is in charge. Indeed, the poor immediate response and confused rescue and recovery efforts in New Orleans and the surrounding US Gulf coastal region following Hurricane Katrina has been blamed on a lack of leadership and coordinated management at all levels of government—federal, state, and local.

In the months and years following a disaster, the focus turns to: (1) obtaining and allocating aid funding; (2) reconstruction, redevelopment, and rebuilding (infrastructure, organizations, facilities); (3) permanently situating (returning home or relocating) victims; (4) dealing with waste and debris; and (5) providing opportunities, jobs, and ongoing support. All this requires numerous projects to, for instance, obtain and allocate financial assistance to individuals, businesses, and local government and provide subsidized housing and building materials.

For example, the December 2004 tsunami caused severe damage to coastal areas in Sri Lanka, Thailand, Indonesia, the Maldives, and other countries around the Indian Ocean and in India alone affected an estimated 2.7 million already-poor people, 80 percent of whose livelihoods depended on fishing and 15 percent on agriculture. The Indian government launched the Emergency Tsunami Reconstruction Project, estimated to cost US$682.8 million, to help repair or reconstruct about 140,000 damaged houses in two coastal regions and assist with the reconstruction of public buildings and the revival of livelihoods in fisheries and agriculture.[15] It is a program that consists of many hundreds of projects, will take many years, and continue for as long as funding holds out.

NASA project and program management[16]

NASA has had a successful history of working in partnership with researchers in universities, industry, and the military. They work closely together on technical problems, but technical initiatives and technical decisions are made by NASA field installations.

NASA organization includes (1) top management, (2) functional support for top management, (3) program offices for developing and controlling major programs, and (4) field installations, which conduct the programs and their projects either on-site or at universities or contractors. NASA is divided into four mission directorates or offices: Exploration Systems, Space Operations, Science, and Aeronautics Research, shown in Figure 1.3.

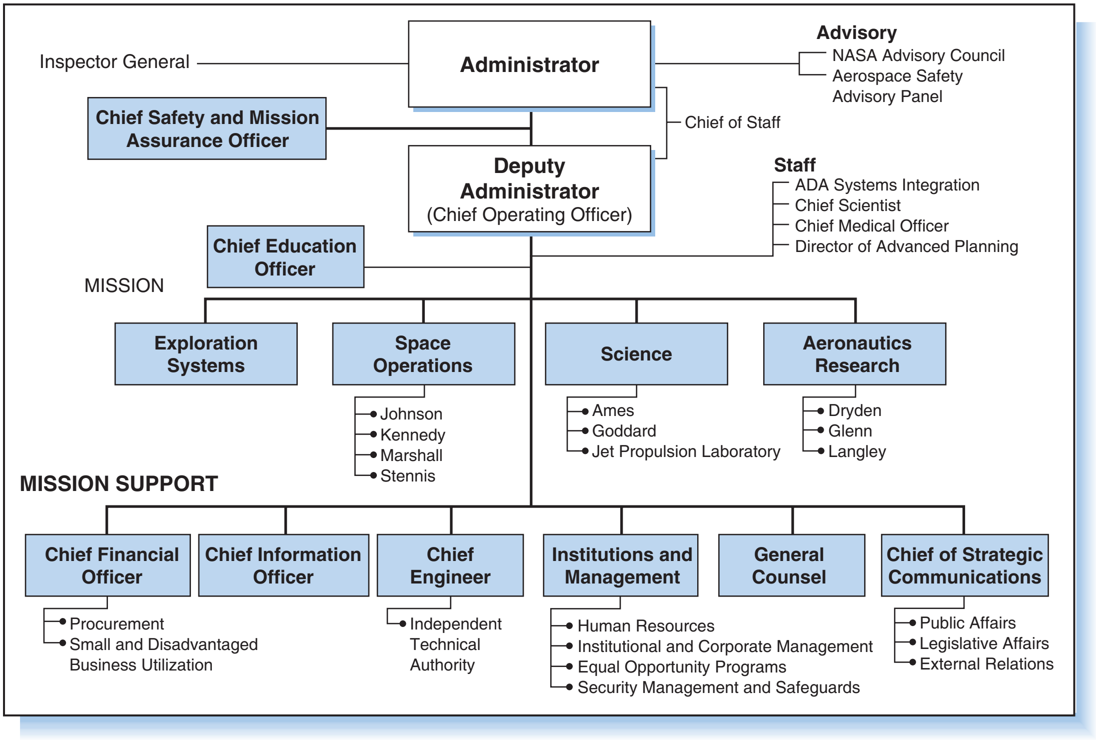


Figure 1.3
NASA program and organization chart.

Each directorate is responsible for development, justification, and management of *programs* that support broad NASA goals. Directorates are assigned field installations to carry out permanent activities for the directorate but still also carry out projects or tasks under the direction of other directorates. For example, though Ames reports to Science, it also contributes to projects in Space Operations.

In a typical non-NASA government project, the government agency prepares specifications for a program, lets a contract, and then relies on the contractor for results. NASA uses a different approach since usually no one company has all of the capability to execute a large project. Although NASA relies upon industry to build, integrate, and test-fly hardware, it relies upon its own in-house management and technical competence to monitor and work with contractors. Because NASA projects call for a diversity of technical and managerial competency, project managers practice the philosophy of "participative responsibility"—an integration of technical and managerial competency across industry, academia, and NASA laboratories. Regardless of location, NASA brings in experts from its own field installations, universities, and other government laboratories to assist contractors in tackling difficult problems. This participative team approach avoids the usual delays caused by working across boundaries that separate government and commercial organizations. The concept utilizes teamwork, central control, and decentralized execution but respects the semi-autonomous status of NASA's field installations.

NASA defines a *program* as a series of undertakings that over several years are designed to accomplish broad scientific or technical goals. It defines a *project* as an undertaking within a program with a scheduled beginning and end that normally involves design, construction, and/or operation and support of specific hardware items.

This project/program duality is reflected in a management duality. Final responsibility for a project's success rests with the *project manager*. She is responsible for executing the project within the guidelines and controls of NASA and for day-to-day supervision, execution, and completion of projects. Although most workers on a project work for contractors and are outside her managerial authority, they nonetheless take directions from the project manager on *project matters*.

Each project manager has a counterpart in Washington, the *program manager*, who is the senior NASA official responsible for developing and administering headquarters' guidelines and controls with respect to a given project. She fights the battles for resource allocation within headquarters, works with all organizations participating in the project, relates the project to NASA's broader goals, and testifies to or justifies authorizations from Congress or the president. The success of a project can largely depend on how well the project and program managers are able to work together. An example is Case 18.4, the Mercury Exploration Program.

See Chapter 18

1.11 Miscellaneous projects

If you still wonder about the myriad situations where project management applies, read on.

Maintenance

All major facilities and machines require maintenance work that sometimes takes on project proportions—everything from small repairs and preventative maintenance jobs to scheduled shutdowns of facilities like chemical plants and power-generating plants. For example, airplanes are removed from service after a certain number of flight hours, stripped down, and inspected, and parts are replaced, repaired, or rebuilt. Jobs like that put facilities and the equipment out of operation and require project management to do quality work, fast.

Events

See Chapter 10

Activities such as fundraising, political campaigns, and sports events, if small, can be handled without project management; as they grow in size and complexity, however, so do the merits of using project management. For major sports events like league championships and the Olympic Games, project management is a necessity. Case 10.2, the FIFA 2010 World Cup, is an example.

Implementation of change

See Chapter 3

Any form of large-scale change effort is a project. Examples include implementing a new corporate strategy, upgrading the safety and health provisions in the workplace, and establishing a new business unit. Applications of project management to such projects are illustrated throughout this book; see, for example: Case 1.2: Flexible Benefits System, and Case 3.1: West Coast University Medical Center.

1.12 Summary

The most identifiable aspect of project management is the project manager, the person who functions to unify project-related planning, communications, control, and direction to achieve project goals. The project manager is the integrator who ties together the efforts of functional areas, suppliers, and contractors and keeps top management and the customer apprised of project progress. Project management includes many things, but in particular it is the organization, systems, and procedures that enable the project manager to plan, organize, direct, and integrate everything necessary to achieve project goals.

Project management can be applied to any temporary, goal-oriented activity, but it becomes more essential as the magnitude, unfamiliarity, and stake of the undertaking increase. Organizations in rapidly changing business and technology environments especially need project management.

Project management takes on a variety of forms such as pure project, matrix, and program management forms. Consumer-oriented firms use new-venture and product-management forms that are similar to basic project management. Project management is applied in similar ways in commercial, nonprofit, and government projects, with variations to account for differences in the environments.

Project management is a "systems approach" to management. The next chapter expands on that concept and discusses the philosophy and methodologies that underlie project management theory and practice.

Review Questions

1. Making a film and carrying out a space mission are both expensive projects conducted by teams and subject to budgetary and schedule constraints. The technical expertise for landing a spacecraft on a planet is similar to that required to create the illusion of a spacecraft landing in a motion picture. Use the NTCP model described in the Introduction to indicate ways in which the two project types differ.
2. Describe five functions of management. Are any of these not performed by all managers? How do you think each of these functions comes into play in the course of a project?
3. List the main characteristics of "projects." How do these features distinguish projects from other, non-project, activities?

4. What are the characteristics of "project management"? Contrast these to functional and other types of non-project management.
5. What makes project management more suitable to project environments than traditional management and organization?
6. Where did project management methods and organization originate? What happened during the twentieth century that made project management necessary?
7. What five criteria do Cleland and King suggest for determining when to use project management? From these, describe briefly how a manager should know when project management is appropriate for the task.
8. When is project management clearly not appropriate? List some "project-type" activities where you think project management should not be used. Describe organizations or kinds of work where both project and non-project types of management are appropriate.
9. Briefly compare and contrast the following forms of project management: program, new venture, product, and portfolio. Give at least one illustration of an organization where each one is used.
10. What are some of the problems of being a project leader in commercial and government projects? Where do organizations in these environments get project leaders?
11. In the industry, service sector, and government examples in this chapter, what common characteristics of the environment, the project goals, and the project tasks make project management appropriate (or necessary)? Also, what seem to be the common characteristics of the roles and responsibilities of the project managers in these examples? What are the differences?
12. Now that you know a little about projects and project management, list some government and private organizations where you think project management might be useful. You might want to check to see if, in fact, they *are* using project management.

Questions About the Study Project

1. In the project you are studying, what characteristics of the company, project goals, tasks, or necessary expertise make the use of project management appropriate or inappropriate? Consider the project size, complexity, risk, and other criteria in answering this question.
2. How does the project you are studying fit the definition of a project?
3. What kind of project management is used—program, product, new venture, or other? Explain. Is it called "project management" or something else?
4. What functions does the project manager serve? What is his or her title?
5. In which way(s) does the industry of the study project differ from other industries described in the chapter? Do the differences have an effect on how projects are managed?

CASE 1.1 DISASTER RECOVERY AT MARSHALL FIELD'S[17]

Early in the morning of April 13, 1992, basements in Chicago's downtown central business district began to flood. A hole the size of an automobile had developed between the Chicago River and an adjacent abandoned tunnel. The tunnel, built in the early 1900s for transporting coal, runs throughout the downtown area. When the tunnel flooded, so did the basements of buildings adjacent to it, some 272 in all, including that of major retailer Marshall Field's.

The problem was first noted at 5:30 a.m. when a member of Marshall Field's trouble desk saw water pouring into the basement. He notified the manager of maintenance, who immediately contacted the Chicago Fire and Water Departments and Marshall Field's parent company, Dayton Hudson, in Minneapolis. Electricity—and with it all elevator, computer, communication, and security services for the 15-story building—would soon be lost. The building was evacuated and elevators were moved above basement levels. A command post was set up and a team formed from various departments such as facilities; security; human resources; public relations; and financial, legal, insurance, and support services. Later that day, members of Dayton Hudson's risk management group arrived from Minneapolis to take over coordinating the team's efforts. The team's goal was to ensure the safety of employees and customers, minimize flood damage, and resume normal operations as soon as possible. They hoped to reopen the store to customers in a week.

An attempt was made to pump the water out; however, as long as the tunnel hole remained unrepaired, the water continued to pour back into the basements. Thus, basements remained flooded until the tunnel was sealed and the Army Corps of Engineers gave approval to start pumping. Everything in the second-level basement was a loss, including equipment for security, heating, ventilation, air-conditioning, fire sprinkling, and mechanical services. Most merchandise in the first-level basement stockrooms was also lost.

Electricians worked around the clock to install emergency generators and restore lighting and elevator service. Additional security officers were hired. An emergency pumping system and new piping to the water-sprinkling tank were installed so the sprinkler system could be reactivated. Measures were taken to monitor ventilation and air quality, and dehumidifiers and fans were installed to improve air quality. Within the week, inspectors from the City of Chicago and Occupational Safety and Health Administration (OSHA) allowed the store to reopen.

After water was drained from Marshall Field's basements, damaged merchandise was removed and sold to a salvager. The second basement had to be gutted to ensure removal of contaminants. Salvageable machinery had to be disassembled and sanitized.

The extent of the damage was assessed and insurance claims filed. A construction company was hired to manage restoration of the damaged areas. The public relations department dealt with the media, being candid yet showing confidence in the recovery effort. Customers had to be assured that the store was safe. The team overseeing the recovery met twice a week to evaluate progress and make decisions, then slowly dissolved as the store recovered.

This case illustrates crisis management, an important element of which is having a team that can move fast to minimize losses and quickly recover damages. At the beginning of a disaster, there is little time to plan, though companies and public agencies often have crisis guidelines for responding to emergency situations. When an emergency occurs, they then develop more specific, detailed plans to guide short- and long-term recovery efforts.

QUESTIONS

1. In what ways is the Marshall Field's flood disaster recovery effort a project? Why are large-scale disaster response and recovery efforts projects?
2. In what ways do the characteristics of crisis management as described in this case correspond to those of project management?
3. Who was (were) the project manager(s), and what was his or her (their) responsibility? Who was assigned to the project team, and why were they on the team?
4. Comment on the appropriateness of using project management for managing disaster recovery efforts such as this.
5. What form of project management (basic, program, and so on) does this case most closely resemble?

CASE 1.2 FLEXIBLE BENEFITS SYSTEM IMPLEMENTATION AT SHAH ALAM MEDICAL CENTER[18]

Senior management of Shah Alam Medical Center decided to procure and implement a new system that would reduce the cost and improve the service of its employee benefits coverage. The new system would have to meet four goals: improved responsiveness to employee needs, added benefits flexibility, better cost management, and greater coordination of human resource objectives with business strategies. A multifunctional team of 13 members was formed with representatives from four departments—Human Resources (HR), Financial Systems (FS), and Information Services (IS)—and six technical experts from the consulting firm of Hun and Bar Software (HBS).

Early in the project, a workshop was held with participants from Shah Alam and HBS to clarify and finalize project objectives and develop a project plan and schedule. Project completion was set at 10 months. In that time, HBS had to develop and supply all hardware and software for the new system; the system had to be brought online, tested, and approved; HR workers had to be trained how to operate the system and load existing employee data; all Shah Alam employees had to be educated about and enrolled in the new benefits process; and the enrollment data had to be entered in the system.

The director of FS was chosen to oversee the project. She had the technical background and had previously worked in the IS group on another project; everyone on the team approved of her appointment as project leader. She selected two team leaders to assist her, one each from HR and IS. The HR leader's task was to ensure that the new system met HR requirements and the needs of Shah Alam employees. The IS leader's task was to ensure that the new software interfaced with other Shah Alam systems.

Members of the Shah Alam team worked on the project on a part-time basis, spending roughly half their time on the project and the other half on their normal daily duties. The project manager and team leaders also worked part-time on the project, although each gave the project priority. Shah Alam's senior management had made it clear that meeting project requirements and time deadlines was imperative. The project manager was given authority over functional managers and project team members for all project-related decisions.

QUESTIONS

1. What form of project management (basic, program, etc.) does this case most closely resemble?
2. The project manager is also the director of FS, one of several departments that will be affected by the new benefits system. Does this seem like a good idea? What are the pros and cons of her being selected?
3. Comment on the team members' part-time assignment to the project and the expectation that they give the project top priority.
4. Much of the success of this project depends on the performance of team members who are not employed by Shah Alam, namely the HBS consultants. They must develop the entire hardware/software benefits system. Why was an outside firm likely chosen for such an important part of the project? What difficulties might this pose to the project manager in meeting project goals?

Notes

1. Adapted from Szilagyi A. *Management and Performance*, 2nd edn. Glenview, IL: Scott, Foresman; 1984, pp. 7–10, 16–20, 29–32.
2. Portions of this section are adapted from Cleland D. and King W. *Systems Analysis and Project Management*, 3rd edn. New York, NY: McGraw-Hill; 1983, pp. 191–192.
3. Portions of this section are adapted from Johnson R., Kast F. and Rosenzweig J. *The Theory and Management of Systems,* 3rd edn. New York, NY: McGraw-Hill; 1973, pp. 395–397.
4. Cleland and King. *Systems Analysis and Project Management*, p. 259.
5. Based upon Hofer W. Lady Liberty's business army. *Nation's Business*; July 1983: 18–28.
6. Sharad D. Management by projects, an ideological breakthrough. *Project Management Journal*; March 1986: 61–63.
7. Adams J., Barndt S. and Martin M. *Managing by Project Management*. Dayton, OH: Universal Technology; 1979, pp. 12–13.
8. Project Management Institute. *The Standard for Program Management,* 3rd edn. Newton Square, PA: PMI; 2013; Office of Government Commerce. *Managing Successful Programmes (MSP)*. London, UK: The Stationery Office; 2007. Currently distributed by Axelos. See https://www.axelos.com/store/book/managing-successful-programmes. (Accessed May 15, 2020).
9. Project Management Institute. *The Standard for Portfolio Management,* 3rd edn. Newton Square, PA: PMI; 2013; Office of Government Commerce. *Management of Portfolios*. London, UK: The Stationery Office; 2011. Currently distributed by Axelos. See https://www.axelos.com/store/book/management-of-portfolios. (Accessed May 15, 2020).
10. This and examples in later chapters of SpaceShipOne illustrate concepts. Much factual information about the project and the systems is available from published sources, but design and development information of the systems is confidential. SpaceShipOne, the X-Prize, and the stakeholders described are all true life, but for lack of information, portions of this and subsequent examples are hypothetical.
11. Based upon information compiled by Jenny Harrison from interviews with managers in Dalian Company (factual company, fictitious name).
12. Based upon information compiled by Darlene Capodice from interviews with managers in the accounting firm (factual company, fictitious name).
13. Information about this project contributed by Daniel Molson, Mike Billish, May Cumba, Jesper Larson, Anne Lanagan, Madeleine Pember, and Diane Petrozzo.
14. Disaster Response. Lesson 7: Emergency Operations Support. University of Wisconsin, Disaster Management Center, http://dmc.engr.wisc.edu/courses/response/BB08-07.html.
15. India: Emergency Tsunami Reconstruction Project. The World Bank Group, May 3, 2005, Press Release No: 453/SAR/2005. *ReliefWeb,* www.reliefweb.int/rw/RWB.NSF/db900SID/VBOL-6C3CF8?OpenDocument &rc=3&cc=ind
16. Portions of this section are adapted from Chapman R. *Project Management in NASA: The System and The Men*. Washington, DC: NASA SP-324, NTIS No. N75–15692; 1973.
17. Information about this case contributed by Jennifer Koziol, Sussan Arias, Linda Clausen, Gilbert Rogers, and Nidia Sakac. The case is factual.
18. Information about this case contributed by Debbie Tomczak, Bill Baginski, Terry Bradley, Brad Carlson, and Tom Delaney. Organizational names are fictitious, but the case is factual.

Chapter 2

Systems approach

> *Big fleas have little fleas upon their backs to bite 'em,*
> *and little fleas have lesser fleas, and so, ad infinitum.*
>
> —Augustus De Morgan

A project can be conceptualized as a collection of people, equipment, materials, and facilities organized and managed to achieve a goal. In other words, it is a *system*, and much of what it takes to manage a project comes from a perspective called the "systems approach." At the same time, many projects are devoted to *creating* systems, and such projects commonly employ methodologies such as "systems analysis" and "systems engineering." This chapter introduces systems concepts that form the basis for project management and systems methodologies used in technical projects.

2.1 Systems and systems thinking

By definition, a *system* is "an assemblage of things or parts interacting in a coordinated way." The parts could be physical entities, such as players on a football team or components in a machine, or abstract or conceptual things, such as words in a language or steps in a procedure. Beyond "assemblage of parts," however, a system has other features:[1]

1. Parts of the system affect the system and are affected by it.
2. The assemblage of parts serves a purpose or goal.
3. The assemblage is of particular interest.

The first feature means that, in a system, the whole is greater than the sum of the parts. For example, the human body is composed of separate components—the liver, brain, heart, nerve fibers, and so on. The parts of the body cannot live outside the body, and without the parts, the body cannot live, either. The parts affect the whole, and the whole affects the parts.

The second feature of systems is that the parts work together to do something. This can usually be observed in the outputs of the system or the way the system converts inputs to outputs. In a human-made system, the parts of the system interact to achieve a purpose or goal.

The third feature is that systems are conceived by people, which means that what you choose to call a system depends on what *you* want to look at; it depends on your purpose.[2] For example, in diagnosing a sick patient, a doctor may consider the human body and all its organs as "the system." If the doctor suspects the illness is an intestinal infection and sends the patient to a specialist, a gastroenterologist (GI), the GI doctor, in investigating the infection, will consider only the digestive tract as "the system." Suppose the diagnosis is food poisoning and the patient thinks it came from a restaurant. In filing a lawsuit, the patient's attorney will expand "the system" to include all the restaurants where the patient most recently ate.

Systems thinking is a particular way of viewing the world, but its key feature is a focus on "the big picture—the whole system or organism"—rather than just the parts of the system. Systems thinkers do look at the parts, too, but they try to understand the relationships among the parts and how they contribute to the whole system.[3] Systems thinking means being able to take a seemingly confused, chaotic situation and perceive a degree of order or harmony in it. As such, it is a useful way of dealing with complex human-created systems and endeavors such as projects.

Project managers must be familiar with the individual parts of the project, but most responsibility for those parts lies with the managers and subject matter experts who specialize in them. Project managers are primarily concerned with the big picture, the whole project, and with all of its elements working to achieve the project goal; as such, they must be systems thinkers.

2.2 Systems concepts and principles

The following concepts and principles apply to all systems.

Goals and objectives

Human-made systems are designed to do something; they have goals and objectives that are conceived by people. For the intentions of this book, a *goal* (sometimes also called a *mission*) is defined as a broad, all-encompassing statement of the purpose of a system and an *objective* as a more detailed, usually quantifiable statement of purpose pertaining to some aspect of the system. The system goal is met by achieving a group of system objectives.

The goal of the project may be defined as, for example, "build a space station for $15 billion in 10 years." Starting with the goal, the project can then be defined in terms of many objectives such as "select overall design for the station," "train crew," "launch components into orbit," "assemble components," "do project for cost $15 billion," and so on. The objectives can be broken down into more detailed, specific objectives called *requirements*. Requirements are the specific criteria to which the system and its parts must conform for the system to meet its overall goals and objectives.

Elements and subsystems

Any system can be broken down into smaller parts or elements. These parts in combination form "the assemblage of parts" that constitutes the system. Some systems can also be broken down into parts that are themselves systems, called subsystems. A subsystem is a system that functions as an element of a larger system. When it is not necessary to understand its inner workings, a subsystem can simply be thought of as an element. Figure 2.1, a common organization chart, illustrates this: the production subsystem may be viewed as an "element" in the company; if we choose to delve into it, however, production itself becomes a system with elements of scheduling, manufacturing, and inventory. Each of these elements could in turn be viewed as a subsystem containing elements. In a project, an element could be a unit of work, a person or group doing the work, or a component of the end-item being produced by the project.

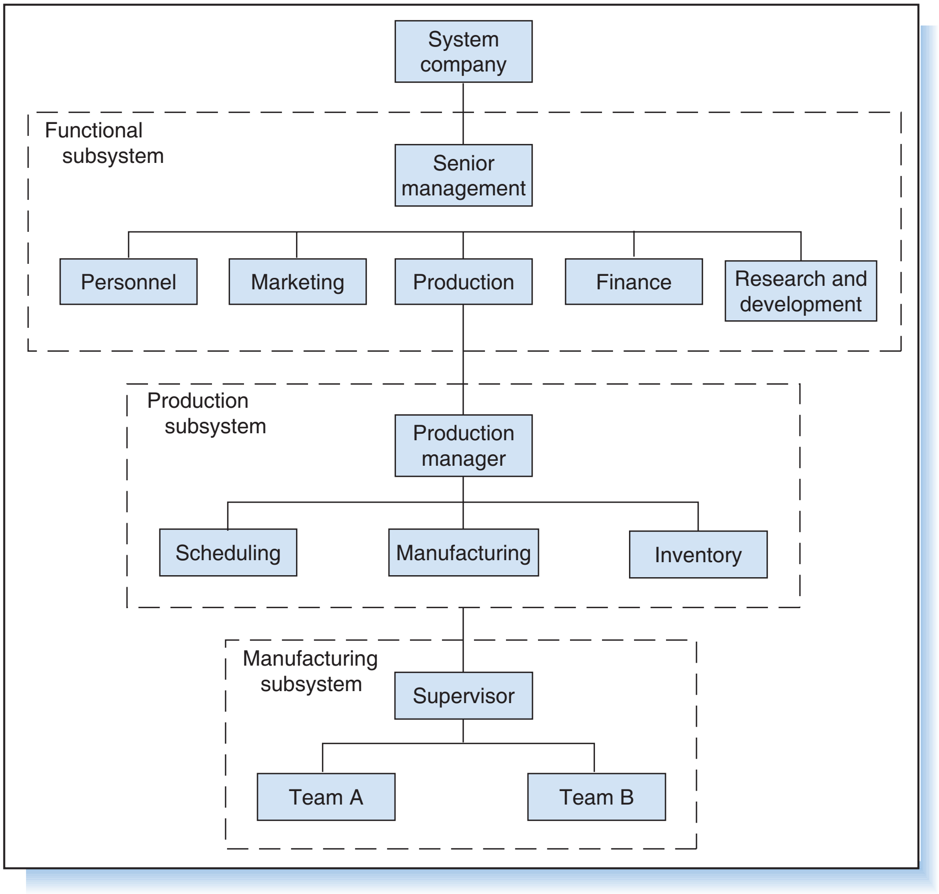


Figure 2.1
A company portrayed in terms of systems, subsystems, and elements.

Attributes

Systems, subsystems, and elements all have distinguishing characteristics called *attributes;* these describe the condition of systems, subsystems, and elements in qualitative or quantitative terms. In human-made systems, attributes are designed so the system will perform as required. Often, the attributes of a system and its components are monitored to track the system's behavior and performance. Time and cost are universal attributes of most of elements in a project, and they are tracked to assess the project's performance.

Environment and boundary

The term *environment* refers to anything *outside* the system that influences the system's behavior or outcomes. In human-made systems, it usually refers to things over which system designers and managers have no control. The environment can include, for example, community or society, the atmosphere, or people associated with the project—although it is not necessarily any of these. A system is separated from its environment by a *boundary*. In many systems, the boundary is somewhat obscure, and it is difficult to separate the system from its environment. To determine whether something is in the environment or in the system, ask two questions: "Can I do anything about it?" and "Is it relevant to the system and its objectives?" If the answer is "no" to the first question, then "it" is part of the environment. If it is "yes" to both questions, "it" is in the system. The following table shows how to distinguish a system from its environment:

		Is it relevant to the system?	
		Yes	**No**
Can system designers or managers control it?	**Yes**	System	Irrelevant Environment
	No	Environment	

"Irrelevant" includes all things that do not influence the system and that do not matter. To a project manager, the planet Jupiter is irrelevant—unless her project is to send a space probe there, in which case Jupiter is relevant, although since she can't control Jupiter, per se, it is part of the project environment. From here on, mention of the environment will always refer to the relevant environment—factors that matter to and affect the system in some way but have to be lived with.

System structure

Elements and subsystems are linked together by relationships. The form taken by the relationships is referred to as the structure of the system. The functioning and effectiveness of a system is largely determined by the "appropriateness" of the structure to the system's objective or purpose. Most complex systems have hierarchical structures consisting of organized levels.

See Chapter 6

Figure 2.2 is an example of a hierarchical structure. Element X represents the entire project; elements A, B, and C are areas of work or management divisions in the project; elements *a* through *g* are specific work tasks. The structure implies that tasks *a*, *b*, and *c* are all subsumed under management division A, tasks *d* and *e* are under division B, and so on. In a project, such a structure is called a *work breakdown structure* and is explained more in Chapter 6.

Inputs, process, outputs, interfaces

Systems achieve goals and objectives by converting inputs into outputs through a defined *process*. This is illustrated in Figure 2.3. Outputs represent the end result of a system and, generally, the purpose for which the system exists. All systems have multiple outputs, including desirable ones that contribute to

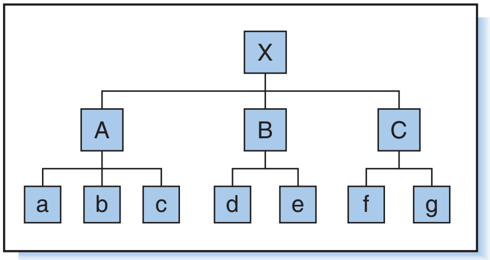


Figure 2.2
One way to conceptualize project structure.

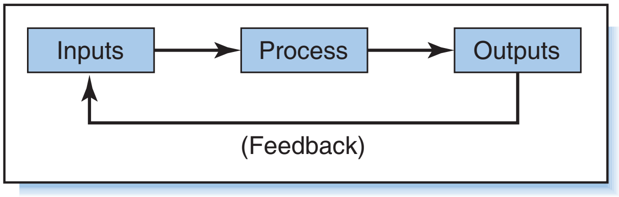


Figure 2.3
Input-process-output relationship.

system objectives, neutral ones, and undesirable or wasteful ones that detract from system objectives and/or negatively impact the environment. Subsystems and most elements have inputs and outputs, too.

Inputs are the raw materials, resources, or procedures necessary for the system to function and produce outputs. They include controllable factors such as labor, materials, information, capital, energy, and facilities, as well as uncontrollable factors such as weather and natural phenomena (i.e. the environment). Inputs that originate from the system itself are called feedback. For example, all systems produce information; usage of that information for guiding system behavior is called feedback input.

Process (also termed *function*) is the means by which the system physically transforms inputs into outputs. An important aspect of system design is to create a process that effectively produces the desired outputs and meets system objectives yet minimizes consumption of inputs and production of wasteful outputs.

In a hierarchical structure where systems are divided into subsystems, the subsystems each have their own inputs, process, and outputs that are interconnected in some way. In Figure 2.2, each of the elements produces outputs, some of which become inputs for other elements. Two elements that fit together or function together (e.g. where the output of one becomes the input of the other) are said to *interface*.

Constraints and conflicts

All systems have *constraints* or limitations that inhibit their ability to reach goals and objectives. Often the constraints are imposed by the environment. Time and money are two universal constraints in projects. The weather and economy are two environmental constraints.

In human-made systems, and especially in projects, the objectives of the subsystems sometimes conflict, which makes it difficult to achieve the overall system's goal. Removing conflict from among the system's elements to enable the system to meet its goal is called integration.

System integration

For a system to achieve its goal, all of its elements, the "assemblage of parts," must work in unison. Designing, implementing, and operating a system that achieves its objectives and requirements through the coordinated (so-called "seamless") functioning of its elements and subsystems is called *system integration*. Project management seeks to integrate tasks and resources to achieve the project goal. In technological projects, it also addresses the integration of the physical components and modules that compose the project end-item. The subject of systems integration is covered in Chapter 15.

See Chapter 15

Open systems and closed systems

Systems can be classified as closed or open. A closed system is one that is viewed as self contained with no interaction with its environment. "Closed-systems thinking" means to focus on the internal operation, structure, and processes of a system without regard to the environment. For some kinds of systems, closed-system thinking applies: to understand how a machine functions, you need only study the machine, its components, and not anything else. This does not mean that the environment does not affect the system but only that the person looking at the system has chosen to ignore the environment. For analyzing or improving the design of many kinds of mechanical systems, closed-system thinking works fairly well.

But what about systems that interact with and must be adaptive to the environment? These are open systems. To understand their behavior and functioning, you cannot ignore the environment. Since mechanical systems rely upon resources from and inject byproducts (e.g. pollutants) into the environment, in many cases they, too, should be treated as open systems. In fact, any system that must be adaptable to the environment, including projects, must be treated as an open system.

Organizations and environment[4]

As open systems, human organizations interact with stakeholders in the environment (customers, suppliers, unions, stockholders, governments, etc.) and rely upon the environment for inputs (energy, information, and raw materials). In turn, they export to the environment outputs of goods, services, and waste (represented in Figure 2.4).

As an open system, an organization must choose goals and conduct its operations so as to respect opportunities presented and limitations imposed by the environment. Cleland and King call this the "environmental problem," meaning that a manager must:[5]

1. appreciate the need to assess forces in the environment;
2. understand the forces that significantly affect the organization; and
3. somehow, integrate those forces into the organization's goals, objectives, and operations.

To the extent that every project is influenced by outside forces, the project manager must try to understand these forces and, having done that, try to guide the project to its goal. A project that is predominantly influenced by forces in the environment will be difficult to control and likely to fail.

Natural systems and human-made systems

Systems can also be classified as natural or human-made. Natural systems originate by natural processes (e.g. ecology of organisms, planetary systems). Human-made systems are designed and operated by

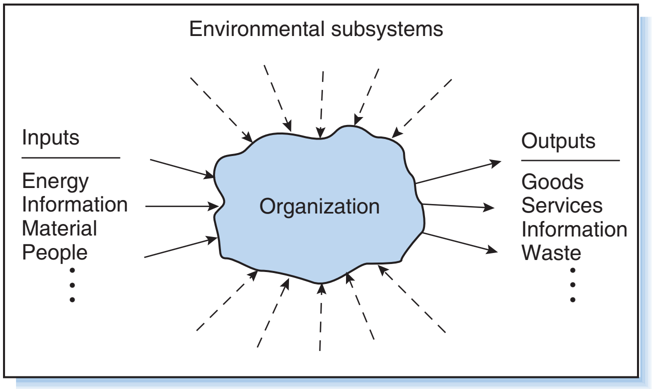


Figure 2.4
Organization as an input-output system.

people (e.g. communication systems, human organizations). Projects are human-made systems (organizations) formed for the purpose of creating other human-made systems.

Natural systems can be altered by or become intertwined with human-made systems. An example is the alteration of a river system and formation of a lake by building a dam; another is the alteration of the composition of atmosphere through CO_2 produced by internal combustion engines.

Human-made systems are embedded in and utilize inputs from natural systems, and both systems interact in significant ways. In recent years, large-scale human-made systems have had a significant, mostly undesirable, impact on the natural world. Examples include global warming, ocean acidification, air and water system contamination, and species extinction. Such consequences, referred to as "side effects," arise largely because designers and users of human systems fail to consider (or deny or choose to ignore) the impacts of their systems on natural systems.

2.3 Systems approach

The systems approach is a way to visualize and analyze physical things and conceptual systems, but more than that, it is an *approach* for doing things—a framework for abstracting problems, solving problems, and making decisions.

Systems approach framework

The systems approach framework utilizes systems concepts such as goals, objectives, subsystems, elements, relationships, integration, and environment. It formally acknowledges that the behavior of any one element may affect other elements and that no single element can perform effectively without help from the others. This recognition of *interfaces, interdependency*, and *cause-effect* among elements of a system is what most distinguishes the systems approach.[6]

Managers who adopt the systems approach recognize the multitude of "elements" in the systems they manage, the relationships among the elements, and reciprocal influences between human-made systems and the environment. As a result, they are better able to grasp the full magnitude of a problem and anticipate consequences of their actions. This reduces the chances that important elements in a situation or consequences of actions will be overlooked.

The systems approach keeps attention on the big picture and the ultimate goal; it allows focus on the parts of the system but only in regard to the parts' contributions to the whole. For instance, a university system can be viewed as separate elements of students, faculty, administrators, and alumni, and it is possible to take action regarding any one of them while ignoring impacts on the others and the environment. But actions that focus exclusively on parts of the system are likely not optimal for the total system because they disregard negative repercussions on the other parts of the system. For example, although curtailing the hiring of faculty reduces costs, it can also lead to larger class sizes and classroom overcrowding, less faculty time for research, fewer research grants, lower prestige to the university, and ultimately, lower enrollments and less revenue. Similarly, air pollution can be reduced by enacting laws, but laws that restrict industry can damage local economies. Every problem is inextricably united to the environment, and attempts to solve it may cause other problems. Churchman calls this the "environmental fallacy."[7]

Examples abound of situations where solutions directed at part of the system have led to worse problems for the whole. These include trying to reduce traffic congestion by building more highways, trying to eliminate drug abuse by outlawing drug sale and consumption, and trying to increase the appeal of wilderness areas by building resorts near national parks. The negative consequences of these problem-solving attempts are well known. The systems approach tries to avoid the environmental fallacy.

Orderly way of appraisal[8]

The systems approach is a methodology for solving problems and managing systems. By its holistic nature, it avoids tackling problems narrowly, head-on. It says, "Let's stand back and look at this situation from all angles." The problem solver does this by keeping in mind the system concepts discussed, namely:

1. The *goals and objectives* of the system.
2. The *environment* of the system.
3. The *resources and constraints* of the system.
4. The *elements* of the system, their functions, attributes, and performance measures.
5. The *interface and interaction* among the elements.
6. The *management* of the system.

The systems approach starts with hardheaded thinking about the *goals* and *objectives* of the system and real ways to measure them. Project managers use this kind of thinking: they begin with the mission or objectives of the system and, thereafter, organize and direct the work to achieve those objectives. The stated objective must be precise and measurable in terms of specific performance criteria (the system requirements). Criteria are the basis for ranking alternative solutions or courses of action to a problem. In a project, criteria for the end-item are referred to as user *requirements* and specifications, explained in later chapters.

The *environment* of the system (other systems, organization stakeholders, and natural systems that affect or are affected by the system) must also be identified—no easy matter because external forces are sometimes hidden and work in insidious ways. Looking to the future, questions must be raised about likely changes in the environment and how they will affect the system. The project manager needs to ask: What can happen on the "outside" that will affect the project and its outcomes?

The *resources* to be used to accomplish system goals must be identified. These are assets or the means that the system utilizes and influences to its advantage; they include capital, labor, materials, facilities, and equipment. Most system resources are exhaustible. The system is free to utilize them only for as long as they are available. Depleted resources become constraints. In the systems approach, the project manager considers the resources needed and available to the project, and the constraints.

The systems approach identifies the key *elements* of the system. In a project, there are actually *two* systems, the one *being produced* by the project (the project end result or end-item) and the one *producing* the end-item (this is the project itself). Defining these involves defining, on the one hand, the subsystems, components, and parts of the hardware or software end-item system being produced and, on the other hand, the work tasks, resources, organization, and procedures of the project. This topic is elaborated upon in Chapter 5.

See Chapter 5

Finally, the systems approach pays explicit attention to the *management* of the system, that is, to its planning and control, taking into consideration its objectives, environment and constraints, resources, and so on. This is precisely the role of project management.

The preceding concepts are not necessarily addressed in the sequence they are listed. In actuality, each concept might need to be dealt with several times before it is completely described and clearly defined. More importantly, each concept serves to suggest numerous open-ended questions that aid in investigating the system:[9] What are the goals, objectives, and criteria? What are the elements? What are the relationships among them? What functions should each perform? What are the resources? What are the tradeoffs among resources?

Systems models

The output of a system depends not only on the system's individual elements but on the way the elements interact. Thus, designing a system or resolving problems in a human-made or natural system requires understanding *the way the elements interact*. Designers use "models" of the system to help understand how the elements interact and how altering the elements and their relationships impacts system behavior and outputs. A model is a simplified representation of a system; it abstracts the essential features of the system under study. It may be a physical model, mathematical formulation, computer simulation, or simple checklist.

An example of a *physical model* is a model airplane. It is a scaled-down abstraction of the real system. It includes some aspects of the system (configuration and shape of main components—wings, fuselage, tail) and excludes others (interior components and crew members). Another kind of model is a *conceptual model*; it depicts the elements, structure, and interactions in a system. The conceptual model in Figure 2.5, for example, helps demographers to understand relationships among the elements contributing to population size and to make population predictions.[10]

Models are used to conduct experimentation and tests. Many human-made systems are too expensive or risky to do "real-life" experiments on. The model permits assessment of various alternatives and their consequences before committing to a decision. For instance, engineers use model airplanes in wind tunnels to test design alternatives and measure the effects of different design parameters on airplane performance. A good model allows designers and analysts to ask "what if" questions and explore the effects of altering the various inputs. It takes into account the requirements, relevant elements, resources, and constraints and allows the consequences of different alternatives to be compared in terms of costs and benefits. Models employed for quality assurance are discussed in Chapter 10.

See Chapter 10

Systems life cycles

Natural and human-made systems change over time in a way that tends to be systematic and evolutionary, and similar kinds of systems follow similar cycles of evolution. One basic cycle, that of all organisms, is the pattern of conception, birth, growth, maturity, senescence, and death. Each of

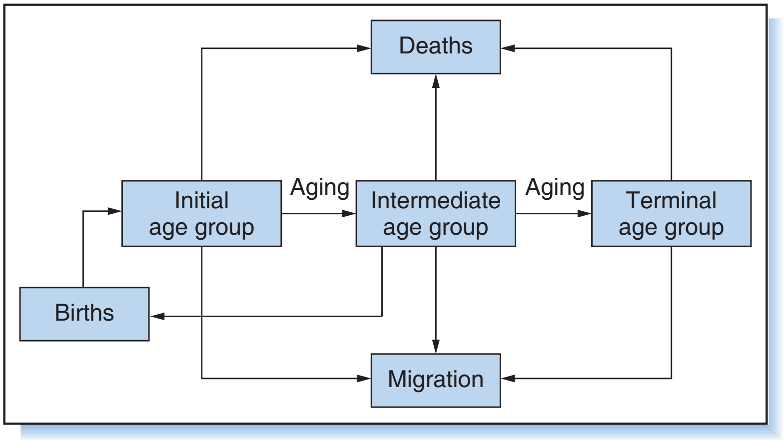


Figure 2.5
A generalized population sector model.

these can be thought of as a life "stage." Historically, even civilizations and societies have followed this pattern. Nonliving, electro-mechanical systems also follow a cycle with the stages of design, fabrication, installation, burn-in, normal operation, and deterioration or obsolescence. Similarly, all products follow a cycle—the "product life cycle," which consists of the stages of conception, design, development, production, launch into the market, capture of market share, then decline and discontinuation. Products such as cell phones may have life cycles only months long; others (Fritos and Levi's jeans) are decades-long cycles.[11] As mentioned in Chapter 1, virtually all human-made systems start out as projects, and most projects follow a cycle called the *project life cycle*.[12] This is discussed in Chapter 3.

See Chapter 3

2.4 Systems engineering

Systems engineering (SE) is an application of the systems approach. It is defined as "the science of designing complex systems in their totality to ensure that the component subsystems making up the system are designed, fitted together, checked and operated in the most efficient way."[13] SE refers to the conception, design, and development of a complex system wherein the *components of the systems themselves* must be designed, developed, and integrated together to meet system objectives. It is a way to bring an entire system into being and to account for its entire life cycle—including operation and phase-out—during its early conception and design.

All systems go

An example of SE is the design and operation of a space vehicle. The expression "all systems go," popularized during the early US space program, means that the overall system composed of the millions of components that make up the space vehicle system and the hundreds of people in its technical and management teams are all ready to "go" to achieve the objectives of the mission.

To get to the point of "all systems go," planners must first have defined the overall system and its objectives. Designers must have analyzed the requirements of the system and broken them down into more detailed requirements and have designed the components and subsystems so as to meet those requirements. They must then have built and combined the components into subsystems and the subsystem into the total system composed of space vehicle, rocket boosters, launch facilities, ground support, crew selection and training, and technical and management capability. In the end, every component and person must be assigned a role and be *integrated* into a subsystem that has been integrated into the overall system.

SE can be applied to any system that must be developed (perhaps from scratch), implemented, and operated to fulfill an immediate or ongoing future goal. Examples can readily be found in the design and implementation of local, national, and global systems for communication, transportation, water supply, power generation and transmission, and defense.

Overview[14]

SE can be described in terms of three dimensions as illustrated in Figure 2.6.

First, it is a multidisciplinary effort. Systems engineers (parties responsible for oversight of designing and building the system) work with the system's stakeholders to determine their needs and what the system must do to fulfill the needs. A stakeholder is any individual or group that affects or is affected by the system; primary stakeholders are customers, builders, and end users: customers finance and own the

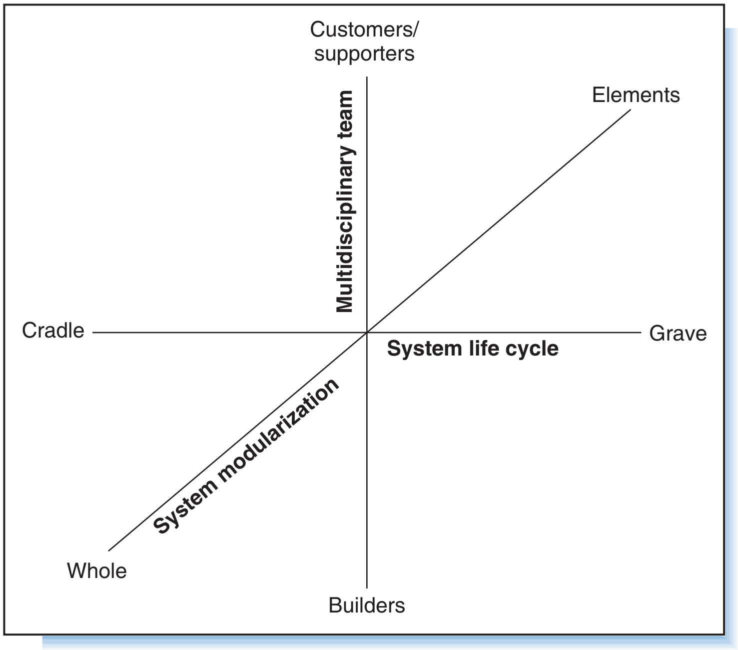


Figure 2.6
Dimensions of systems engineering.

system; builders design and create it; users operate and maintain it. Stakeholders' objectives and needs are the basis for determining the system requirements that specify *what* the system will do. The practice of involving key stakeholders in the early phases of the system conception and development is called "concurrent engineering," discussed in Chapters 4 and 15.

See Chapters 4 and 15

Second, SE addresses *every aspect* of the system, starting with the whole system and ending with its individual elements. System elements, modules, and subsystems are designed to perform the functions necessary to satisfy the objectives and requirements of the whole system. This aspect of SE focuses on which system functions need to be met. None of the elements and subsystems function independently; they all rely on the outputs of other elements and, in turn, provide inputs to still others; in a word, they *interface*. SE addresses the necessary interactions between elements and how the elements should interface.

Finally, SE also takes into account how the system will be produced, operated, maintained, and ultimately disposed of—the system's full life cycle, cradle to grave. This helps ensure that the system will be economical to develop, build, operate, and maintain and friendly to users and the environment. A multidisciplinary team approach that involves all the system's stakeholders promotes this life-cycle kind of thinking.

Once systems engineers have learned what stakeholders want and defined the system's objectives and requirements, they then investigate ways to meet the requirements. This involves research, analysis, and studies of alternative approaches to the system design and to the estimated costs, schedules, risks, and benefits associated with each. Says Brooks, "The hardest part of building a [system] is deciding precisely what to build. No other part of the conceptual work is so difficult as establishing the detailed technical requirements [and] no other part of the work is so crippling to the resulting system if done wrong. No other part is more difficult to rectify later."[15]

Example: Advanced Automation System[16]

The centerpiece of the Federal Aviation Administration's program to modernize the air traffic control system was the Advanced Automation System (AAS), which would provide controllers with new displays and computer equipment for processing radar and flight data. The FAA awarded the contract for AAS to IBM following a 4-year design competition. Requirements from the FAA initially filled a thick book, but as the program progressed, they kept increasing and eventually grew to a stack 20 feet high. As the number of requirements grew, so did program delays, costs, and tensions between the FAA and IBM. Congress balked, and after 10 years and an estimated $1.5 billion, it cancelled the program.

Eliciting the expectations and needs of operators and users and then translating them into measurable requirements can be difficult for engineers, which is why multidisciplinary SE teams sometimes include behaviorists and psychologists. Developing the flight deck for a commercial aircraft, for example, should include the suggestions of pilots, the airlines, pilot associations, and human factors experts. A common way to elicit responses to or suggestions about a proposed design is for users to try out a mockup or simulator of the system.

Modularization: iterative analysis-synthesis-evaluation cycle[17]

Systems are designed and assembled from subsystems that are themselves designed and assembled from subsystems, and so on, so the process of defining what will go into system is a series of steps to define the subsystems and elements that will compose the system. The practice of forming systems as a collection of subsystems, called *modularization*, is what makes the design, assembly, and operation of complex systems feasible and practical. Herbert Simon gives the example of a watchmaker who assembles a watch of 100 parts. The process requires concentration and is time consuming and expensive. If the watch should need repair, finding and fixing the problem might be difficult. If, instead, the watch were made of ten modules, each with ten parts, assembly would be simple. If the watch develops a problem, the repair will be simple: just identify the module with the malfunction and replace it.[18]

The design of systems occurs by designing subsystems and modules so that each performs a *necessary function* of the system. Functions are the means by which a system meets its objectives and requirements. In everyday systems, it is easy to identify the modules and the functions they perform. A desktop computer, for example, is almost completely modularized: it has a processor, controllers, and drives and peripheral devices that each perform a specialized function such as data processing, data storage, and input/output processing.

The process of defining the functions a system, its subsystems and modules must perform is illustrated by Forsberg and Mooz's "V-model" in Figure 2.7.[19] It involves iterative cycles of (1) *top-down* analysis of details (i.e. decompose the system into smaller pieces), (2) *bottom-up* synthesis (build up and integrate the pieces into successively larger pieces), and (3) evaluation (check that the resulting pieces meet requirements).

1. The **top-down stroke** of the V represents subdividing the functions of the system into subfunctions and requirements, level by level. At each level, designers address the question: "What must the functions at this level do to meet the requirements of the function at the next higher level?" In this way, requirements are defined for functions at all levels.

   The way in which system functions are grouped into modules is called the *system architecture*. The architecture of an airplane is an example: an airplane must perform several major functions, including propulsion, lift, and payload stowage; the visibly familiar modules of engines, wings, and fuselage, respectively, serve these functions. But each function is itself a composite of several

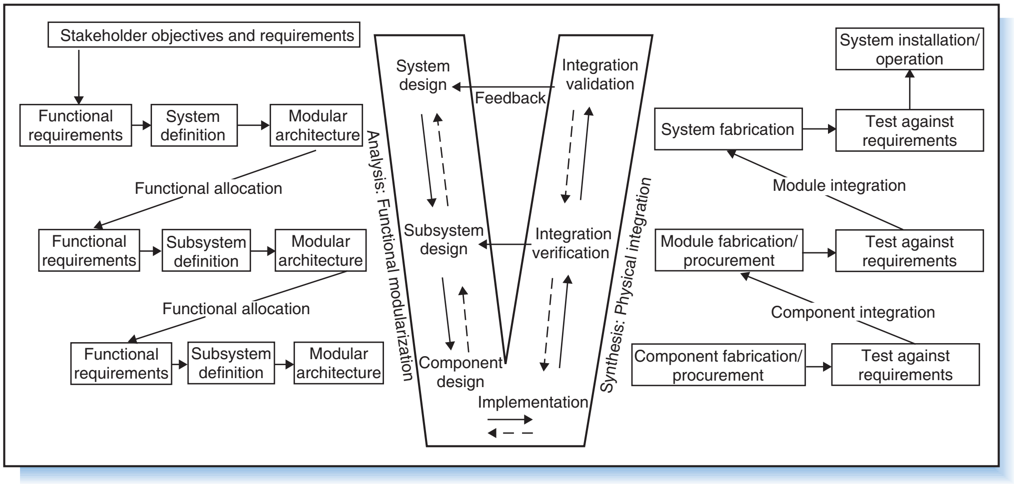


Figure 2.7
Forsberg and Mooz's V-model.
Source: Adopted from Forsberg K and Mooz H in *Software Requirements Engineering*, 2nd edn, Taylor R, Dorfman M, and Davis A (eds). Los Alamitos, CA: IEEE Computer Society Press; 1997, pp. 44–77.

subfunctions; hence, each module is composed of submodules. A wing, for example, is composed of ailerons, flaps, spoilers, and so on, each of which performs a specific aerodynamic function.

Different ways to meet requirements at each level are assessed; ultimately they show up in the final system as pieces of hardware and software and will result in procuring or designing and building subsystems and components in the upstroke.

2. The **bottom-up stroke** of the V represents implementing design decisions, converting designs into physical parts, integrating the parts, and verifying that the integrated parts meet the requirements.
3. Components are checked individually and then assembled into modules; the modules are tested and then combined with others and tested again. If tests reveal that parts or modules do not meet requirements, then the process returns to the top-down stroke to determine why, and the analysis-synthesis-evaluation cycle repeats. As illustrated by the many dashed arrows in Figure 2.7, the process moves back and forth within each top-down/bottom-up stroke; at times during the upstroke, it loops back and over to the downstroke.

One rule of the systems approach is "Don't rush to solutions! Look for alternatives." Multidisciplinary teams are good at this: they combine knowledge from experts in disparate areas and generate alternatives that transcend any one person's or field's area of expertise.

The design and development of complex technical systems can be vexing, but SE offers a way to do it. In practice, SE follows a process very similar to the project life cycle, described in Chapter 3, and it employs practices for defining systems, described in Chapter 4. But whereas the project life cycle applies to generic projects, SE applies more specifically to complex, usually technical, projects. Steps and tools that characterize SE are covered in Appendix A to Chapter 4.

See Chapters 3 and 4

2.5 Project management: a systems approach[20]

Project management is a systems approach to management: its focus is on achieving the *overall* mission and objectives of the project, it emphasizes decisions that optimize the *overall project* rather than the elements of the project, and it recognizes interaction and synergy among working elements of the project. This contrasts with more traditional management, which tends to focus narrowly on individual functions and tasks and on decisions that optimize the performance of individual departments, even if at the expense of the larger organization.

In *Winning at Project Management*, author Robert Gilbreath[21] describes the "right" way to visualize a project. From an outsider's perspective, he says, a project may look like something with no discernible parts, like a barrel containing thousands of earthworms. Obviously, if you have to manage a project, such a perspective is not very useful; you need another perspective, one that involves subdividing the mess into a collection of elements and defining the characteristics of each.[22] Good project managers, says Gilbreath, conceptually subdivide the project into pieces and make sure each piece is well managed. But the project manager knows how all the pieces impact the others and the overall project.

Gilbreath discusses another feature of project managers: the ability to "change focus," to zoom in on the performance of discrete elements, then zoom out and check the direction and performance of the overall project. The zoom-out view enables the project manager to direct the project toward its goals and not get hung up with the pieces.[23] The ability to zoom in and zoom out, to see and know what is important to the big picture—*that* is the essence of the systems approach. Whether you call it the "systems approach" or not, the point is, when managing a project, it helps to think of it as a system.

2.6 Summary

A system is an assembly of parts where (1) the parts are affected by being in the system, (2) the assembly does something, and (3) the assembly is of particular interest. What is called "the system" depends upon one's point of view and purpose. Projects are systems created for the purpose of making systems.

Systems thinking is a way to deal with complex phenomena. It imparts the ability to impose order and structure on a seemingly confused or chaotic situation. Systems thinking includes the "systems approach," which is a way of conceptualizing physical entities and addressing problems. The principal components of the systems approach are (1) the *objectives* and *performance criteria* of the system; (2) system *environment* and *constraints*; (3) *resources* of the system; (4) *elements* of the system, their functions, attributes, and performance measures; (5) *interaction* among the elements; and (6) *management* of the system. For development and operation of large technical systems, the systems approach is implemented through the systems engineering methodology.

Part I of this book has given you an overview of project management. Projects are of finite duration—they have a beginning and an ending. What happens in between—the stages of tasks and activities—tends to be remarkably similar, regardless of the kind of project. These stages are analogous to stages in the system life cycle and were alluded to in the examples in Chapter 1. Part II discusses these stages and describes a framework for conducting projects: the systems development cycle.

Review Questions

1. What distinguishes systems thinking from analytical thinking? Is systems thinking something new, or is it just another perspective? Explain.
2. Define "system." What notable features enable you to see something as a system? Describe briefly the American legal or education system in terms of these features.
3. How can several people looking at the same thing see the "system" in it differently?
4. Define the following concepts and explain how they fit into systems thinking: objectives, elements, subsystems, attributes, environment, boundary, structure, inputs, outputs, process, and constraints.

5. Describe the difference between open and closed systems and between human-made and natural systems. Are all natural systems open systems?
6. Is a space vehicle an open system? Is an organization an open system? Explain.
7. Describe the systems approach. Where does the systems approach apply? Explain in a sentence what a manager does in the systems approach that she might not do otherwise.
8. What is the "environmental fallacy"?
9. What things does the problem solver keep in mind when applying the systems approach?
10. Describe how the following elements of the systems approach apply to projects and project management: objectives, environment, resources, subsystems, and management.
11. Give some examples of physical models; of graphical models; of mathematical models.
12. What is the systems life cycle? What is the systems development cycle?
13. Discuss the dimension of systems engineering in Figure 2.6.
14. What is modularization? What are its benefits in system design and operation?
15. In systems engineering, the first stage is identification. Identification of what?
16. Who are the stakeholders in systems engineering?
17. What are requirements? What aspects of the system or stakeholder needs should the requirements incorporate?
18. Distinguish stakeholder requirements and system requirements.
19. Why is project management a systems approach?
20. What is the relevancy of the systems approach to project management?

Questions About the Study Project

1. Conceptualize the project organization (the project team and the parent organization of the team) you are studying as a system. What are the elements, attributes, environment, and so on? What are its internal subsystems—functional breakdown and management-hierarchy subsystems? What is the relevant environment? Who are the decision-makers?
2. Describe the role of the project manager with respect to these subsystems, both internal and external. What is the nature of his or her responsibilities in these subsystems? How aware is the project manager of the project "environment," and what does he or she do that reflects this awareness?
3. Now, conceptualize the output or end-item of the project as a system. Again, focus on the elements, relationships, attributes, subsystems, environment, and so on. All projects, whether directed at making a physical product (e.g. computer, space station, skyscraper, research report) or a service (e.g. giving consultation and advice), are devoted to producing systems. This exercise will help you better understand what the project is doing. It is also good preparation for topics in the next chapter.
4. If the study project involves engineering or integration of many components, was the systems engineering (SE) process used? Is there a section, department, or task in the project called SE? If so, elaborate. Are there aspects of the project that seem to resemble the SE process?
5. As described in this chapter, besides the main end-item or operating system (i.e. the output objective of the project), SE also addresses the support system—that system that supports installation, operation, maintenance, evaluation, and enhancement of the operating system. Describe the support system in the study project and its development.
6. Were the stakeholder requirements clearly defined at the start of the project? Were system requirements clearly defined? What are the requirements? In your opinion, were stakeholders identified and involved early in the project? Were their needs identified and addressed? Did the project deliver a system that met their needs?

CASE 2.1 GLADES COUNTY SANITARY DISTRICT

Glades County is a region on the Gulf Coast with a population of 600,000. About 90 percent of the population is located in and near the city of Sitkus. The main attractions of the area are its clean, sandy beaches and nearby fishing. Resorts, restaurants, hotels, retailers, and the Sitkus/Glades County economy in general rely on these attractions for tourist dollars.

In the last decade, Glades County has experienced a near doubling of population and industry. One result has been the noticeable increase in the level of water pollution along the coast, due primarily to the increased raw sewage dumped by Glades County into the Gulf. Ordinarily, the Glades County sewer system directs effluent waste through filtration plants before pumping it into the Gulf. Although the Glades County Sanitary District (GCSD) is usually able to handle the county's sewage, during heavy rains, the runoff from paved surfaces exceeds sewer capacity and must be diverted past filtration plants and directly into the Gulf. Following heavy rains, the beaches are cluttered with dead fish and debris. The Gulf fishing trade is also affected since pollution drives away desirable fish. Recently, the water pollution level has become high enough to damage both the tourist and fishing trades. Besides coastal pollution, there is also concern that as the population continues to increase, the county's primary fresh water source, the Glades River, will also become polluted.

The GCSD has been mandated to prepare a comprehensive water waste management program that will reverse the trend in pollution along the Gulf Coast as well as handling the expected increase in effluent wastes over the next 20 years. Although not yet specified, it is known that the program will include new sewers, filtration plants, and stricter anti-pollution laws. As a first step, GCSD must establish the overall direction and mission of the program.

QUESTIONS

Answer the following questions (given the limited information, it is okay to advance some logical guesses; if you are not able to answer a question for lack of information, indicate how and where, as a systems engineer, you would get it):

1. What is the system? What are its key elements and subsystems? What are the boundaries, and how are they determined? What is the environment?
2. Who are the decision-makers?
3. What is the problem? Carefully formulate it.
4. Define the overall objective of the water waste management program. Because the program is wide ranging in scope, you should break this down into several subobjectives.
5. Define the criteria or measures of performance to be used to determine whether the objectives of the program are being met. Specify several criteria for each subobjective. As much as possible, the criteria should be quantitative, although some qualitative measures can also be included. How will you know if the criteria that you define are the appropriate ones to use?
6. What are the resources and constraints?
7. Elaborate on the kinds of alternatives and range of solutions to solving the problem.
8. Discuss some techniques that could be used to help evaluate which alternatives are best.

CASE 2.2 LIFE AND DEATH OF AN AIRCRAFT DEVELOPMENT PROJECT

Law and Callon[24] describe the history of a large British aerospace project in terms of two entities: the global system and the project system. The *global system* comprised parties and organizations *outside* the project that had a stake in the project. The *project system* comprised all work in the project and all the organizations contracted to do it.

The global system

The principal stakeholders in the global system were:

1. The Royal Air Force (RAF), which initiated the project with a request for a new supersonic aircraft with short take-off capability. The aircraft would be a "tactical strike and reconnaissance fighter" called TSR.
2. Ministry of Defense (MOD), which wanted an aircraft that would best fit the nation's current overall defense needs.
3. The Treasury, which wanted an inexpensive aircraft that would have market appeal for sale outside the United Kingdom, such as to the Royal Australian Air Force (RAAF).
4. The Royal Navy, which wanted to buy *a different* aircraft but was under pressure by MOD to buy the TSR.
5. The Ministry of Supply (MOS), which wanted an aircraft that would be produced by a consortium of several UK airframe and engine manufacturers.

As is typical of most projects, each stakeholder conceptualized the project differently: to the RAF and MOD, it would yield an aircraft for a specific mission; to the Treasury, it would fit the defense budget and generate revenue; to the Navy, it was a competitive threat to the aircraft they really wanted; and to the MOS, it was an instrument of industrial policy. The parties had different reasons for contributing resources and support: some were economic (in return for funds, an aircraft would be built), some political (in return for a demonstrated need, objections of the Navy would be overruled), some technical (in return for engineering and technical effort, the aircraft would meet RAF performance requirements), and some industrial (in exchange for contracts, the aircraft industry would be consolidated).

The project

The Treasury would not approve project funding until the aircraft's basic design, manufacturer, cost, and delivery date were defined. The RAF and MOD sent requests to the aircraft industry for design ideas and selected two manufacturers, Vickers Corp. and English Electric (EE). They favored Vickers for its integration capability (combining aircraft, engine, armaments, and support equipment into a single weapons package), but they also liked EE for its design experience with supersonic aircraft. So they decided to contract with both companies and adopt a design that would utilize features from both. The idea was approved by all other parties in the global system, and funding for the project was released.

The project grew as Vickers and EE hired subcontractors and expanded their teams for design, production, and management. The two companies and several other contractors merged to form a single new organization called the British Aircraft Corporation (BAC).

Relationships between the global system and the project

As the project grew, so did the problems between it and the global system. MOS wanted centralized control over all aspects of the project and all transactions between the project and stakeholders in the global system. Although BAC was the prime contractor and ostensibly responsible for managing the project, MOS would not confer upon it the necessary management authority. Rather, MOS formed a series of committees with members from the global system and gave them primary responsibility to manage the project. This led to serious problems:

1. The committees were allowed to make or veto important project-related decisions. They, not BAC, awarded important contracts; when the RAF wanted to change its requirements, it consulted with the committees, not with BAC.
2. The committees often lacked sufficient information or knowledge. Technical committees made decisions without regard to costs; cost committees made decisions without regard to technical realities. Decisions focused on particular aspects of the project; seldom did they account for impacts on other parts of the project or the project as a whole.

Distrust grew between BAC and MOS; neither was able to effectively integrate the resources, information, and decisions flowing between parties in the project and the global system. Subcontractors became difficult to control. Many ignored BAC and worked only with MOS and RAF to get favorable treatment.

Global system reshaped

Everyone knew the project was in trouble. Project costs doubled. One of the test engines exploded, and the RAF recognized it would take years to understand the cause. In addition, the RAAF announced that it would not order the TSR but instead was buying the US-built F-111. Opposition to the project grew, and in the upcoming general election, the Labor Party promised that, if elected, it would review the project. When the Labor Party won, it immediately began an assessment of the project, which included comparing the TSR to the F-111—considered by now an alternative to the TSR. As cost overruns and schedule delays continued, MOS slowly withdrew support. Then the RAF withdrew its support when it discovered that the F-111, which was already in production, would meet all of its requirements. The project was canceled.

QUESTIONS

1. In this case history, what is the “system”? What are its elements? What is the “environment”? What are the elements of the environment?
2. Describe the interaction between the system and its environment.
3. Do you feel that important decisions made in this project represent “system thinking”? Explain.
4. Comment on the concept of “integration” in the project. How were aspects of the project integrated or not integrated?
5. What are the main factors that contributed to cancellation of the project? Which of these factors would you characterize as project management?

CASE 2.3 JUBILEE LINE EXTENSION PROJECT[25]

The Jubilee Line Extension Project (JLEP) was an expansion of the London Underground (LU) system. It expanded the LU through six London boroughs, linking Westminster to Docklands and Stratford. The project actually comprised 30 projects (i.e. it was a "program") that included 22 km of tunnels, five underwater crossings, 11 new stations, and complex installations of machinery and equipment. Everywhere care had to be taken to ensure the safety of over 30 buildings in central London. JLEP in many ways mirrors another large underground project—Boston's Big Dig (see Cases 10.1 and 16.3).

Started in 1993 for an estimated £2.1 billion cost, JLEP was completed in December 1999, 20 months behind schedule and over £1.4 billion over budget (at the time, the most expensive project in the world). Four major events contributed to the overruns:[26]

- Work stoppage to secure private-sector funding.
- Collapse of express tunnels at Heathrow Airport, which utilized the same tunneling method in JLEP and necessitated a complete safety review of the method.
- Failure of the new signaling system.
- Decision to site the Millennium Dome at Greenwich, for which JLE was to be a major source for access.

Other contributors were the differences in contracts and resulting ambiguities over roles and responsibilities of the involved parties. Two kinds of contracts were used; one was based upon payment schedules and milestones, the other upon design and performance specifications. These differences later proved incompatible.

JLEP required significant design changes throughout the project; many of them were poorly controlled and managed or were approved post facto. Differences between early proposed designs and working design drawings were poorly communicated, and many designs were "frozen" by engineering and architectural groups even though elements of the design were still in the conceptual stage. Construction contractors were minimally involved in the design. The project team faced political pressure to complete JLE in time to serve as a main transport link to the Millennium Dome, which was then in construction. Consequently, it set an overly ambitious project deadline of 53 months.

The project was managed through the project director, project manager, and a large project team. Contractors were chosen independently, and interfaces between them were not defined. This led to confusion and left the project team with the substantial task of managing all contractor interfaces and coordinating their work. Substantial changes in design and lack of clear targets and milestones led to difficulties in monitoring progress and applying the milestone payment system.

London Underground management treated JLE as a "bolt on" to the existing railway line; that is, it treated JLE as almost independent of existing transportation lines and communication systems to which it would be linked. The project team actually took the view that *existing LU lines had nothing to do with them*. Despite the fact that JLE would substantially increase the size of the LU system—and impact the system and be impacted by it—LU management viewed JLEP as simply a construction project whose ultimate operation would be independent of the overall LU system. Only a relatively small amount was budgeted to other parts of the LU to handle increased passenger traffic resulting from JLE. Early planning of JLE did not fully address operational issues, and it was *more than a year after* the project started that a plan for the operation of JLE was first addressed.

The project was originally scheduled to go "online" all at once; only much later, after setbacks, was it decided that JLE would open in a phased manner.

JLEP was completed with no fatalities and has been successful in relieving congestion; several of its stations have received awards for architectural design, and JLE is cited as a contributor to the success of the 2012 London Olympic Games. But it was completed for £3.5 billion instead of the budgeted £2.1 billion and in 73 months instead of the planned 53 months, this despite a substantial reduction in its scope (replacing an intended new-technology signaling system with a traditional system).

QUESTIONS

1. The case illustrates a situation where the systems approach to design and management is necessary. Why is it necessary?
2. Is there evidence in the case to demonstrate that JLE planners and management used the systems approach or systems engineering? In your discussion, consider the following: JLE as a "system," stakeholders' identification and needs identification, requirements definition, interface management, and system operation.

CASE 2.4 SANTA CLARA COUNTY TRAFFIC OPERATIONS SYSTEM AND SIGNAL COORDINATION PROJECT[27]

The road infrastructure of Santa Clara County consists of (1) freeways managed by the state of California, (2) city streets and highways managed by individual municipalities, and (3) limited-access highways and signalized intersections managed by the county. The county conducted a study of the feasibility of integrating all of these traffic operations and signaling systems into one Intelligent Transportation System (ITS). The ITS would upgrade the county's Traffic Operations Center, traffic signal system, communications, and intersection surveillance and provide communication links with municipal control centers. The study identified interfaces among the disparate systems and described the ITS architecture. The project began in 1998, and within the legislated budget and 7-year timeframe, the ITS was fully operational.

Among challenges experienced during the project were:

- Rapid changes in video-camera and video-transmission technology for traffic surveillance.
- Availability of new technologies to allow traffic signaling and ITS communication systems to transition from analog to digital Internet protocol.
- The "dot.com" boom, which affected the supply of fiber optic cabling and led to an 18-month delivery schedule and a potential doubling of costs.

A post-hoc analysis of the project conducted by the INCOSE Transportation Working Group concluded that the project's management had taken the following major steps:

- Created a clear statement of the operational concept.
- Developed system requirements.
- Controlled the revision of the requirements during the design and construction phases to accommodate changes in technology.

- Clearly defined during the design stage the verification tests necessary for acceptance of subsystems.
- Defined early in the project the performance measures to be used in system validation.

The INCOSE group also concluded that the project's management had effectively used risk management planning, especially regarding potential delivery delays due to shortages of fiber optic cable. Soon after the communications requirements were declared fixed, the client initiated procurement of the fiber cable and processes to incorporate the cable into construction contracts.

During system design and implementation, senior staff (both client and consultant) reviewed the user requirements and revised the design concept, which removed technological biases in requirements and made it possible to accommodate later revisions in technology.

Twelve years after the start of the project, communications protocols had changed. The modularity of the system design, however, enabled the system to be upgraded in stages without changing the equipment or underground communication infrastructure.

QUESTION

Although the project team did not intentionally set out to follow the systems approach, much of what it did, in fact, conformed to systems engineering practices. Compare the limited information provided about the project with the systems engineering concepts and V-model described in the chapter.

Notes

1. Naughton J. and Peters G. *Systems Performance: Human Factors and Systems Failures*. Milton Keynes, UK: The Open University; 1976, pp. 8–12.
2. Innumerable systems can be perceived from any one entity. Boulding K. *The World as a Total System*. Beverly Hills, CA: Sage; 1985 describes the world as physical, biological, social, economic, political, communication, and evaluative systems.
3. Schoderbek P., Kefalas A. and Schoderbek C. *Management Systems: Conceptual Considerations*. Dallas: Business Publications; 1975, pp. 7–8.
4. Kast F. and Rosenzweig J. The modern view: A systems approach. In Beishon J. and Peters G. (eds), *Systems Behavior*, 2nd edn. London, UK: Harper & Row; 1976, pp. 19–25.
5. Cleland D. and King W. *Management: A Systems Approach*. New York, NY: McGraw-Hill; 1972, p. 89.
6. Churchman C.W. *The Systems Approach and Its Enemies*. New York, NY: Basic Books; 1979.
7. Ibid., pp. 4–5.
8. Much of the discussion in this section is based on Churchman C.W. *The Systems Approach*. New York: Dell; 1968, pp. 30–39.
9. Thome P. and Willard R. The systems approach: A unified concept of planning. In Optner S. (ed.), *Systems Analysis*. Harmondsworth, UK: Penguin Books; 1973, p. 212.
10. Hamilton H. *Systems Simulation for Regional Analysis*. Cambridge, MA: The M.I.T. Press; 1972.
11. The life cycle of technological products is eloquently described by Foster R. *Innovation: The Attacker's Advantage*. New York, NY: Summit Books; 1986.
12. As common parlance, the term *project life cycle* is the recognition that all projects tend to follow a similar sequence of activities, start to finish. Since every project, however, has a start and finish, when referring to a particular project, the more precise term is *project life span*.
13. Jenkins G. The systems approach. In Beishan J. and Peters G. (eds), *Systems Behavior,* 2nd edn. London, UK: Harper and Row; 1976, p. 82.
14. Auyang S. *Engineering—An Endless Frontier*. Cambridge, MA: Harvard University Press; 2004, pp. 175–189.
15. Brooks F. *The Mythical Man Month*. Reading, MA: Addison Wesley; 1995, p. 199.

16. Auyang. *Engineering—An Endless Frontier*, p. 183.
17. Ibid., pp. 192–197.
18. Herbert Simon, quoted in Auyang. *Engineering—An Endless Frontier*, p. 194.
19. Forsberg K. and Mooz H. In Taylor R., Dorfman M. and Davis A. (eds), *Software Requirements Engineering,* 2nd edn. Los Alamitos, CA: IEEE Computer Society Press; 1997, System Engineering Overview, pp. 44–77; V-model adapted from reprint in Auyang. *Engineering—An Endless Frontier*, p. 197.
20. Cleland and King. *Management: A Systems Approach*, pp. 171–173; and Johnson R., Kast K. and Rosenzweig J. *The Theory and Management of Systems,* 3rd edn. New York, NY: McGraw-Hill; 1973, pp. 135–136.
21. Gilbreath R. *Winning at Project Management*. New York, NY: John Wiley and Sons; 1986.
22. Ibid., pp. 95–96.
23. Ibid., pp. 98–102.
24. From Law J. and Callon M. The life and death of an aircraft: A network analysis of technical change. In Bijker W. and Law J. (eds), *Shaping Society/Building Technology*. Cambridge, MA: MIT Press; 1992.
25. Information for this case is derived from three sources, all accessed October 30, 2014: (1) *Project Profile, Jubilee Line Extension*. Omega Centre, University College London (no date), www.omegacentre.bartlett.ucl.ac.uk/studies/cases/pdf/UK_JLE_PROFILE_120909.pdf; (2) *Jubilee Line Extension, London, UK* (no date), www.omegacentre.bartlett.ucl.ac.uk/studies/cases/pdf/UK_JLE_2P_080911.pdf; and (3) Systems Engineering Case Study # 8 Jubilee Line Extension. *Systems Engineering in Transportation Projects: A Library of Case Studies*. INCOSE Transportation Working Group; 2013, www.incose.org/practice/techactivities/wg/transport/docs/CaseStudyLibrary_6_0.pdf.
26. Mitchell B. *Jubilee Line Extension: From Conception to Completion*. London, UK: Thomas Telford Publishing; 2003.
27. Adapted from Systems Engineering Case Study # 7 Santa Clara County Traffic Operations System and Signal Coordination Project. *Systems Engineering in Transportation Projects: A Library of Case Studies,* INCOSE Transportation Working Group, 2013, www.omegacentre.bartlett.ucl.ac.uk/studies/cases/pdf/UK_JLE_2P_080911.pdf, accessed October 30, 2014.

Part II

Systems development and project life cycle

Most systems move through a series of developmental stages. In human-made systems, the developmental stages follow an intentional, logical sequence of prescribed activities called the systems development cycle. Project management occurs within this cycle and is the function responsible for planning the work activities and organizing and guiding their execution. The three chapters in this section introduce the systems development cycle and describe its first three phases: conception, definition, and execution and closeout—the project life cycle.

Chapter 3

Project life cycle and project conception

There is . . . a time to be born, and a time to die; a time to plant, and a time to reap; a time to kill, and a time to heal; a time to break down, and a time to build up.

—Ecclesiastes 3:1

One feature of the systems approach is the concept of "life cycle"—the basic pattern of change that occurs throughout the life of a system. Two ways the systems approach accounts for this are to (1) recognize the *natural process* that occurs in all dynamic systems—that of birth, growth, maturity, and death, and (2) incorporate that process into the planning and management of systems. The practice of project management does both.

The process of developing, implementing, and operating any human-made system follows a logical sequence of phases called the *systems development cycle*. Projects also follow a sequence of phases from beginning to end called the *project life cycle*. This chapter describes the system development and project life cycles and the first phase of both, conception.

3.1 Project life cycle

Systems are dynamic—they change over time. Often, the change follows a distinct pattern that is repeated again and again. Mentioned in Chapter 2 was the life cycle of organisms—birth, growth, maturity, senescence, and death—and its similarity to cycles in human-made products and systems.

Similarly, projects follow a cycle called the *project life cycle*. Each project has a starting point and progresses toward a predetermined conclusion; during this time, work effort in the project grows, reaches a peak, and then declines—the pattern shown in the lower curve in Figure 3.1 (the upper curve shows cumulative work effort). Effort can be measured in various ways, such as the amount of money being spent on the project and materials being used, number of people working on it, and so on.

Besides the level of work effort changing, the nature and emphasis of the effort change, too, and so do the people involved. For example, customers and planners are active early in the project; then designers and builders take charge; then, at the end, users and operators take over.

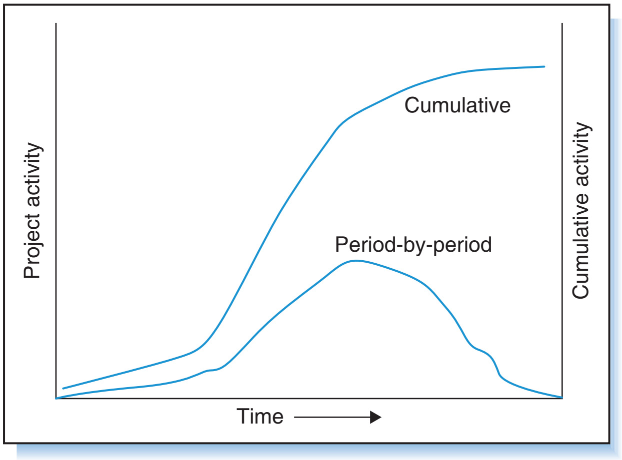


Figure 3.1
Level of effort during the project life cycle.

Managing the project life cycle requires special treatment. Unlike non-project operations where everything tends to be somewhat familiar and stable, many things in projects—resources, schedules, work tasks, and so on—are unfamiliar or in a constant state of change. Much of what is done in a project can be considered non-repetitive or non-routine. Work schedules, budgets, and tasks must be uniquely tailored to fit the work. Unforeseen obstacles can cause missed deadlines, cost overruns, and poor project performance. Managers must try to anticipate the problems, plan for them, and adjust activities and shift resources to mitigate or overcome them.

3.2 Systems development cycle

The project life cycle is part of a larger life cycle called the *systems development cycle* that virtually all human-made systems follow. The SDC has four phases of this cycle (Figure 3.2):

1. Phase A: Conception phase
2. Phase B: Definition phase
3. Phase C: Execution phase
4. Phase D: Operation phase

The project life cycle typically spans Phases A, B, and C, because virtually all human-made systems start out as projects. When Phase C ends, so does the project. The system ceases to be the end-item of a project and becomes an operational entity; this is Phase D, operation.[1]

Phase A: conception

Every project is an attempt to solve a problem or fill a need, so a first step in system development is recognizing that the problem or need exists. After that, the individuals facing the problem—the customers, users, stakeholders—seek out someone who can help. The steps they take—soliciting contractors who can do the work, evaluating their proposals, and reaching an agreement—are all part of the so-called *procurement management* process.

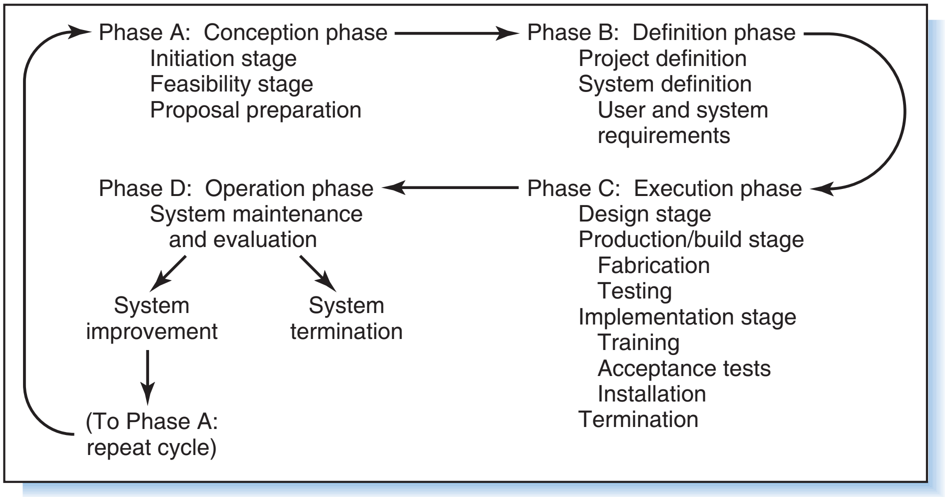


Figure 3.2
Four-phase model and stages of the systems development cycle. The project life cycle is Phases A, B, and C.

If the customer is an organization that has someone internally capable of doing the work, it turns to them. If not, it looks to outside contractors, possibly by sending them a formal request for help called a *request for proposal*, or RFP. Each contractor examines the customer's problem and requirements as stated in the RFP and determines the technical and economic feasibility of undertaking the project. If the contractor decides to respond to the request, it sends the customer its proposed solution (or "system concept") in a *proposal* or *letter of interest*. The customer then examines the proposals from all the contractors and makes a choice. The result is a formal agreement or contract between the customer and the chosen contractor. Most ideas or proposals never get beyond Phase A because the problems addressed are judged as insignificant or the proposal as impractical, infeasible, or lacking benefits to justify funding and resources. The few that are approved and reach a contractual agreement move on to Phase B.

Phase B: definition

Having reached agreement with the customer, the contractor begins a detailed analysis of the system concept, during which it defines requirements that the system must fulfill to meet the customer's needs and the necessary functions and elements of the system to meet those requirements. This definition results in a preliminary design for the system. As the process continues, the major subsystems, components, and support systems of the proposed system are determined, as are the resources, costs, and schedules necessary to build the system. Meanwhile, project management assembles a comprehensive project plan that defines the work activities, schedules, budgets, and resources to design, build, and implement the system.

In some industries, the tasks in Phases A and B are referred to as "front-end loading" (FEL) or "frontend planning," which refers to everything that happens in a project prior to the work execution in Phase C. FEL is discussed in Chapter 4.

See Chapter 4

Phase C: execution

The execution phase is when the work as specified in the project plan is carried out; the phase is sometimes also referred to as the "acquisition" phase because most system resources are acquired then, and following the phase, the user acquires the system.

The execution phase often includes the stages of "design," "production/build," and "implementation," referring to the progression through which a system moves from being an idea to a finished, operational end-item. All systems are composed of elements arranged in some configuration or structure, and in the *design* stage, these elements and their configurations are defined. In the *production* stage, the system is built, either as a single item or mass-produced item. Finally, during *implementation*, the system is installed and becomes a part of the user's environment.

Phase D: operation

In the operation phase, the customer or user takes over to operate the system and maintain it. For systems such as products and equipment that people use or rely upon daily, Phase D may last for years or decades, and the phase includes not only operation and maintenance of the system but improvement and enhancement to keep the system viable and useful. Every system eventually outlives its purposes or simply wears out. When that happens, the choices are to either scrap the system or upgrade it so it remains useful. In the latter case, the "upgrade" is essentially a new system concept, which initiates a new SDC and a new project.

For some systems, Phase D is short or nonexistent: examples are political campaigns and rock concerts—the project ends on Election Day or upon completion of the concert performance.[2]

Virtually all projects progress through Phases A, B, and C, though not necessarily through the stages shown in Figure 3.2. In some projects, certain stages receive little emphasis or are entirely skipped; many projects, however, move through all the stages, even if informally. For instance, although not every project requires proposal preparation, every project does start with a proposal from *someone*. Similarly, while many projects do not involve "production," every project involves the production of something—even if only information. A great many projects follow a pattern similar to the cycle in Figure 3.2. The next two examples illustrate.

Example 3.1: New Product Development Cycle at Jamal[3]

Jamal Industries is a medium-sized manufacturing firm that produces products for major retailers under the retailer's own labels such as Costco and True Value. It develops and produces products in the phases of *initiation, feasibility, analysis, design*, and *manufacturing*. Jamal initiates and implements most projects internally, although sometimes it contracts out development and manufacturing work. This example is such a case.

A competitor had introduced a computerized timer that would have a major impact on Jamal's market share. To examine the feasibility of launching a new product, Jamal engineers analyzed samples of the competitor's device to see whether they could quickly develop their own version. The analysis focused on whether a device as good or better could be made and sold under the retailers' private labels for 20 percent less than the competitor's price. As an alternative, Jamal could seek other distribution channels to sell the product under its own label. The study indicated that the first alternative was not feasible, although the second one was.

An in-depth analysis was done to determine how Jamal could contract out work to avoid a capital investment that it could not afford. The research director, who served as the project manager, and his engineering staff analyzed contracting alternatives and decided to hire a general contractor to design and manufacture the product. They identified a foreign contractor that could design and make a superior timer that Jamal could market at a price $12 lower than the competition. The bulk of the planning, scheduling, and budgeting associated with the project was delegated to the contractor. Within a year, the product was designed, manufactured, distributed, and in stores.

The contractor will continue to produce the device as long as Jamal markets it. Jamal's design team was transferred to other projects, although the research director continues to monitor the contractor to ensure quality standards are maintained.

Example 3.2: Software System Development Cycle at Microsoft[4]

New software development at Microsoft commonly follows the phases of *planning, development*, and *stabilization*, wherein some of the phases pass through a series of iterations.

The planning phase produces a vision statement; specification document; and plans for marketing, integrating components from other products, testing, and documentation. The phase runs from 3 to 12 months depending on whether the product is new or an upgrade. The vision statement guides the project; it is a short statement about the product goals, focus, and priorities. The specification document is a preliminary statement of the product's features and packaging. The document starts out small (sometimes a single sentence) but expands as the project progresses. This document is combined with project plans and time estimates to create a schedule. The phase concludes when management approves the plans and schedule.

The development phase is subdivided into four sub-phases, with three internal product-release milestones. Each sub-phase is scheduled to run 2 to 3 months, which includes time buffers to accommodate unanticipated problems and enable sub-phases to be completed by the milestone date. Three sub-phases are devoted to development and coding, testing for bugs and functionality, and documentation of product features. The goal of each sub-phase is to meet the requirements for a set of product features that would be fully ready to "ship," even though shipping isn't yet possible because the features have yet to be integrated into the product. In the event that a competitor threatens to release a similar product, the third, or even second, sub-phase can be bypassed to cut 4 to 6 weeks from the development process. The product would have fewer features but would beat the competition to launch. During the fourth sub-phase, product features are further tested and debugged and a freeze imposed, which means no major changes can be introduced thereafter. This enables the education group to write documentation that will accurately correspond to the product when released. The sub-phases of the development are a variation of the "agile" approach to system development, described in Chapter 14.

See Chapter 14

In the last phase, *stabilization*, all the features developed in the previous phase are combined and tested. "Zero bug release" occurs when all bugs are fixed or features with bugs are removed from the product (to be fixed and included in later product releases). This phase concludes with the release of a "golden master" disk from which manufacturing will make copies. The project concludes with a project team meeting to review the project and what was learned from it.

Most project-oriented companies undertake projects in ways best suited for them, and they prescribe or mandate ways to manage and perform tasks in those projects; that is, they create their own project *methodology*. The two previous examples illustrate two such project methodologies. Throughout this book, we will repeatedly refer to the methodology that encompasses phases A thorough C in Figure 3.2. We use this methodology not because it is always the best but because it conveys a common pattern that is very similar to methodologies we have seen in many companies. Another methodology similar to Figure 3.2 is the systems engineering process, tools for which are discussed in Chapter 4. Other methodologies are discussed in Chapter 18.

See Chapters 4 and 18

Phased project planning and fast-tracking

The phases and stages in a project life cycle are sometimes undertaken in a stepwise fashion called *phased project planning* or project *gating*. At the end of each phase, management reviews the project objectives, costs, and outcomes and decides whether to continue, suspend, or cancel the project. This is elaborated upon in Chapter 4.

See Chapter 4

The project phases are not always performed in discrete sequence but can be overlapped in a practice called *fast-tracking*. Before Phase B is completed, elements of Phase C are started; before Phase C is completed, Phase D is started. Fast-tracking compresses the project duration, though it poses the risk of overlooking or misdefining tasks and having to repeat or undo them.

In projects using the so-called *agile* methodology, aspects of phases are repeated. The execution phase and, sometimes, the definition phase are repeated in cycles, each cycle intended to refine, enhance, or build upon the results of the previous cycle. Agile is covered in Chapter 14.

See Chapter 14

Stakeholders

The SDC has many stakeholders. The main stakeholder groups are:

1. System customers (also called buyers, clients, or owners), including:
   a. Customer management
   b. Users and operators
2. System contractors (also called the systems development organization—SDO, developer, promoter, consultant, or seller), including:
   a. Contractor top management (corporate and functional managers)
   b. Project management (project manager and staff)
   c. “Doers”—professional, trade, assembly, and other workers

Customers are the persons or groups for whom the project is being done and who will acquire and/or operate the system when it is completed. Customer management pays for and makes decisions about the project. Users and operators utilize, maintain, or in other ways are the recipients of the project end-item. It is important to identify the actual users since, ultimately, it is for them the end-item system is created. Although the terms customer and user are used somewhat interchangeably, it is important to keep in mind the distinction between them:

- The customer (owner, buyer, sponsor) *pays* for the system.
- The users *use* and operate it.

The contractor is the party that studies, designs, develops, builds, and installs the system. The contractor is usually external to the customer organization, although it might well reside within the same organization, as is the case of internal consulting/support groups. Since the contractor is usually an *organization*, it can be referred to as the system development organization.

Because in most cases the customer pays the contractor to perform the project, think of the customer as the *buyer* and the contractor as the *seller*. These terms make sense when you think of a project in the context of being a contract between two parties, wherein one (the contractor-seller) agrees to provide services in return for payment from another (the user-buyer). This is discussed in detail in the chapter on procurement management and contracts.

See Chapter 12

Besides these, the life cycle involves other key parties—individuals, groups, and organizations with vested interests and/or influence on the conduct of the project. Anyone who is affected by the project, perceives to be affected by it, or potentially can alter its outcome is a *stakeholder*. Project stakeholders are discussed throughout the book and somewhat in depth in Chapters 16 and 18.

See Chapters 16 and 18

The remainder of this chapter will focus on the first phase of the project life cycle and how projects are conceived and started.

3.3 Phase A: conception

The conception phase nominally comprises two stages. The first, project initiation, establishes that a “need” or problem exists and that it is worthwhile to investigate. The second, project feasibility, is a detailed investigation of the need or problem, a formulation of possible alternative solutions, and the selection of one. The phase ends with an agreement that a chosen contractor will provide a specified solution to the customer.

Project initiation

Conception begins when the customer or user perceives a *need*; that is, it recognizes a problem or opportunity and, possibly, ways to deal with it.[5] Sometimes the need is expressed as a vision.

Example 3.3: Vision Statement at Microsoft[6]

As mentioned in Example 3.2, each new product development project at Microsoft starts with a short statement about a product and its goals called a vision statement. For a recent version of Excel, it was just five pages long.

The purpose of the vision statement is to communicate the concept and requirements of the product to the development team, management, and other product groups. The vision includes an executive summary with a one-sentence objective, a list specifying what the product will do and not do, and definitions of the typical customer and competition. It might describe product features and priorities in enough detail to begin preparing schedules for development, testing, user education, and preparation of English and non-English product versions. It might also list requirements for the operating system, memory, storage space, processor speed, graphics, and dependencies on printer drivers and components. The statement gives everyone a common overview about what they need to do.

Beyond perceiving the need, project initiation requires proving that the need is significant and can be fulfilled at practical cost. It is easy to identify problems and muse about solutions, but most ideas are ephemeral and not worth much. If a customer decides to take an idea beyond speculation, he might take the “quick and dirty” route and simply accept the first solution that comes along, or he might undertake a more protracted, albeit systematic and thorough, approach and consider only ideas with a reasonably high degree of success or return on investment. To cull the few good ideas, the customer organization undertakes a brief initial investigation.

Initial investigation

Many users know a problem exists but not what it is or even how to explain it. Before committing resources to a full-fledged study, the user undertakes a short internal investigation to clarify the problem and evaluate possible solutions. The investigation starts with fact-finding—interviewing managers and users, gathering data, and reviewing existing documentation. A clear statement of the problem is formulated, objectives are defined, and a list of alternative potential solutions is compiled. The investigation focuses on the elements of the problem, including:

- The environment
- The needs, symptoms, problem definition, and objectives
- Preliminary solutions and estimated costs, benefits, strengths, and weaknesses of each
- Affected individuals and organizations.

Based on the investigation, the customer decides whether to proceed. Most ideas never get further than this, and it is obvious why: there are endless ideas about needs and potential solutions, but resources are scarce and organizations can commit only to those comparative few that provide the most benefits and have the best chances of success. To approve the concept for further study, the customer must be convinced that the idea:

- Fits a need that is real and funding is available to support it.
- Has sufficient priority in relation to other ideas.
- Has particular value in terms of, for example, applying new technology, enhancing reputation, increasing market share, or raising profits.
- Is consistent with the organization's goals and resources.

See Chapter 19

Pertaining to the last bullet, some organizations *pre-screen* proposed projects and consider for further analysis only those that align with organizational goals and available resources. Pre-screening is an aspect of *project selection and portfolio management*, discussed in Chapter 19.

The initial investigation is usually conducted by the customer and requires but a few days or weeks at most. Also called the *idea stage* or *pre-feasibility stage*, its purpose is to determine if the idea deserves further study; if it does, it then becomes a "potential project" and moves to the next stage, feasibility.

3.4 Project feasibility

Feasibility is the process of studying a need, problem, or solution in sufficient detail to determine if an idea is economically viable and worth pursuing. The initial investigation is a form of feasibility study (*pre-feasibility*) but is usually rather cursory and hence insufficient to commit to a project. A *feasibility study* is a more protracted, rigorous study that considers alternative solutions (system concepts) and the benefits and costs of each. The customer might perform the feasibility study but will hire an outsider (contractor) to do it if the study requires special expertise. Deciding to build a new airport, power plant, highway, or tunnel are examples where the feasibility studies are undertaken by contractors and where the studies are themselves big, expensive projects.

When several alternatives exist for the project, project feasibility may depend on the life-cycle cost (LCC) of the end-item system; this is the system's total cost over its entire useful life, including installation, operation, and disposal. The cost of the system includes all costs associated with all phases of the SDC—conception, definition, execution, and operation. The topic of LCC is covered in Chapter 9.

See Chapter 9

Some projects involve multiple feasibility studies. Product development and research projects often have both a *technical feasibility* (to assess the risk that the technology might not work) and a *commercial feasibility* (assess the risk that the product might fail in the market). Another matter regarding feasibility is the question of how the project will be financed and its expenses covered throughout the project life cycle. Project financing is a subject unto itself and beyond the scope of this book; however, it is of major importance and, quite often, the deciding factor in project approval. In other words, a project's feasibility might have less to do with the technical or commercial merit of the project than with funds available to support the project. For large projects, the execution plan (see Chapter 6) might include a section on project financing that addresses funding arrangements and means for controlling cash flow and managing money.

See Chapter 6

If the feasibility study indicates that the concept is viable, one of two things happens (Figure 3.3).

Theme A: if the concept is something the customer can handle itself, it is passed along to an internal group for development and execution;

Theme B: if the concept cannot be executed internally, it is given to outside contractors (SDOs).

Companies like Boeing, Microsoft, and Toyota routinely do feasibility studies for new products and then hand the approved concepts to their own teams for the design, development, and production of the products. But companies like Ritz-Carlton and Swissôtel, after deciding to build a hotel at a specific location, hire outside contractors to execute the project. They solicit proposals from multiple contractors and select the best.

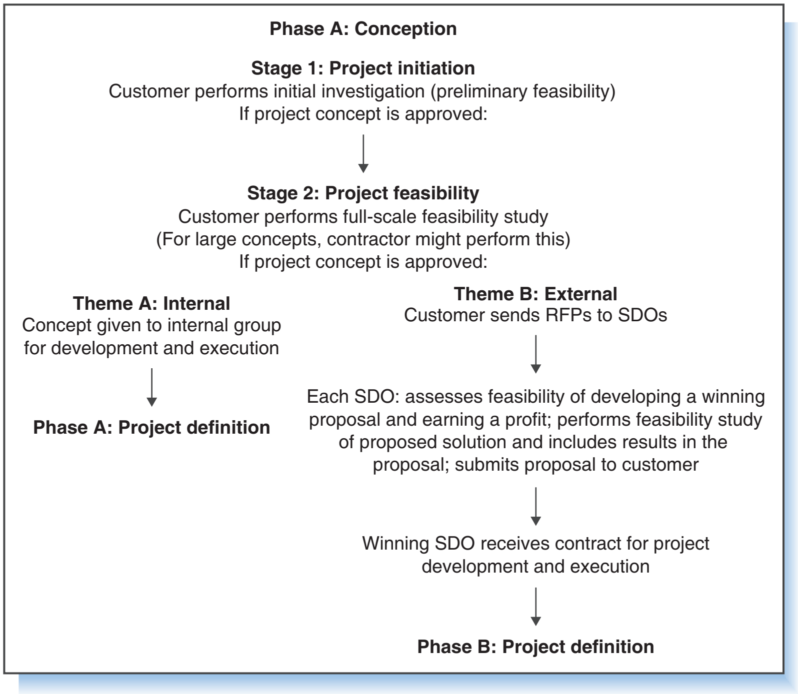


Figure 3.3
Feasibility study as part of the conception phase.

Each contractor competing for the project must also perform a feasibility study to assess the merits of the project and whether it wants to participate. If a contractor decides to go forward, it will investigate possible solutions (system concepts) to the customer's problem, choose one, and describe it in a proposal. This is called the "proposal preparation process." Upon receiving the proposals, the customer reviews them and selects the one it thinks is best, that is, is the "most feasible."

In summary, project feasibility involves multiple studies and decisions—the customer assessing the "feasibility" of funding the project, the contractor determining the "feasibility" of winning the contract, the contractor conceiving and proposing the "most feasible" solution to the customer, and the customer assessing proposed solutions and choosing the "most feasible" to buy. When the customer reaches an agreement with a contractor, the project moves forward to Phase B.

Sometimes contractors decide not to prepare proposals because they don't have solutions that will make a profit or fit the customer's request. Sometimes customers conclude that *none* of the proposals meet the requirements. Either way, the concept is judged as "not feasible," and the process ends there.

Request for proposal[7]

See Chapters 12 and 19

The RFP—request for proposal—is a document the customer sends to potential contractors explaining the customer's problems, objectives, requirements and desire to hire someone; it might also state what the customer wants to see in the proposal (proposal requirements) and how the winning proposal will be selected (proposal evaluation criteria) (see Figure 3.4). Additional forms of customer requests and the process of selecting the best proposal are described later in this chapter and in Chapters 12 and 19.

A purpose of the RFP is to outline the user's need, problem, or idea; another is to solicit suggestions (proposals) for solutions—usually with the intent of awarding a contract. The customer can send RFPs to contractors on its own *bidders* list—a list of prequalified contractors—or it can also distribute RFPs to the broader market via the Internet using commercial online sourcing tools. Thus, contractors learn about upcoming jobs either by directly receiving RFPs from customers or by requesting RFPs through online

Statement of work

- Description of problem, need, or general type of solutions to be investigated.
- Scope of work to be performed by contractor, work to be included, work excluded, and work restrictions; criteria of acceptance for results or end-items.
- Requirements for the solution, results, or end-item, including specifications and standards; description of how work will be measured; expected relationship between user and contractor; expected completion date; constraints on cost of work to be performed.

Proposal requirements

Conditions placed on the proposal such as proposal contents and format, data requirements, sample forms to include, and submission location and deadline.

Contractual provisions

Type of contract to be awarded, sample contract, and nondisclosure provisions.

Technical information or data

Any additional data, or name of a contact person for requesting additional data, necessary to develop a solution and prepare the proposal or price quote.

Proposal evaluation criteria

Explanation of criteria and procedures for assessing the proposal and selecting a contractor.

Figure 3.4
Contents of a request for proposal.

newsletters and bulletins. For example, web the publication *Commerce Business Daily* gives a synopsis of all US federal jobs over $10,000. Businesses scan the jobs and request RFPs for those they find of interest.

Often the customer will precede the RFP with a *request for qualifications*, which is a request for contractors to describe their qualifications. The customer sends RFPs only to contractors it deems qualified for the work.

Project foul-ups can often be traced back to a poor RFP. The RFP must be clear, concise, and complete: when it is, the customer can expect contractors to respond with proposals that are clear, concise, and complete; when it is not, the customer can expect proposals in kind. Ultimately, the ability of contractors to *develop* solutions that uniquely fit the customer's needs will depend in part on their understanding of the requirements as specified in the RFP. Similarly, the ability of the customer to *select* a contractor that is qualified and has the best proposal will depend on information provided in the RFP. Appendix A at the end of the book is an example RFP.

See Appendix A

Each competing contractor must consider its capability of preparing a winning proposal and, should it win, of performing the proposed work. Among the considerations are:

- Have competitors already gotten a head start?
- Does the contractor have sufficient money, facilities, and resources to invest in the project?
- Could performance on the project enhance (or damage) the contractor's reputation?
- Other considerations similar to the criteria employed by the customer in the initial investigation.

Sometimes a contractor will submit a proposal knowing full well it cannot win the project, doing so to maintain its relationship with the customer, remain on the customer's bidders list, or keep the field competitive. Sometimes a customer sends out RFPs with no intention of ever signing with a contractor; it simply wants to gather ideas—a situation of which contractors must be wary.

Contractors can also submit proposals to potential customers without an RFP. Whenever a developer believes it has a system or solution that satisfies a need or solves a problem, the project manager works with his marketing department to identify prospective customers, to which they might send *unsolicited proposals* describing the merits of the new system. Unsolicited proposals are also sent to current customers for potential follow-up work on current projects.

The feasibility study

As mentioned, a feasibility study can be performed at multiple times and with different parties in a project: minimally, the customer performs a study to determine if the project is worth pursuing, and the contractor also performs one to determine if the job is worth doing. In this section, we consider the latter, although the same steps would apply to most anybody doing a feasibility study.

The statement of the problem (or "statement of work") as defined in the RFP is frequently incomplete, vague, or even incorrect. If the contractor has received an RFP, it will likely contain such a statement. Thus, one of the first steps before responding to an RFP is to develop a definition of the problem that is more concise, accurate, and complete than the one in the RFP.

The prime source of information about the problem is interviews and documented information provided by the customer and users. It is thus important that the contractor identify who the users really are—parties who are familiar with both the problem and the workings of the organization. Surprisingly, this is not always obvious. The real users, those who will operate, maintain, or be the main beneficiary of the system, are often confused with persons who only represent the users. If the customer is an organization, the contractor must determine the individuals whose needs are to be met, then try to work with them during the feasibility study. Sometimes, however, the RFP specifies that in order to make the competition "fair," the customer will maintain an "arm's-length" relationship with competing contractors. Even then, however, contractors are usually permitted to make inquiries to or seek additional information from a customer contact person.

The business case

Sometimes the feasibility study results in a business case, a document that assesses the value and risks (feasibility) of a project at an early stage and attempts to convince the customer/sponsor to authorize and undertake the project. It is sometimes used to obtain financing for the project from commercial banks (*a bankable business case*). In the process of choosing between projects, some companies use the business case to compare projects in terms of benefits versus risks and costs. This is discussed in Chapter 19.

See Chapter 19

The content of the business case depends on the findings of the feasibility study. Whereas the feasibility study compares alternative solutions and determines if the project is viable, the business case tries to justify the chosen alternative.

A business case typically includes:

- Cost-benefit analysis: estimated project costs compared to the benefits
- Estimated project duration (when a financial return depends on the timescale)
- Financial aspects such as the funding approach
- Risks, issues, and a preliminary risk management plan
- Assumptions.

The business case contains estimates for costs and benefits, although often those estimates are updated as the project moves through its early phases. For example, the PRINCE2 methodology specifies developing an *outline business case* at project start and thereafter reviewing and updating the estimates after each project phase. In some industrial mega-projects, the first two phases of a project are referred to as FEL-1 (Front-End Loading-One) and FEL-2; FEL-1 concludes with a *preliminary business case*, FEL-2 with a verified, *detailed business case*.

Sometimes the business case is included as part of a more comprehensive feasibility report that, in addition to arguing the business case, addresses technical, environmental, financial, and other aspects of the project in greater detail than would a typical business case.

Needs definition

A problem is an unsatisfied need, and a solution is a way to satisfy the need. Since both problems and solutions originate from needs, it is important that the solution adopted for the project address the right needs. Conducting a feasibility study and preparing a proposal should begin with defining user needs. J. Davidson Frame suggests the following steps:[8]

1. *Ask the user to state the needs as clearly as possible.*
2. *Ask the user a complete set of questions to further elicit the needs. For example:*
    Are these real needs, or are there other, more fundamental ones?
    Are they important enough to pursue?
    Are we are capable of fulfilling these needs, or is someone else better suited?
    If the needs are fulfilled, will they give rise to other needs?
    Will satisfying these needs also satisfy other needs, too?
    What effect do the unmet needs have on the organization and the user?
    What other parties are affected by these needs, and how will they react to our efforts?
3. *Conduct research to better understand the needs.* "Research" means probing to gather whatever information is necessary to better understand needs, define the problem, and propose solutions. Information sources include interviews, reports, memos, observation, models, and analysis of technical data and empirical test results.

4. *Based on information from steps 2 and 3, restate and document the needs.*
5. *Give the restated needs to the user.*

The steps are repeated as often as necessary, concluding with a needs statement that the user agrees best represents his interests (rather than the interests of the contractor or other parties).

Since every project is an effort to fulfill needs, a clear, well-stated, and correct needs statement is necessary to avoid a project that is meandering or irrelevant. But attaining such a needs statement is not easy. Frame describes the following troublesome aspects.[9]

- *Some needs are ever changing*. They are a moving target; thus, for each need, the question must be asked, "Is this likely to change?" When the answer is yes, the solutions and project plans that address the need must be flexible and easy to change.
- *Solutions are confused with needs*. Rather than stating a need, the user or contractor states a solution. For example, the statement "We need a new building" is a solution, not the need. True, maybe a new building will be required, but a new building is only one of perhaps many ways of satisfying the need to, for example, overcome a space shortage.
- *The needs identified are for the wrong user. Who* is the user? Is it the party that actually *feels* the need and is most affected by it, or is it the party who *pays* to resolve it? Usually they are different. The needs statement should reflect the opinion of the party to which the solution will be directed—the user. Do not let one party to tell you another party's need. Talk to the other party.
- *There is more than one user, and their needs differ*. The user embodies several parties, all with valid needs. The question is "Can all of their needs be addressed?" Given multiple users, an attempt must be made to organize, classify, and prioritize their needs.
- *User's needs are distorted by the "experts."* Inadvertently or intentionally, the contractor leads the user to a distorted definition of needs. The customer should be wary that the contractor might:
    1. Extend the list of needs to be much broader than the user thought. This increases the size of the problem, and, no surprise, the contractor's billable work as well.
    2. Reframe the needs in terms of what he, the contractor, is best suited to do. The contractor readily fulfills the stated needs, but the user's needs remain unaddressed.
    3. Not ask for but rather *state* the user's needs (because, after all, the contractor is the expert).

Regarding the last point, sometimes it is the users who are resistant to clarifying needs; they expect the contractor to do it for them. The contractor should involve the user and ensure the two parties work together until they reach an agreed-upon statement of user needs. The process helps both parties to better understand the needs and problems and to ensure that the adopted solution is the right one.

User requirements definition

Conversation between a user and contractor:

USER: "You installed my computer. Why didn't you install the network router, too?"
CONTRACTOR: "You said you wanted the computer installed."
USER: "But the computer won't be of much use to me without a router."
CONTRACTOR: "You said you wanted the *computer* installed. I did just what you requested."

Another exchange:

CONTRACTOR: "The lighting for the office addition is finished. As we agreed, I wired 20 ceiling lights."
USER: "But the room seems kind of dark."

CONTRACTOR: "You said you wanted 20 lights."
USER: "Yes, but the room isn't bright enough for what I need."

Both cases illustrate user-contractor disagreements about end results. Misunderstandings like these delay project completion, drive up costs, and sometimes become legal disputes that end up in court. The problem is lack of clear *user requirements*. User requirements should describe in unambiguous terms what the user wants in the finished solution. Derived from user needs, the requirements are the measures by which the user determines whether the end result is acceptable. They are the quality measures for the project. In the previous examples, they would address the *functions* that the installed computer system and overhead lighting must serve.

Ideally, user requirements address the needs not only of users but also builders, suppliers, and other stakeholders who will benefit from, manage, maintain, or otherwise be impacted by the system. Perhaps obviously, user requirements are stated in the *language* of the users and other stakeholders. The project should not begin until the requirements have been combined into a *user requirements* list and the customer and contractor agree that the list is complete.

Often users do not understand the necessity for and importance of good requirements; thus, it is the project manager's responsibility to make sure the requirements are complete, clear, and accurate. When the project is completed and the contractor says "Here's what you ordered," the user should be able to say "Yes, it satisfies all my needs and requirements."

Objectives and life-cycle requirements

There are many kinds of user requirements. Some account for the system's objectives, life cycle, and operational modes, others for constraints and interfaces with other systems.

See Chapter 1

Every project and the end-item system start with a statement of objectives that elaborate on the needs; these objectives provide the basis for defining requirements. Consider the SpaceShipOne example from Chapter 1. The need—"a reusable three-person vehicle that can be launched into space twice within a 2-week period"—can be defined in terms of the following set of objectives:

Develop a spaceship that can:

1. attain a minimal altitude of 100 km (altitude where "space" begins),
2. be reused (launched) every 2 weeks, and
3. carry three people.

Each objective can then be elaborated upon in terms of a set of requirements. The requirements must account for whatever the users and other stakeholders think will be significant throughout the expected *life cycle of the system*, which means they should incorporate issues regarding how the system will be developed, built, used, marketed, financed, maintained, and disposed.

Operational modes requirements

During the product life cycle, what are the different ways and kinds of environments in which the system will be used or operated? These are referred to as *operational modes*. For example, the modes for the previously mentioned reusable spacecraft include:

- Flight mode
  - Launch and boost into space
  - In-space

  - Return from space
  - Landing
- Turn-around-between-flights mode
- Crew training mode
- Ground transport mode
- Maintenance and testing mode

The system will be expected to perform different functions and satisfy different conditions in each of the modes, and these functions and conditions must be specified in the requirements.

Constraints and interface requirements

Every system is subject to limitations imposed by the environment and other systems with which it must interface, as well as mandated policies, procedures, and standards, and limits on resources, time, funding, technology, and knowledge. In addition, it faces environmental constraints, including technological requirements, laws, and even social norms and customs. For instance, among numerous constraints and interfacing systems, the spaceship must conform to FAA regulations, technical standards of the aerospace industry, and local noise and pollution laws, and it must be able to interface with existing systems for air traffic control and communication.

The current system

Conceptually, a need arises because of inadequacies of the *current system*; there is a gap between the current system's capability and a desired capability. (Of course, sometimes needs arise for *lack of* a current system; that would be the case for SpaceShipOne.) A purpose of the feasibility study is to *understand* and *document* the current system, including its inputs, outputs, functions, subsystems, components, relationships, attributes, resources, and constraints. The system schematic in Figure 3.5, for example, shows the elements and supply flow for a hospital system; it was developed for a project to reduce the supply chain costs in the operating room.

Analysis of alternative solutions

Through the process of defining and documenting needs, requirements, and the current system, the contractor develops a good understanding of the problem and is able to delimit the scope of the alternatives to solve it. The contractor begins to develop alternative high-level (system-level) solutions to the problem from studies and models that account for what the system must do (user requirements), how it could be done (technical considerations), and what it would cost (economic considerations). The solutions may include *new* systems developed from scratch or modifications of *off-the-shelf systems* and existing technology. Good project managers encourage creativity and free flow of ideas in the search for solutions.

Alternatives are analyzed for ability to satisfy objectives and user requirements within the available resources and imposed constraints. The best solution is chosen and proposed to the customer. The following example illustrates.

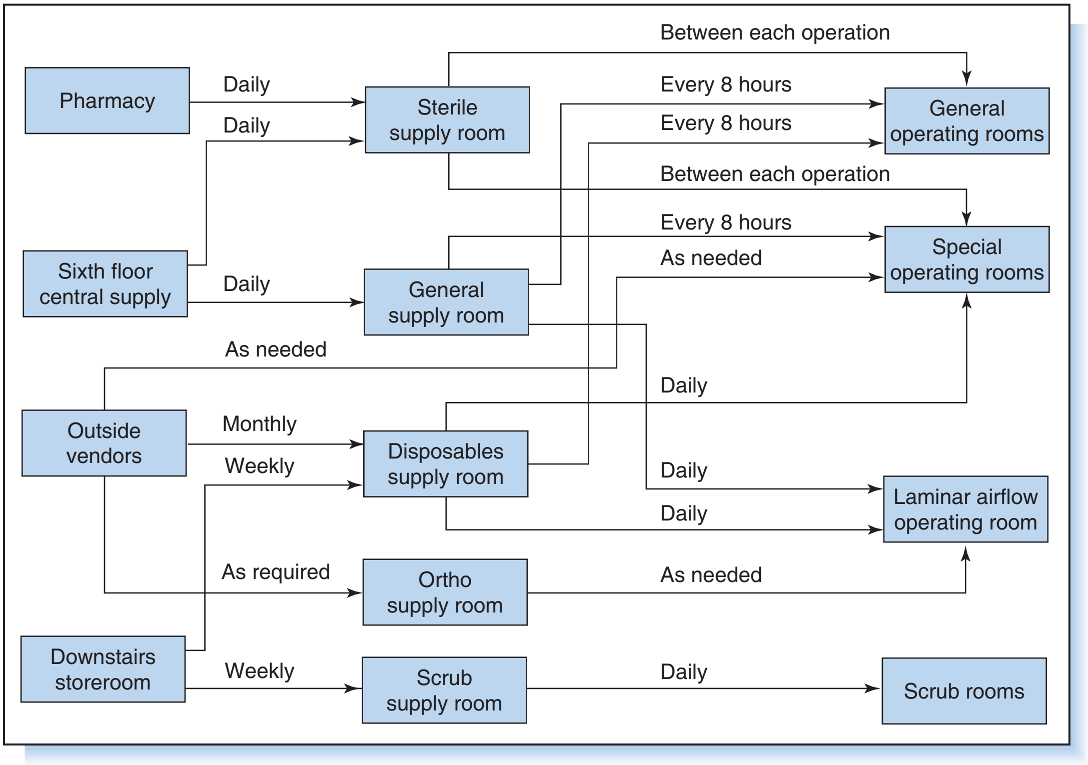


Figure 3.5
System schematic: flow of supplies to the operating room.

Example 3.4: User Requirements and Feasible Solution for the X-Prize Project

See Chapter 1

The X-Prize competition described in Chapter 1 required developing a complete system that would meet numerous requirements relating to everything necessary to design, build, and operate a spaceship. Among numerous user requirements for the spaceship are:

- Climb to an altitude of at least 100 km
- Carry three people
- Provide safe and comfortable flight
- Be relatively inexpensive to design, build, and launch
- Have a maximum "turn-around" time for reuse of at most 2 weeks.

Associated with each requirement are many issues, problems, and alternative solutions. One issue that impacts all of the requirements is the basic question of how, exactly, do you get people into space and then back home safely?

The alternatives are:

1. Getting into space
    a. Launch spaceship from atop a booster rocket
    b. Launch spaceship from a high-flying airplane
2. Being in space
    a. Enter Earth orbit (orbital)
    b. Do not enter Earth orbit (suborbital)
3. Getting back to Earth
    a. Follow a wide parabolic arc
    b. Follow a narrow arc going almost straight up and almost straight down
4. Landing
    a. Land in a "zone" using a parachute
    b. Land at an airport like an airplane

Designer Burt Rutan chose the combination of alternatives 1-b, 2-b, 3-b, 4-b: launch the spaceship from a high-flying airplane, do not enter orbit, follow a narrow parabolic trajectory up and down, and land airplane-like. These choices were the result of much study about the overall best way to meet the requirements in terms of technology, costs, and risks.

Environmental impact

Part of a project's feasibility is determining the impact of the project or its end-item system on the natural environment. In 1969, the United States enacted legislation mandating that all projects receiving federal funding or licensing must assess and report on the project's environmental impacts in an Environmental Impact Statement (EIS). Since then, Canada, Australia, New Zealand, Japan, countries of the European Union, and others have ratified laws requiring Environmental Impact Assessments (EIAs).

The contents of the EIS vary by state, country, and region but typically include:

1. A summary of proposed development and/or management plans
2. Alternative sites and technologies for the proposed project
3. A description of the project's existing site and surrounding area
4. Potential project impacts on:
    - Greenhouse gas emissions
    - Quality of air, soil, watersheds, wetlands, flood plains
    - Fisheries; sensitive plants; sensitive, endangered, or threatened species
    - Scenic resources, societal and aesthetic experiences
    - Heritage resources (sites, structures, buildings, districts, objects)
    - Historical resources (logging, ranching, grazing, mining, recreation)
5. Adverse impacts that cannot be avoided
6. Long-term impacts on resources
7. Ways to prevent, minimize, or offset impacts; ways to monitor actual impacts.

The EIS is followed by a series of public reviews and hearings to discuss the findings and determine follow-up actions, especially concerning the last bullet previously. Since the results of the EIS often affect the project plan and the system's design, the project's managers and supporters should try to develop a positive working relationship with the environmental assessment team.

Sustainability

In recent decades, increased energy consumption and usage of non-renewable resources has led to harmful environmental effects such as habitat destruction, biodiversity loss, desertification, and climate change. Projects themselves and the end-items they produce contribute significantly to such effects. Consequently, one way to mitigate the harm is to design and build end-item systems—and manage the projects that produce them—so as to minimize these effects, that is, the concept of sustainability.

Many industries have taken strides to incorporate environmental and social responsibility into the role of project management. For example, the construction industry has created guidelines (sometimes by government mandate) for designing and constructing buildings (so-called "design for environment" and "green construction," respectively) to reduce air and water pollution, landfill waste, and carbon emissions. As examples, building design guidelines in the United Kingdom mandate the use of:

- Passive ventilation systems
- Whole-building heat recovery systems
- Renewable/recycled materials
- Materials with no damaging effects on the environment and energy efficiency in terms of manufacture, use, and disposal.

Construction guidelines in the United States include:

- Reduce landfill waste: crush/reuse aggregates (stone, etc.), use suppliers who accept returns/exchanges, reuse packaging, and use reclaimed/recycled building products.
- Minimize dust from concrete/mortar; avoid air/water pollution.
- Use timber and wood products with the Forest Stewardship Council's trademark.
- Use low energy forms of construction to minimize CO_2 from site activities.
- Reduce trips to/from the site and use local suppliers to reduce transport CO_2.

In the United States, the LEED (Leadership in Environmental and Energy Design) certification program has created standards of sustainable building design and development. The standards include many of the guidelines listed previously, as well as:[10]

- Installation of windows that provide ample fresh air and natural light.
- Site selection: do not build on prime farmland or too close to a threatened animal habitat.
- Build near transportation alternatives and within walking distance to ten basic services.

Matters of sustainability arise throughout the project life cycle: in project initiation, feasibility, and definition; in the RFP, proposal, contract, requirements, and project plan; in risk analysis; and in project execution. This is illustrated in Example 3.5 and the European Union's attempt to meet climate change challenges head on.

Example 3.5: Addressing Climate Change in Major Projects[11]

The European Regional Development Fund and the Cohesion Fund provide financial backing for major projects, where a "major project" is defined as one that has a total eligible cost exceeding €50 million (about $56 million) and €75 million ($80 million) for transport projects. More than 500 major projects were predicted for the period 2014–2020.

To receive consideration for funding, measures for climate change adaptation and mitigation must be integrated in the preparation and approval of each major project. **Adaptation measures** seek to ensure adequate resilience of a project to adverse impacts of climate change such as flooding and drought. Consideration of such measures requires identifying which climate hazards the project is vulnerable to, assessing the project's level of risk, and adopting alternatives to reduce the risk to an acceptable level.

Mitigation measures seek to reduce the emission of greenhouse gases, for example, by selecting low-carbon options in project operations. This is addressed through the quantification of the expected greenhouse gas (GHG) emissions, or "carbon footprint," of the project and its end-item system and adopting measures to reduce those GHG emissions.

Consideration of climate change requirements for adaptation and mitigation into a project and its products must be initiated as early as possible. Only by doing so can climate adaptation measures and mitigation options be optimally integrated in the system development cycle. This is illustrated in Table 3.1, which gives an overview of the system development cycle stages and where and how in the cycle considerations regarding climate change can be included.

Table 3.1 Integrating climate change requirements in the development of major projects.

System Development Cycle	Adaptation Measures: Enhance resilience to the adverse impacts of climate change	Mitigation Measures: Reduce emission of greenhouse gas
Strategy	• Strategic climate vulnerability screening—use principal steps as for vulnerability and risk assessment	• Link to climate policy and GHG emission targets • Consider less carbon-intensive solutions in planning
Feasibility Design	• Assess vulnerability and risk • Do option analysis: climate risk and adaptation • Take measures to ensure resilience to current/future climate • Review technical aspects, for example, location and design • Review environment and climate change factors • Do economic analysis • Do risk assessment/sensitivity analysis	• Measure CO_2 footprint shadow prices • Assess contribution to climate targets in EU2020 Strategy • Consider less carbon-intensive options • Review environmental and other factors • Do economic analysis

Table 3.1 (*Continued*)

System Development Cycle	Adaptation Measures: Enhance resilience to the adverse impacts of climate change	Mitigation Measures: Reduce emission of greenhouse gas
Build/ Procure **Operate** **Decommission**	• Implement adaptation measures in construction and operation • Monitor critical climate hazards • Regularly review climate hazards (which may change over time), update risk assessment, review structural and non-structural adaptation measures, and report to the project owner and others as required	• Reduce GHG emissions in construction and operation • Verify actual GHG emissions

Adapted from European Commission Climate Action, "Climate Change and Major Projects," p. 4. EU Publications Office; 2016, https://ec.europa.eu/clima/sites/clima/files/docs/major_projects_en.pdf.

Although in some cases, project managers have little ability to influence sustainability matters, in others, they do; they can influence designers of the end-item and select contractors and suppliers with a focus on sustainability and minimizing the project's environmental impact.[12] At minimum, the project manager should ensure that the project and its outcomes comply with local, state, and federal environmental laws; where laws are inadequate, project managers must take the lead.

3.5 The project proposal

Proposal preparation[13]

The feasibility study results in a preferred solution to the stated problem and user requirements and the reasons for its selection. The feasibility study, when combined with a rudimentary project plan, bid price, and contractor qualifications, form the project proposal.

Through the proposal, the contractor tells the customer what it intends to do; it is also the basis for the customer selecting a contractor. The effort to prepare the proposal is itself a project and thus should be managed like one. Since preparing a proposal sometimes involves significant time and money, it usually requires top management authorization. Upon authorization, management identifies a technically competent person to oversee the proposal preparation, and sometimes this person becomes the project manager if the contract is won. She might be responsible for managing the entire proposal preparation effort or, alternatively, work with another manager who specializes in conducting proposal-related activities. The project manager selects the project team, or part of it, to help prepare the proposal; the bulk of the team is not chosen until after the contract is won.

The project manager reviews the requirements in the RFP and prepares a detailed summary of the to-be-proposed project. This summary guides the effort and prevents the focus from shifting to irrelevant technical or managerial considerations.

The proposal team outlines the work to be done for the solution identified in the feasibility study and prepares a *statement of work* or SOW. The SOW will include the system and project objectives, technical solution, high-level requirements, and major areas of work required to deliver the solution. If a SOW appeared in the RFP (e.g. Figure 3.4), then the SOW in the proposal might repeat it but should also include new information culled during the feasibility study and particulars about the chosen solution. In cases where the contractor believes the SOW in the RFP is inaccurate or incorrect, it should state that in the proposal.

During preparation, the proposal team should seek input representing many perspectives, for example, from people in marketing, legal, accounting, estimating, engineering, and procurement.

Companies often have checklists/templates for preparing proposals and standard clauses that address most of the issues that arise in projects. Matters the team must address include:[14]

- Scope of work
- Completion date
- Contract type
- Payment terms
- Customer obligations and items to be supplied
- Warranties and guarantees
- Limitations of liabilities
- Insurance and tax matters
- Confidentiality, patents, and proprietary information
- Insurance
- Ways for handling project termination, changes, delays, and cost escalation

During proposal preparation, the proposal team must think through the entire project and prepare a rudimentary project plan that will address project time, cost, and performance issues. It uses a *work breakdown structure* (WBS) to determine the tasks necessary to achieve the requirements and to prepare a schedule and cost estimate (topics discussed in later chapters). The proposal sometimes includes the WBS, schedule, and a cost breakdown showing how the project price was derived. When multiple solutions are proposed, a rough plan of each is included.

The proposal is a sales device and, if accepted, also a contract: a good proposal gives not only the price, schedule, and other details but convinces the customer that the contractor is competent and capable of doing the work.

All functional departments in the contractor organization able to provide relevant information are called upon to assist with the proposal. This increases the accuracy of proposal estimates and builds commitment from groups that will later work on the project.

During proposal preparation, the contractor should try to establish a dialogue with the customer to determine which solutions it prefers and which requirements are dominant among time, cost, and performance. Even with a clear RFP, this will help ensure that the proposal will satisfy the user's requirements. Proposal preparation can be iterative: acceptance of one proposal leads to preparation of another, more detailed proposal, as illustrated next.

Example 3.6: Proposal Development for Real Estate Projects at Wutzrite Company

The real estate department at Wutzrite Company helps clients choose among real estate investment alternatives. A meeting is set with the client to define the client's investment "problem" and goals, and the client and several Wutzrite employees brainstorm to get a clear, accurate definition of the problem. Afterward, a project director prepares a proposal for the client that includes the problem statement, a proposed solution, and the price. Proposals that involve site development or designing and constructing a building include a feasibility study; for proposals that involve only evaluating, improving, or determining the value of a site, no feasibility study is needed. If the client likes the proposal, the director prepares a second, more detailed proposal that includes a WBS and updated schedule. If the client approves it, the second proposal becomes the high-level project plan. It specifies tasks to be done and target dates and is the basis for assigning personnel to the project.

Approval of the second proposal usually calls for a feasibility study; demographic study; and analysis of financing, tax, and accounting ramifications of the recommended solution. The results are combined and submitted to the client in a third proposal that suggests particular courses of action regarding the solution.

The feasibility study and proposal preparation may take weeks or months to complete. Although enough time must be spent to produce a good proposal, not so much time should be spent that it becomes overly time consuming or expensive. A rule of thumb is: Do not do the entire project while preparing the proposal! In some technical projects, this may be unavoidable since the proposal must include a full-scale demonstration of the proposed solution. Developing the system for demonstration is itself tantamount to a full-sized project.

To ensure nothing is overlooked in the proposal preparation, project managers employ checklists that, over the years, grow to accumulate all important matters to be addressed, including, for example, considerations for design, assembly, test, shipment, documentation, facilities, subcontractors, travel, labor, training, and payment. Before submitting the proposal to the customer, contractor top management must be briefed about the project's scope, resources needed, price, and so on and approve it.

See Appendix A

Proposals range in length from a few pages to many hundreds. The content varies depending on, for example, format favored by the customer, relationship between customer and contractor, technical complexity of the work, and whether the proposal was solicited or unsolicited. Figure 3.6 shows the main ingredients of a typical proposal.[15] If the proposal is in response to an RFP, its content and format should conform *exactly* to the proposal requirements or guidelines stated in the RFP. Appendix B at the end of the book is a proposal in response to the RFP in Appendix A.

The cost to a contractor in preparing proposals and the proportion of contracts it wins significantly affect the contractor's overhead, since expenses for proposal preparation are charged to overhead. Only in rare cases such as major US defense contracts are the winning contractors reimbursed for proposal expenses.

Selecting the winning proposal

See Chapters 12 and 19

Upon receiving proposals from multiple contractors, the customer compares and evaluates them. Selecting the best proposal, reaching an agreement with the contractor, and committing funds are all part of the "project selection" process. Most companies follow a prescribed procedure for evaluating and comparing proposals. When the selection involves assessing each proposed project for its contribution to a *portfolio* of projects, the procedure also includes appraising the project's contribution to company strategic goals, the resources it will entail, and its comparative financial benefits. The topics of project selection and project portfolios are expansive and covered more fully in Chapter 12 and Chapter 19. Here we give a brief overview of the project selection process.

In general, project selection is based upon consideration of many criteria (sometimes provided to contractors in the RFP), for example:

- Project price
- Ability of contractor to satisfy stated needs (solution or technical approach)
- Return on investment

- Project plan and contractor management
- Contractor qualifications and reputation
- Likelihood of success or failure (risks)
- Fit to contractor resources and technological capability.

The customer may assume that a competent contractor with a good plan will do a good job and thus select the contractor with the best qualifications or best plan rather than best solution or technical approach. Thus, the proposal should highlight contractor credentials and include a basic but concise project plan. Methods for preparing the plan are discussed in Chapters 6 through 11.

See Chapters 6 to 11

Selecting the best proposal often begins with pre-screening the proposals and rejecting the ones that fail to meet certain cut-off requirements such as too-high price tag, too-low rate of return, or insufficient experience of the contractor.

Executive summary
Perhaps the most important part of the proposal, this section must convince the customer that the remainder of the proposal is worth reading. It should be more personal than the proposal, briefly state the qualifications, experience, and interests of the contractor and draw attention to the unique or outstanding features of the proposal, the price, and the contractor's ability to do the project. In case the customer has questions, the contractor "contact" person is identified here. From reading this section the customer decides whether or not to examine the rest of the proposal.

Technical section (SOW)

(a) Indicates the scope of the work—the planned approach. It must be specific enough to avoid misunderstandings and demonstrate the method and appropriateness of the approach, yet not so specific as to "give away" the solution. It should also discuss any problems or limitations inherent to the approach.

(b) Describes realistic benefits in sufficient detail to demonstrate that user needs will be fulfilled, but not so specific or enthusiastic as to promise benefits that might be difficult to deliver.

(c) Contains a schedule of when end-items will be delivered. It should be based upon a work breakdown structure and include the major project phases and key tasks, milestones, and reviews. In developmental projects, portions of this section might have to be negotiated.

Cost and payment section
Breaks down projected hours for direct, indirect, and special activities and associated labor charges, materials expenses, and price of project. The preferred or required contractual arrangement and method of payment are also included.

Legal section
Contains anticipated, possible, or likely problems, and provisions for contingencies; e.g. appropriate procedures for handling changes to the scope of the project and for terminating the project.

Management/qualifications section
Describes the background of the contractor, related experience and achievements, and financial responsibility. Also includes organization of management, and resumes of project manager and key project personnel.

Figure 3.6
Contents of a proposal.

Proposals that survive pre-screening are subjected to closer scrutiny: a common evaluation method, called *simple rating*, rates proposals according to multiple evaluation criteria on a checklist. Each proposal is given a score s_j for each criterion j. The overall score for the proposal is the sum of the scores for all criteria,

$$S = \sum_j s, \text{ where } j = 1, 2, \cdots, n$$

The proposal receiving the highest overall score wins.

A limitation of the method is that all evaluation criteria are treated as equally important. When some criteria are clearly more important than others, a method called *weighted rating* is used instead, wherein the relative importance of each criterion j is indicated with an assigned weight w_j. After a given criterion has been scored, the score is multiplied by the weight of the criterion, $s_j \cdot w_j$. The overall score for the proposal is the sum of $s_j \cdot w_j$. For all criteria,

$$S = \sum s_j \; w_j, \text{ where } j = 1, 2, \cdots, n$$

$$\sum w_j = 1, \text{ and } 0 \le w_j \le 1.0$$

The procedures for the two methods are illustrated in Example 3.7.

Example 3.7: Evaluating the Proposals at MPD Company

In response to its RFP for the LOGON project (Appendix A, end of book), MPD Company received proposals from three contractors: Iron Butterfly Contractors, Inc.; Lowball Company; and Modicum Associates. Each proposal was reviewed and rated by a group of operations managers at MPD on five criteria using the following 4-point scale:

Criteria	1	2	3	4
Technical solution approach	Poor	Adequate	Good	Excellent
Price of contract USD $M	>1.8	1.6–1.8	1.4–1.6	<1.4
Project organization and management	Poor	Adequate	Good	Excellent
Likelihood of meeting cost/schedule targets	Poor	Adequate	Good	Excellent
Reputation of contractor	Poor	Adequate	Good	Excellent

Simple Rating

The results of the assessments for the three proposals were as follows:

	Scores		
Criteria	Iron Butterfly	Lowball	Modicum
Technical solution approach	3	1	4
Price of contract	4	4	1
Project organization/management	4	2	3
Likelihood of meeting cost/schedule targets	3	2	4
Reputation of contractor	3	3	4
Sum	17	12	16

Based on the sum of simple ratings, Iron Butterfly was rated the best.

Weighted Rating

Using the simple rating, Lowball was clearly the worst, but Iron Butterfly and Modicum were considered too close to differentiate. The rating group then decided to look at the criteria more closely and to assign weights to the criteria based on their relative importance:

Criteria	Weight
Technical solution approach	0.25
Price of contract	0.25
Project organization and management	0.20
Likelihood of meeting cost/schedule targets	0.15
Reputation of contractor	0.15
	1.00

Taking the weights into account, the proposals scored as follows:

		Iron Butterfly		Modicum	
Criterion	**Weight (*w*)**	*s*	(*s*)(*w*)	*s*	(*s*)(*w*)
Technical solution approach	0.25	3	0.75	4	1.0
Price of contract	0.25	4	1.0	1	0.25
Project organization/management	0.20	4	0.8	3	0.6
Risks of solution	0.15	3	0.45	4	0.6
Reputation of contractor	0.15	3	0.45	4	0.6
	Sum		3.45		3.05

Using the sum of the weighted ratings, Iron Butterfly is clearly the superior proposal.

More examples of weighted ratings for project selection are provided in Chapter 19.

See Chapter 19

Assessment of proposals commonly also includes evaluation of project risk, especially when the proposed solutions and associated levels of risk differ significantly between proposals. Methods for identifying and assessing risks are discussed in Chapter 11.

See Chapter 11

As mentioned, the contract award sometimes depends more on the contractor's qualifications than the proposed solution. Among factors the customer might consider are:[16]

- Is the contractor big enough or adequately financed to do the project?
- Does it have a good track record with this kind of project?
- Does it have a good reputation in the industry?
- Has it been involved in litigations and arbitrations?
- Will its management be accessible?
- Does it have ISO 9000, ISO 14000, or other certification?
- Will the relationship with the contractor likely be amicable or touchy?

Proposal finalists are notified and might be requested to provide more data or give presentations or live demonstrations of their proposed solutions or systems. If none of the proposals are acceptable or the feasibility studies conclude the project would be too costly, risky, or time-consuming or not provide adequate benefits, the process ends with nobody getting a contract.

For contractors who did not get the job, good practice is to conduct a proposal "post mortem" to determine why not, lessons learned, and what to do differently next time.

The RFP/proposal process outlined in the last few sections addresses the question of *who will do the work*. Whether it is a customer choosing a contractor or a contractor choosing subcontractors, each party follows a similar process to define its needs, solicit ideas, and choose potential contractors. The effort required of all parties to define their requirements, prepare proposals, and review and hire qualified contractors can be quite time consuming, especially in international projects. Thus, extra time must be allotted for it in the project schedule; if not, the process can substantially delay the start of the project. Initiating projects and preparing proposals often involves convolutions that are hard to anticipate. The following story illustrates.

Example 3.8: Proposal for the Apollo Spacecraft[17]

The US space program to land human beings on the moon involved thousands of contracts awarded by NASA in separate competitions. The biggest contracts were for the biggest components, namely the Apollo spacecraft; the lunar lander; and the first, second, and third stages of the rocket that would propel the spacecraft and lander to the moon. Harrison Storms was vice president of North American Aviation's Space Division (NA) in Los Angeles when NASA opened bidding for the Apollo spacecraft. His division had already been working feverishly to solve difficult technical problems for a proposal to build the rocket's second stage. The technical requirements were so demanding that only a handful of contractors had stayed in the competition. Most managers in the middle of such a big effort would have considered themselves already overextended, but not Storms: he wanted to go after the *big prize* contract—the Apollo spacecraft contract. The Apollo spacecraft would contain systems for life support, guidance, and navigation (ultimately comprising over 2 million parts) and would take three men to the moon and back. Problem was, NA had never built a spacecraft before, and it would be expensive to learn how. Storms gathered up his best people and put together a presentation for the company chairman and founder, old "Dutch" Kindleburger, arguing that NA should prepare a proposal for Apollo. Dutch was skeptical, but he pledged $1 million support. Storms knew that wouldn't be nearly enough but took it anyhow. Now NA would bid on *both* the second stage *and* Apollo (Figure 3.7).

The allotted $1 million had long since been exceeded—maybe by three times, but no one knew. Back then, cost statements ran 30 to 60 days behind billings, and Storms gambled that NASA would receive the proposal before his boss saw the final bill. With less than 6 weeks to go, he picked John Paup to be Apollo program manager, someone he thought perfect for the role, a "witty, engaging person" who understood the technology. For the next month, Paup listened to presentations 18 hours a day, slept in a cot, and ate from vending machines. Every morning he gathered his team for a standup meeting; anyone not there by 7:45 was locked out. No coffee, no seats, he wanted to hear the problems and how each would be fixed within 24 hours.

The proposal was encyclopedic in size, and NASA wanted dozens of copies submitted no later than 5 p.m. 2 days before the presentation. The whole bundle, weighing 100 pounds, was hand-delivered just under the wire. Next day Paup and his team, looking like zombies from lack of sleep, boarded the company plane for the presentation to NASA in Virginia. Each company had 60 minutes to present its proposal to an evaluation team of 75 top engineers, some of them legends. Undaunted, Paup hit all the presentation high points and finished 10 minutes early.

Days later, Storms received a telegram: NASA wanted to know how, given NA's second-stage contract, it could possibly handle Apollo too? The written response was too long to telegraph back, so Storms

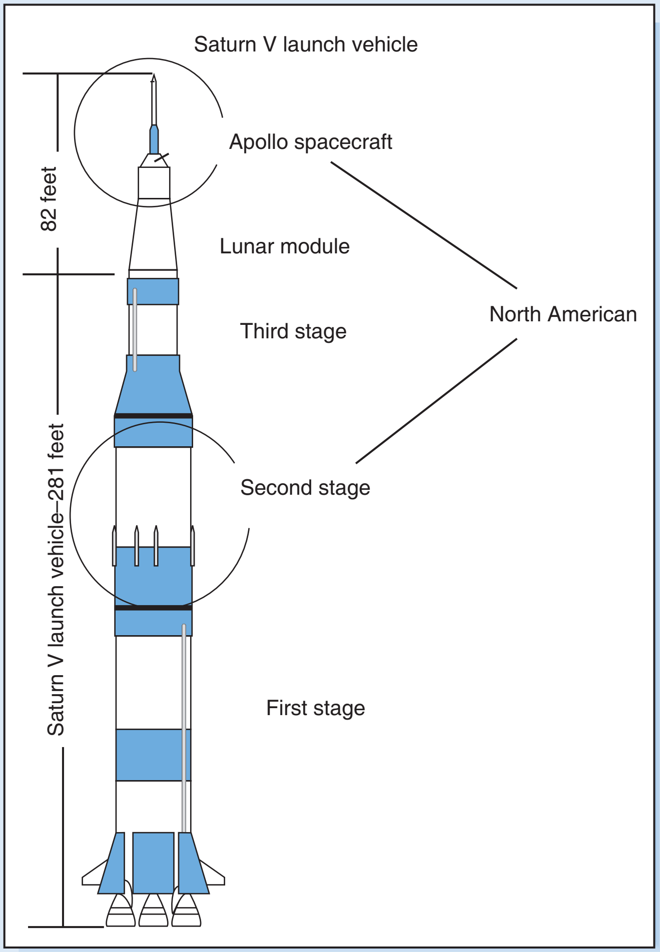


Figure 3.7

Apollo/Saturn moon rocket and North American components.

Source: Picture courtesy of NASA

and Paup jumped on a plane to hand-deliver it. This violated an unwritten rule that a contractor does not meet with the customer evaluating the proposal. But Storms had little regard for such rules, especially with so much at stake.

Meantime NA headquarters had determined that the proposal cost five times the allotted $1 million, and it was fuming. But to say the overrun was worth it would be an understatement. North American won the contract, although it would take another year to formalize the details: in return for a target cost of $884 million and a fee of $50 million, NA was to deliver several mockups, test versions, and flight-ready Apollo spacecraft (Figure 3.8). The risks of sending humans to the moon were overwhelming, so the contract was cost-plus. By the time the lunar program ended 10 years later with the return of the seventh crew from the moon, NA as prime contractor had earned $4.4 billion—over $27 billion in 2020 dollars.

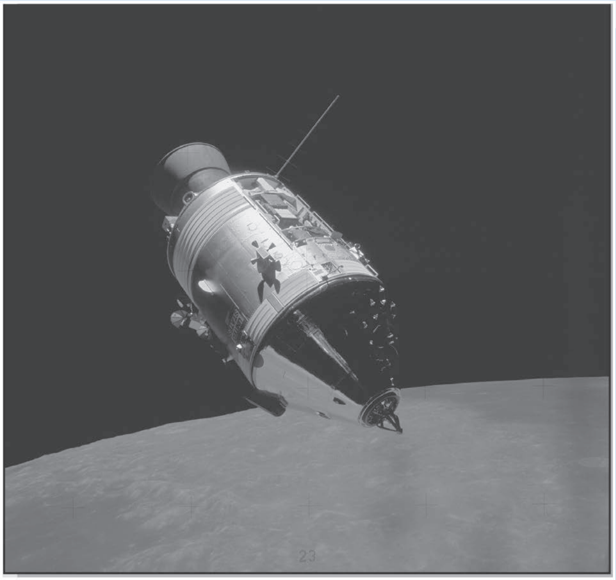


Figure 3.8
Apollo spacecraft.
Source: Photo courtesy of NASA

3.6 Contractual agreement and negotiation

The usual result of the RFP/proposal process is the selection of a preferred contractor and the signing of a contractual agreement. If several contractors receive close marks during the selection process, then the parties might enter a process of negotiation to settle upon a final agreement.

The purpose of contract negotiation is to clarify technical or other terms in the contract and reach agreement on project price and time, schedule, and performance obligations. The process is not necessary for standardized projects wherein the project terms are simple and costs are fairly well known. In fact, in such cases and where *price is the only selection criterion*, the customer will issue an invitation for bid (IFB) rather than an RFP, and negotiation is considered unethical and prohibited. Nonetheless, for complex systems projects that involve high-risk or difficult developmental work, reaching the contractual agreement almost always involves negotiation.

See Chapter 12

Different kinds of contractual agreements offer different advantages to the customer and contractor, depending on the nature of the project. The most common forms of contractual agreements, described in much more depth in Chapter 12, are:

- *Fixed Price Contract*: The price paid by the customer for the project is fixed regardless of the costs incurred by the contractor. The customer knows what the project will cost.
- *Cost-Reimbursement Contract*: The price paid is based on the costs incurred in the project plus the contractor's fee. The contractor is assured his costs will be covered.
- *Incentive Contract*: Variation on fixed-price and cost reimbursement contracts: the amount paid depends on the contractor's performance as compared to the target price, schedule, or technical specification. The contractor receives a bonus for exceeding the target or pays a penalty for not meeting it.

In general, work that is contracted or procured from contractors and suppliers is referred to as "procured" goods, work, and services. Like everything else in projects, such work must be planned, scheduled, budgeted, and controlled—it must be managed; this includes keeping the agreement up to date with respect to changes to the project, customer needs, and the contractor capabilities and checking that all work conforms to the agreement. This, referred to as *contract administration*, and the broader topic of *procurement management*, are the subjects of Chapter 12.

See Chapter 12

3.7 Contract statement of work and work requisition

Each contract contains a statement of work that is similar to the SOW in the proposal or the original RFP or is a restatement of either to reflect the negotiated agreement. This so-called *contract statement of work* (CSOW) defines the expected performance of the project in terms of scope of work, requirements, end results, schedules, costs, price, payment schedules, and ways to handle changes or variations, plus each party's responsibilities and liabilities.

When the customer and the contractor both agree on the CSOW, the project is considered "approved" and ready to go. Before work can actually begin, however, it must be divided among the involved departments of the SDO and contractors, and requirements specified in the CSOW must be translated into terminology that people in these groups understand. The translations, aimed at the groups that will perform the work, must be identical interpretations of the requirements and work scope specified in the CSOW. The document containing the SOW for each work group is called a *work requisition* or *work order*. Its purpose is to describe the work expected of each party and to authorize the work to begin. This topic is discussed further in Chapter 12.

See Chapter 12

Authorization of the work to begin marks completion of Phase A; it marks authorization for the project to begin and to proceed to Phase B. The steps in Phase A are summarized in Figure 3.9.

3.8 Project initiation: variations on a theme

Projects are initiated in response to a need, but they do not always involve an RFP or even a proposal. The RFP/proposal process as described largely applies to projects where the work is *contracted out*, that is, where the customer and the contractor are not in the same organization. For internal projects—projects where the organization has the capability to do the work on its own—a project might initiate with a business case study, as described earlier. Common examples of this are projects in product development (PD) and IT—two areas where companies often exhibit significant internal prowess. In PD, the "need" is manifest as the desire or mandate to fill a perceived market niche or respond to a competitive threat. The business case study addresses the proposed product, market, competition, risk, cost, and benefits and argues in favor of launching a new PD effort. If the case is approved, the project is turned over to the PD department to begin work. The business case study thus serves a dual purpose: it is both the feasibility study and the proposal. IT projects are similarly initiated by business case studies.

The department that would do the project, if approved, prepares the business case study and argues for the proffered end-item or solution. Approval or denial of the project involves rating the case against competing cases in terms of the resources required, benefits compared to goals, and priority of needs—the selection process described in Chapter 19. If the project is approved, a project charter is created, as described in Chapter 4.

See Chapters 4
and 19

The RFP/proposal process as described represents projects with relatively few stakeholders or a single, clearly identified customer and its potential contractors. In large technical projects that touch many stakeholders, the process is more protracted. Examples include projects for infrastructure and transportation systems (Boston Big Dig, Delhi Metro, telecommunication systems, Chunnel), technical

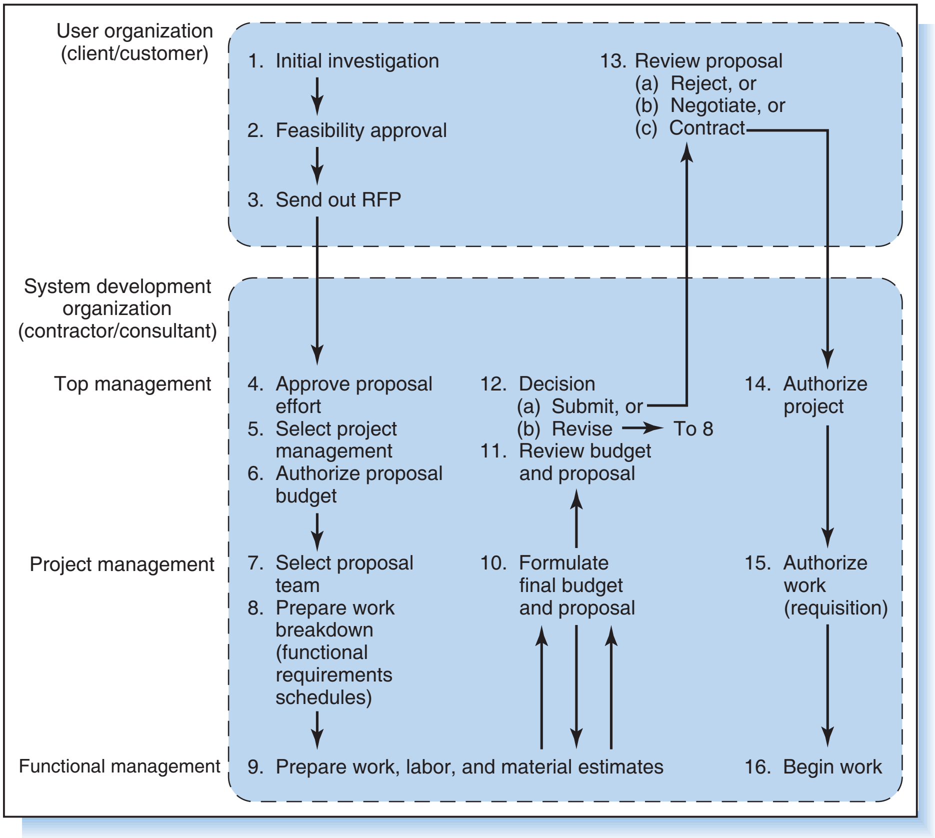


Figure 3.9
Project initiation, proposal preparation, and authorization process.

systems wherein subsystems and components must be developed from scratch (commercial aircraft, SpaceShipOne, medical devices), and large-scale property developments (resorts, airports, planned communities). In such cases, it is more difficult to identify the stakeholders and define their multiple and sometimes conflicting needs, so the RFP/proposal process must include a "front-end" component to identify the important stakeholders and combine their needs into a list of stakeholder requirements. The contractor to gather the stakeholder requirements might be hired solely for that purpose and not be the same as contractors hired to perform the project work; after the stakeholders and their needs have been identified, other contractors are solicited to review the requirements and suggest solutions through the RFP/proposal process. The process of identifying stakeholders and their requirements is a systems engineering effort that takes into account the end-item system's far-reaching effects and the many stakeholders it will touch throughout its life cycle.

3.9 Summary

The systems development cycle can be divided into four phases: conception, definition, execution, and operation. The first three phases constitute the project life cycle.

Phase one, conception, includes formulating the problem, defining needs and user requirements, evaluating alternative solutions, and preparing a proposal to conduct the project. At the start of this phase, most activities are in the hands of the customer; by the end of the phase, most activities have been taken over by the contractor or system developer. The relationship between the customer and the contractor is initiated and cemented through the RFP/proposal process, negotiation, and contractual agreement.

Phase A is the "foundation" part of the systems development cycle; it establishes the needs, objectives, requirements, constraints, agreements, and patterns of communication upon which the remaining phases are built. It is a crucial phase and the place where, often, the seeds of project success or failure are planted.

Review Questions

1. How are projects initiated? Describe the process.
2. What factors determine whether an idea should be further investigated?
3. Who is the user in the systems development process? Who is the contractor?
4. Besides the user and the contractor, what other parties are involved in the systems development cycle? Give examples for particular projects.
5. What does the term "fast-tracking" imply?
6. How does the contractor (SDO) become involved in a project?
7. What is the purpose of an RFP? Describe the contents of an RFP.
8. What is a feasibility study? Describe its contents and purpose.
9. What are user needs? Describe the process of defining user needs and the problems encountered.
10. What are user requirements? How do they differ from user needs?
11. Who prepares the proposal? Describe the proposal preparation process.
12. What is the statement of work (SOW)? In what documents does the SOW appear?
13. Describe the contents of the proposal.
14. How is the best proposal selected? Describe the process and the criteria used.
15. Three proposals (W, X, and Y) have been rated on six criteria as follows: 1 = poor, 2 = average, 3 = good. Choose between the three proposals using (a) the simple rating method and (b) the weighted rating method.

Criteria	Weight	W	X	Y
Attention to quality	0.25	2	1	3
Cost	0.20	3	3	1
Project plan	0.20	2	2	1
Project organization	0.15	3	2	3
Likelihood of success	0.10	2	3	3
Contractor's credentials	0.10	2	2	3

16. What contractor qualifications might the customer look for in a proposal? What else about the contractor might the customer look for?
17. What parties are considered subcontractors in a project?
18. Discuss the purpose of a business case study for internal projects. What does the study include, and who prepares it?
19. How is the RFP/proposal process adapted to large projects that potentially have numerous stakeholders but initially only a few have been identified?
20. In contracting out work, does the customer relinquish all control over the project to the contractor? Explain.

21. How can a contractor be both the sender and receiver of RFPs; that is, how can it both prepare and submit proposals and receive and review proposals?
22. When a contractor hires a subcontractor, to whom is the subcontractor obligated—the end-user customer or the contractor?
23. What must the project manager know to be able to effectively negotiate a contract? Consider aspects of the customer, competition, and technical content of the proposal.
24. Discuss the difference between the SOW, CSOW, and work requisition or work order.

Questions About the Study Project

As appropriate, answer Questions 1–14 regarding your project. Also answer the following questions: How are contracts negotiated, and who is involved in the negotiation? What kinds of contracts are used in the project?

CASE 3.1 WEST COAST UNIVERSITY MEDICAL CENTER

West Coast University Medical Center (WCMC) is a large teaching and research hospital with a national reputation for excellence in health care practice, education, and research. Seeking to sustain that reputation, the senior executive board decided to install a comprehensive medical diagnostic system. The system would be linked to WCMC's servers and be available to physicians from their homes and offices via the Internet. By clicking icons to access a medical specialty area, then keying answers to queries about a patient's medical symptoms and history, a physician could receive a list of diagnostics with associated statistics.

The senior board sent a questionnaire to every department asking managers about the needs of their areas and how they felt the system might improve doctors' performance. Most managers replied that the system would save doctors' time and improve performance. The hospital information technology (IT) group was assigned to assess the cost and feasibility of implementing the system. They interviewed managers at WCMC and several vendors of diagnostic software. The study showed high enthusiasm among the managers and a long list of potential benefits. Based on the feasibility study, the board approved the system.

The IT manager invited three well-known consulting firms that specialized in medical diagnostic systems to give presentations and then hired one to assist his group in selecting and integrating several software packages into a single, complete diagnostic system.

One year and millions of dollars later, the project was completed, but 6 months later, it was clear the system was a failure. Although it did everything the consultants and software vendors had promised, few doctors used it; of those that did, many complained that the "benefits" were irrelevant and that features of the system they would have liked were lacking.

QUESTIONS

1. Why was the system a failure?
2. What was the likely cause of its lack of use?
3. What steps or procedures were poorly handled in the project conception phase?

CASE 3.2 X-PHILES DATA MANAGEMENT CORPORATION: RFP MATTERS

X-Philes Data Management (XDM) Corporation (motto: "The truth is out there") is preparing to contract out work for two large projects: Scully and Mulder. The projects are comparable in terms of size, technical requirements, and estimated completion time but are independent and will be performed by separate project teams.

Two managers at XDM, one each assigned to Scully and Mulder, prepare RFPs for the projects and send them to several contractors. The RFP for Scully includes the following: a SOW that specifies system performance and quality requirements, maximum price, completion deadline, and contract conditions; an incentives clause stating the contractor will receive a bonus for exceeding minimal quality requirements and finishing the project early or will be penalized for poor quality and late completion; and a requirement that the contractor submit detailed monthly status reports showing progress on key quality measures. The RFP for Mulder includes a brief SOW, a maximum budget, the desired completion date, but nothing else.

Based on proposals received in response to the RFPs, the managers responsible for Scully and Mulder each select a contractor. Unknown to either manager is that they select the same contractor, Yrisket Systems. The Scully manager selects Yrisket because its bid price is somewhat below the budget limit and its reputation in the business is good. The Mulder manager selects Yrisket for similar reasons—good price and reputation. In preparing the Scully proposal, Yrisket managers had to work hard to meet the maximum price specified on the RFP, but they felt that by doing quality work, they could make a tidy profit from the incentive offered.

A few months after the projects are underway, some of Yrisket's employees quit. To meet their commitments to both projects, Yrisket workers have to work long hours and weekends. It is apparent, however, that these extra efforts might not be enough, especially because Yrisket has a contract with another customer and must begin work soon.

QUESTIONS

1. What do you think will happen?
2. How do you think the crisis facing Yrisket will affect the Mulder and Scully projects? The two projects are very similar, yet do you expect Yrisket to treat them the same?

CASE 3.3 PROPOSAL EVALUATION FOR APOLLO SPACECRAFT[18]

Five proposals were submitted to NASA to design and build the Apollo spacecraft. An evaluation board of more than 100 specialists reviewed the proposals and ranked them as follows (maximum = 10).

	Technical Approach (30%)	Technical Qualification	Business Strength (30%)	Weighted Total (40%)
Martin Company	5.58	6.63	8.09	6.90
General Dynamics Astronautics	5.27	5.35	8.52	6.59
North American Aviation	5.09	6.66	7.59	6.56
General Electric Company	5.16	5.60	7.99	6.42
McDonnell Aircraft Corporation	5.53	5.67	7.62	6.41

The board unequivocally recommended to NASA senior management that Martin be awarded the contract but suggested North American as the next-best alternative based upon NA's experience in developing high-performance military and research aircraft. This experience (technical qualification) sufficiently impressed the board that it put NA ahead of General Dynamics, despite NA's lower ratings on technical approach (design of the space capsule) and business strength (organization and management). The board mentioned that any shortcomings in NA's technical approach could be corrected through additional design effort. Seeing the board's recommendations—and aware of NA's long, close association with NACA (NASA's predecessor agency), NASA senior management immediately selected North American.

QUESTIONS

1. How were the points in the "Weighted Total" column determined? Show the computations.
2. North American rated third out of five contractors in the Weighted Total column, yet was awarded the contract. How did that happen? What are the lessons from this example?

Notes

1. There are many ways to categorize the phases of the project life cycle. PMBOK, 6th Ed., categorizes them as (1) starting the project, (2) organizing and preparing, (3) carrying out the work, and (4) ending the project. PRINCE2 specifies the final phase as post-project assessment. The three-phase project life cycle in this book addresses virtually everything in these other categorizations, regardless of terminology.
2. It could be argued that Phase D in an election-campaign project will be extended *if* the candidate is elected, whereupon the "operation" phase represents the elected official's full political term—but that would be stretching the analogy.
3. Based upon information collected and documented by Cary Morgen from interviews with managers of Jamal Industries (factual case, fictitious name).
4. Cusumano M. and Selby R. *Microsoft Secrets*. New York, NY: Free Press; 1995, p. 210.
5. A need is a value judgment that a problem exists. Different parties in an identical situation might perceive the situation differently; as a consequence, a need is always identified with respect to a particular party—for example, the user. See McKillip J. *Need Analysis: Tools for the Human Services and Education*. Newbury Park, CA: Sage Publications; 1987.
6. Cusumano and Selby. *Microsoft Secrets*, p. 210.
7. In the United States, a request for quotation or invitation for bid commonly suggests that selection of a contractor will be based primarily on price; in an RFP, the nature of the solution and competency of the contractor are as or more important than price. Elsewhere in the world, the terms *proposal* and *bid* often are used interchangeably, a bid being the equivalent of a full-fledged proposal.
8. Adapted from Frame J.D. *Managing Projects in Organizations*. San Francisco, CA: Jossey-Bass; 1987, pp. 109–110.
9. Ibid., pp. 111–126.
10. Sundblad D. Sustainable Construction Techniques, http://greenliving.lovetoknow.com/Sustainable_Construction_Techniques, accessed November 12, 2014.
11. European Commission Climate Action. Climate Change and Major Projects. European Union Publications Office, 2016. https://ec.europa.eu/clima/sites/clima/files/docs/major_projects_en.pdf, accessed March 30, 2019,
12. Hamilton G., Byatt G. and Hodgkinson J. How project managers can help their companies 'go green': Program and project managers can contribute to sustainability. *CIO*, November 2, 2010, www.cio.com.au/article/366509/how_project_managers_can_help_their_companies_go_green_/, accessed November 14, 2014.
13. Hajek V.G. *Management of Engineering Projects*, 3rd edn. New York, NY: McGraw-Hill; 1984, pp. 39–57; Rosenau M.D. *Successful Project Management*. Belmont, CA: Lifetime Learning; 1981, pp. 21–32.
14. Kerzner H. *Project Management*, 8th edn Hoboken, NJ: John Wiley, 2003, p. 829.
15. Roman D. *Managing Projects: A Systems Approach*. New York, NY: Elsevier; 1986, pp. 67–72; Stewart R. and Stewart A. *Proposal Preparation*. New York, NY: John Wiley and Sons; 1984.

16. Murphy O. *International Project Management*. Mason, OH: Thompson; 2005, pp. 159–161.
17. Primary source for this example is Gray M. *Angle of Attack: Harrison Storms and the Race to the Moon*. New York, NY: W.W. Norton; 1992, pp. 87–116; the other source is Brooks C., Grimwood J. and Swenson, Jr., L. *Chariots for Apollo: A History of Manned Lunar Spacecraft*. Washington, DC: NASA Scientific and Technical Information Office, SP-4205; 1979, sections 2.5 and 4.2.
18. Brooks, Grimwood, and Swenson. *Chariots for Apoll*o, Chapters 2–5.

Chapter 4

Project definition and system definition

When one door is shut, another opens.

—Cervantes, *Don Quixote*

The beginning of wisdom is to define.

—Aristotle

The result of Phase A is a formalized systems concept that includes a (1) clear problem formulation and list of user requirements, (2) rudimentary but well-conceptualized solution to the need or problem, (3) elemental project plan in the proposal, and (4) agreement between the customer and the contractor about all of these. The project is now ready to move on to the "middle" and "later" phases of the systems development cycle and bring the systems concept to fruition.

Much of this chapter and the previous one concern conceptualizing and defining the "system"—the end-item of the project. It is also the thrust of the systems engineering methodology, which is often applied to projects that involve more stakeholders, greater technical complexity, and greater risk and have farther-reaching consequences than other projects. Interested readers are encouraged to see Appendix A at the end of the chapter for additional systems engineering methods and tools.

4.1 Phase B: definition

As Figure 4.1 shows, with approval of the project in Phase A, the thrust of the effort now moves to Phase B, definition. Most of the effort in Phase A was devoted to investigating the *problem*—what is it, is it significant, should it be resolved, and can it be resolved in an acceptable fashion? Now in Phase B, the *solution* is scrutinized: it is analyzed and defined sufficiently so that designers and builders will be able to produce a system that meets the customer's needs.

The underlying principle behind Phase B, definition, is, simply, prepare as best you can for what you intend to do *before* you start doing it. Definition says, "Think through what you want to happen and how best to make it happen; do not just jump in and begin!" Definition is important because its outcomes dictate what will happen in the future. In the definition phase, before things are defined and plans are set, planners still have broad latitude in decisions and the ability to influence project outcomes. Things are still easy to change because the "things" are just plans. Later in the project, after plans are set and work is underway, things are hard to change because the "things" include work already done or fully committed

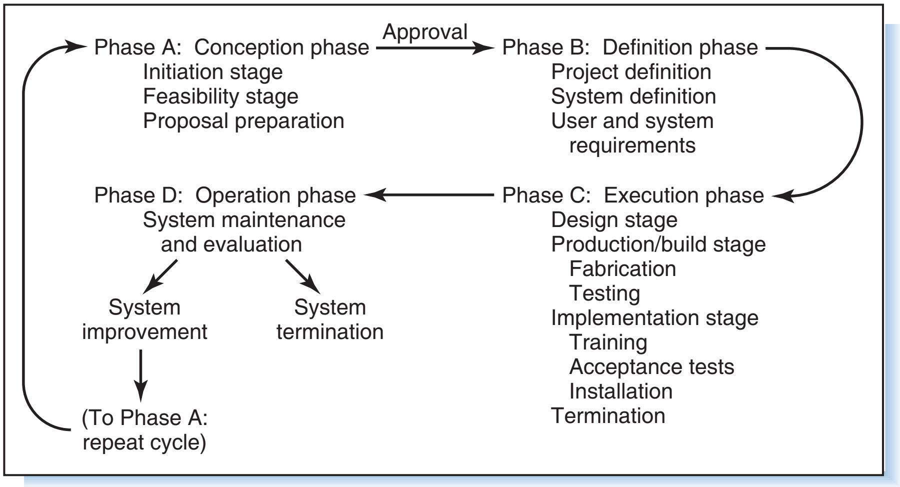


Figure 4.1
Four-phase model of system development cycle.

to. At some point the project will be stuck conforming to decisions already made, even bad ones. For instance, it is easy to decide in definition whether a building will have 5, 10, or 15 floors. But once you decide on 10 floors, after 6 floors have been built, you cannot change the decision to 5 floors (without tearing down a floor) or to 15 floors (if the foundation was built for only 10).

This is illustrated by three curves in Figure 4.2. Early in the project, it is easy to make decisions that will affect project outcomes, and the cost of changing those decisions is little. Early on, very little will have been spent (cumulative cost), so it is also easy to cancel the project then. As the project progresses, however, and especially after it enters execution, the cumulative cost rises dramatically. It is not so easy to cancel the project then because of the high sunk cost. It is also not so easy to change decisions (go from 10 floors to 5 or 15 floors) because so much has already been done and it is costly to redo, undo, or alter it. Definition is that phase where ideas and plans are fleshed out before final commitments are made and work begins. The thrust of the phase is twofold: project definition and system definition.

Project definition vs. system definition

There are two ways to look at a project: one is to see the end-item or result of the project, and the other is to see the *effort* directed at achieving that result. Looking at both is necessary: if you focus too much on the end-item and too little on the effort, the project will run into problems for lack of preparation and coordination of resources, costs, and schedules; if you focus mostly on the effort and less on the end-item, the project will again run into problems—this time for not meeting user requirements. System definition and project definition are equally important. System definition aims at achieving a good understanding of what the *end-item* must do to satisfy user requirements; project definition aims at specifying what the *project team* must do to produce the end-item. While it is not surprising that much of the literature on project management is preoccupied with project definition, it is surprising how little attention it gives to system definition.

System definition begins with defining user needs and requirements; project definition begins with addressing those requirements in the project proposal. Hence, some of the definition work necessary for the project is initiated in Phase A. Phase B continues this definition work and concludes with a set of system specifications and a project plan—a full suite of everything necessary to execute the project in Phase C.

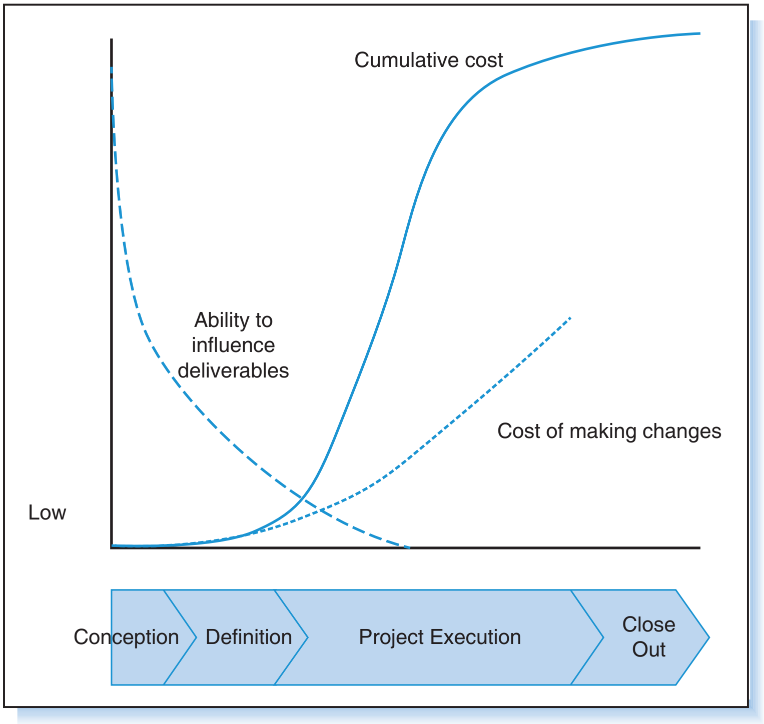


Figure 4.2
Project costs and ability to influence outcomes vs. project phase.

Project kickoff

The project formally begins with a kickoff meeting—the first formal meeting of the project team and key stakeholders. The purpose of the meeting is to announce that the project is about to commence, communicate what the project is about, develop common expectations, and generate enthusiasm and commitment to project goals and deliverables. The project manager plans and runs the meeting. Attendees include the project team (or, if too large, only managers, team leads, and project staff), supporters, and others who should know that the project is about to begin. For a multilocation project, multiple kickoffs at each location or a video or phone conference might be necessary. The kickoff runs 1.5 to 2 hours and is mostly a formal presentation followed by questions and answers.

Invited attendees should be formally notified in advance and provided information about the meeting agenda, a list of invited participants and their project roles, and a rudimentary project plan. The meeting introduces the following: the project manager; the project SOW, goals, and deliverables; the proposed plan—budget, schedule, main work packages; constraints and risks; the customer, other key stakeholders, and their needs and requirements; the project organization and key team members; and immediate next steps and who is to do what. Much of this information will have been worked out for the project proposal; if not, the project manager and project team must prepare it for the meeting.

Every project should start with a kickoff meeting. A large project might also have a kickoff for the proposal preparation effort and then one again for each project phase.

The purpose of the kickoff is to provide information, not to reach consensus of opinion, develop working relationships, or establish guidelines so team members can work together. The latter is the purpose of team building, for which subsequent meetings should be held shortly after the kickoff. Team building is discussed in Chapter 17.

See Chapter 17

Project name

The project name is often the first thing that people hear about the project—often with no accompanying explanation.[1] The name will appear again and again in virtually all communication and persist for as long as the project—and perhaps longer. A carelessly chosen name can cause misunderstanding or a blank stare about the project, it can cause people to confuse the project with other projects, and it can influence the way they react to the project. Unless the intention is to obfuscate the project's purpose ("Manhattan Engineering District"—the atomic bomb project; "Have Blue"—the F-117 stealth fighter project), the name should clearly suggest what the project is about.

Clever or cute names should be avoided; they tend to be ambiguous and, sometimes, annoying. All projects are apt to acquire nicknames, which tend to indicate how people *feel* about the project ("Project from Hell") but not much else. If, however, the nickname gains widespread usage, then sometimes the sensible thing is to formally adopt it. (Boston's Central Artery/Tunnel became the "Big Dig"—not to be confused with Canada's "Big Dig," the Wascana Lake Urban Revitalization Project in Saskatchewan. The 1960s geological research project to drill through the earth's crust to the Mohorovicic discontinuity was named Project Mohole, but as political and technical problems mounted, it became known as "Project Nohole.") A project is often named for a place, person, or the end-item it creates (Petronas Towers; Bandra-Worli Sea Link Bridge), and for long-named end-items, it is okay to adopt an acronym (BWSL)—though it's always a good idea to first check the acronym before adopting it for the project name; a serious project should not make people chuckle whenever they see its acronym (Automated Network for Uniform Security).

4.2 Project definition

Project definition addresses the question: What must the project do to deliver the system concept and satisfy the user and system requirements? Project definition and system definition happen concurrently and interactively. The work to be done as laid out in the project plan must meet the system requirements, but the system requirements must conform to the work methods, budgets, and schedules specified in the project plan.

Detailed project planning

Prior to Phase B, a portion of the project definition will already have been done. At minimum, some definition was necessary in Phase A to prepare the project proposal. But that definition effort will have resulted at best in an outline of what is to come. During Phase B, that outline must be expanded and elaborated upon in detail. The renewed definition effort will involve identifying the necessary work tasks and resources, project team and leaders, subcontractors, and support staff and creating schedules, budgets, and cost control systems.

The project team begins to evolve from the skeletal group that prepared the proposal, sometimes in a cascading manner: the project manager selects team leaders who, in turn, fill in team positions under them. The project manager negotiates with functional managers to get specific individuals or people with the requisite expertise assigned to the project. Sometimes she seeks the customer's approval in adding members to the project team, which is advisable whenever the customer must work closely with the team or when the customer might have an objection. Good customer–project team rapport is crucial to maintaining a healthy customer-contractor relationship.

Project execution plan

As key members of the project team are assembled, they begin preparing the detailed project plan—the "execution plan" (a.k.a. project plan or project management plan). The audience of the execution plan is whoever will be doing the project, so the plan should address whatever they will need to know, including, for example:

- Scope statement or SOW that includes high-level user requirements and system requirements.
- Work breakdown structure and work packages or tasks.
- Project organization.
- Responsibility assignments of key personnel to work packages.
- Project schedules showing events, milestones, or points of critical action.
- Budget and allocation to work packages.
- Quality plan for monitoring and accepting project deliverables, including testing plan.
- Risk plan and contingency or mitigation measures.
- Procurement plan.
- Communication plan
- Work review plan.
- Change control plan.
- Implementation plan to guide conversion to, or adoption of, deliverables.
- Health, safety, and environmental (HSE) policies and plan.

See Chapter 6

See Chapter 3

The execution plan is described more fully in Chapter 6, and its elements are described throughout the book. About the last element on the previous list, HSE: perhaps obvious is that project management is responsible for protecting the project team, stakeholders, and society from injury arising from immediate and long-term health hazards associated with the project and its outcomes. Minimally, the project plan must include measures to guard against accidents and health hazards; comply with industry standards and municipal, state, and federal laws and regulations; and meet unique circumstances of the project.[2] The plan also includes measures to mitigate negative environmental impacts of the project, although such measures might also be addressed in sections of the project plan such as SOW, work breakdown, risk, and so on. Company policies regarding HSE should be referenced in the plan. The project manager is held responsible for ensuring the policies are implemented, that specific HSE roles and responsibilities are defined, and staff receive appropriate health and safety training.[3] Significant hazards that cannot be eliminated should be included in the risk management plan. Preparation of the HSE plan includes attention to environmental and sustainability matters, as discussed in Chapter 3.

See Appendix C

All of the elements of the execution plan must be integrated; each must be tied to, compatible with, and supportive of the others. Details of these elements are discussed in Part III of the book, and a sample project execution plan is in Appendix C at the end of the book.

In large projects, the planning is divided into subplans created by members of the project team, including subcontractors. The project manager coordinates their efforts to ensure that the subplans are thorough and tie together. Contractor top management and the customer review the final plan for approval. Contractor top management makes sure that the plan fits into existing and upcoming projects and capabilities, and the customer makes sure it conforms to user requirements and the conditions stated in the contract.

Anxious to get the project underway, many contractors skip reviewing the project plan with the customer. This is shortsighted, since the plan could contain elements to which the customer might object. Often the project is conducted and implemented within the customer's organization, so everything in the plan must fit: the project schedule must fit the customer's schedule; project cash flow requirements must fit the customer's payment schedule. The contractor's personnel and procedures must complement those of the customer, and the materials and work methods must be acceptable to the customer.

Once management and the customer approve the project plan and system specifications, the project team turns its attention to the detailed design and building of the system, which is what happens in Phase C, as covered in Chapters 5 and 13. As explained next, however, project planning never stops; it continues throughout the project life cycle.

See Chapters 5 and 13

4.3 Phased (rolling-wave) project planning

A major thrust of Phase B is to develop the project plan, but seldom does it result in a comprehensive plan for the entire project. The fact is, despite all the effort devoted to planning in Phase B, often, the plan is developed in phases, not all at once. At the start of a project, there are too many unknowns, and it is impossible to specify exactly what will or should happen for the whole project. Only as the project progresses and the unknowns decrease can details of the plan be filled in. The situation is analogous to planning an off-the-road route to some destination but without the benefit of knowing the obstacles. Since you can only see the landscape directly ahead, you can only plan the first part of the route in detail; beyond that, the route is vague. This is represented by Phase I in Figure 4.3a. As you move through Phase I, you see more of the obstacles ahead, which enables you to plan the next part of the route, Phase II (b). The process continues, filling in details of the route, phase by phase, until you reach the destination (c and d).

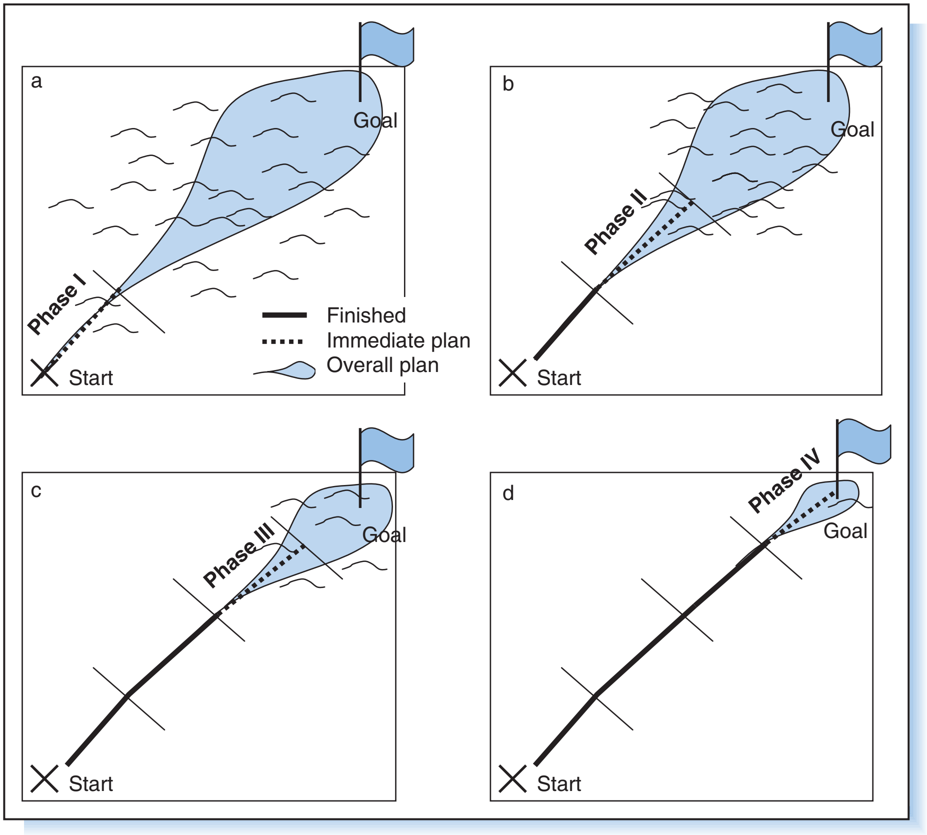


Figure 4.3
Phased project planning.

At the onset of a project, the customer wants to know the project cost and completion date, which can be estimated by preparing an initial rough plan. Although much of the initial plan is somewhat vague (analogous to the shaded blobs in Figure 4.3), the plan is usually sufficient to enable managers to estimate project resources, time, and cost. As the project gets underway, more detailed plans are created but only for *the most immediate phase* of the project (dotted lines, Figure 4.3). Whereas the initial plan was based upon information from similar projects, estimates, and forecasts, the detailed portions of the plan are based upon facts about upcoming work, facts identified as the approaching work gets closer.

For highly unique projects, the initial rough plan should be seen as just that—a rough indication of project deliverables, cost, and delivery date—but not necessarily a commitment. That plan was first prepared during the feasibility study or business case study, but as the project progresses, it is replaced with more detailed plans and more specific work tasks and schedules. Only for the most immediate phase where the "terrain" is clearly visible is it possible to create a detailed plan and make commitments to work, dates, and costs. Application of this rolling-wave planning is a major feature of agile projects, described in Chapter 14.

See Chapter 14

In some projects, all formally identified project phases conclude with a *phase gate*, at which time the customer or executive managers review the project's deliverables and performance; if satisfied, they approve the deliverables and pay for work done thus far. At the same time, they review the detailed plan for the next phase and assess the costs, risks, and so on of the updated high-level plan for the rest of the project. Note, this requires the plan *for each phase* to be largely prepared in the *prior* phase, as illustrated in Figure 4.4. If satisfied with the plan, they authorize the project to proceed to the next phase. If a project is to be terminated, that happens only at the end of a phase, unless termination is forced as the result of unforeseen external circumstances.

In some organizations, this "phase-gate review" process is a mere formality, a "rubber stamp" to proceed to the next phase. More often, however, it serves an important purpose, in some cases having strategic implications. For example, each phase-gate review can result in a:

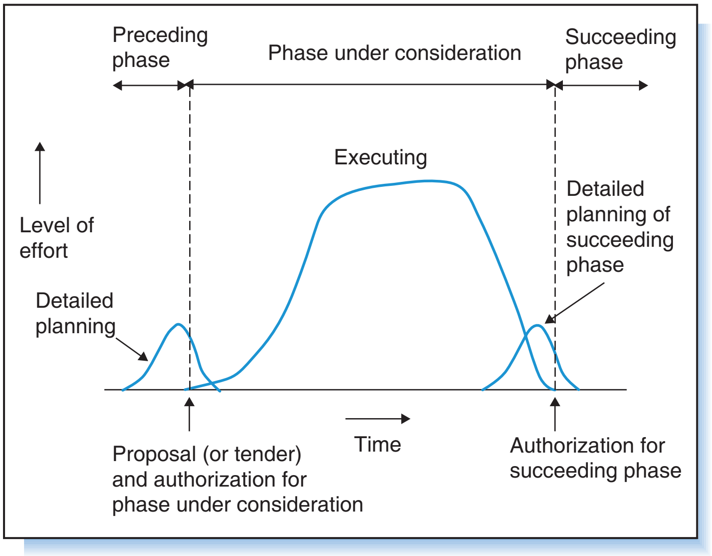


Figure 4.4
Detailed planning for each project phase.
Source: Adapted from Steyn H. (ed.) *Project Management—A Multi-Disciplinary Approach*. Pretoria: FPM Publishing; 2003. p: 27.

1. Green Light: all relevant stakeholders are satisfied with the work performed so far. They accept the plans for the rest of the project and believe that the risks and business impact of the project justify continuing with the project. The project is authorized to proceed to next phase.
2. Yellow Light: the stakeholders feel the business impact of the project justifies continuing the project but not that the objectives of the phase were met or plans for the rest of the project are adequate. The project team must re-do part or all of the preceding phase and/or part of the plan.
3. Red Light: due to changes in the business environment or risks or disappointing results so far, stakeholders might consider the business impact of the project insufficient and decide to terminate the project. If the possibility exists that conditions might improve later, the project can be "put on ice" for later reconsideration.

Companies that do multiple simultaneous projects sometimes use phase-gate reviews to compare the projects—their benefits, resource requirements, and relative performance—and to determine whether to give the green, yellow, or red light; this is discussed in Chapter 19. The phased approach to project planning and approval is illustrated in Example 4.1.

See Chapter 19

Example 4.1: Mary and Peter's New House

Mary and Peter buy property to build a new house upon. They approach NewHome Construction and describe to Paul, its owner, what they have in mind. Among other things, they want to know what it would cost. Having been in the business for many years, Paul has an idea of the cost but is wary to quote a fixed price since he doesn't know Mary and Peter very well and whether their tastes are cheap or expensive. Also, he is wary of possible hidden costs arising from, for example, poor soil conditions of the site. He therefore gives a range of possible prices based upon the estimated square footage of the house and an estimated completion date for the house. Nobody has as yet made any commitments. On the question, "Where do we go from here?" Paul answers that the first phase is to do a concept design and create sketches of the house. He also outlines the other phases of the project he foresees and the deliverables and approximate schedule and cost for each.

Mary and Peter sign a contract for Paul to provide a preliminary design and sketches. The contract specifies when they will see the design and sketches, what the sketches will include and exclude, and what they will cost. Within a month, they receive and approve the design and sketches.

Paul now presents them with a second contract, this time for detailed drawings that the construction team will use to build the house. Just like the first phase, the contract specifies the deliverables (drawings), delivery date, and price. A few months later, Mary and Peter approve the drawings, and construction begins.

Paul notes that the construction work will also be done in phases, although now, he says, there is sufficient information about the project and its cost so that only one contract is needed. He shows them the contract, which lists the remaining phases of the project and includes a guarantee period (following completion of construction) during which NewHome will fix any defects free of charge. The contract indicates milestones and deliverables for each of the phases and specifies that a payment will be due upon reaching each milestone. Before each payment, Mary and Peter will have the opportunity to inspect the work and verify that it has been completed and meets workmanship standards as specified in the contract.

This example illustrates the benefits of phased project planning: at the start, NewHome does not have to commit to the cost of building an as-yet-undefined structure, and during the project, Mary and Peter do not have to commit to work beyond any one phase (in fact, at the conclusion of any contracted phase, they can walk away from the project). The milestone payments improve NewHome's cash flow and reduce interest payments on money for construction borrowed from the bank. They also provide NewHome with some protection against bad debt: if Mary and Peter miss a milestone payment, NewHome simply stops work.

Project charter

The project charter is a proclamation that management has approved a project. For some projects, it is created once, following a feasibility study or acceptance of a proposal; for others, it is created and expanded at multiple points during the conception and definition phases. For *internal* projects, the charter serves the purpose of announcing and formally authorizing the start of the project. For *external* projects, that same purpose is served by a contract, so, generally, there is no charter.

The charter describes the project to stakeholders in the organization and establishes the project manager's authority to organize and use resources; thus, it should be signed by at least one executive manager. It includes whatever information is necessary to give the reader a good overview of the project. Often the charter contains sections similar to the project plan, and sometimes it *is* the project plan, although commonly it is somewhat brief and provides only an *overview* of the execution plan described earlier.

For any reasonably sized project, the project charter is developed after some prior planning and a feasibility study. In large projects conducted in phases (e.g. FEL, described later), a charter is created for and used to authorize *each* phase. The PRINCE2 methodology prescribes three charters: one (called a "mandate") authorizes the first, pre-project, stage of the project; another (a "brief") authorizes the second, initiation, stage; and a final ("project initiation document") authorizes subsequent stages.

For a small project or initial phase of a project, the charter can be rather short. For most projects, however, it is more comprehensive and can include the following:

- Project vision, purpose, benefits; problem it will solve or opportunity it will exploit.
- Project justification (business case and environmental impact analysis findings).
- Approach to be followed.
- Project scope statement.
- Main deliverables, criteria for acceptance, individuals responsible for acceptance.
- Clients and key stakeholders.
- Identification of the project manager and his authority and responsibilities.
- Identification of other decision-makers, their authority, responsibilities, and reporting relationships.
- Listing of resources, including project team staff, required training, subcontractors, and so on.
- Project organization and work breakdown structure.
- Project budget summary and cash flow plan.
- Master schedule, project phases, key milestones, planned due dates.
- Perceived risks and issues.
- Objectives for sustainability.
- Plans for: procurement: safety, health, environmental protection; communication.
- Control procedures.

Despite similarities, the project charter differs from the execution plan in one important way. Whereas the purpose of the charter is to *describe*, *justify*, and *authorize* the project, the purpose of the execution plan is to *give direction* to parties working in the project (team, contractors, etc.). This leads to major differences in the content of each and, usually, an execution plan that is substantially longer, more detailed, and more comprehensive than the charter.

Front-end loading[4]

A variation of phased project planning and approval used by some industries (chemical, mineral, oil, and gas) in major industrial infrastructure projects (typically costing over $1 billion) is the "front-end loading" approach. FEL overlaps the conception and definition phases in Figure 4.1 and includes all the data gathering, analysis, and documentation necessary to justify and launch a project. It is divided into three phases, FEL-1, FEL-2, and FEL-3.

FEL-1, called "opportunity identification," is the idea-generation and evaluation phase; it corresponds somewhat with the "pre-project stage" in the PRINCE2 methodology. The proposed project is in competition with other projects to receive funding; thus, the objective of FEL-1 is to confirm that the project is compatible with organizational strategy and is a "preferred project" (discussed in Chapter 19). The output of FEL-1 is a preliminary business case that confirms the feasibility of the proposed capital investment.

See Chapter 19

FEL-2 goes by different names depending on industry, for example, "business planning," "concept study," and "appraise." In this phase, the project is "shaped" in terms of scope, technology selection, and execution strategy. The output of FEL-2 is a detailed business case and a scope statement that enables reliable cost and schedule forecasts. Typically, only 1 percent of total project cost is incurred during FEL-1 and FEL-2.

FEL-3 is "project definition" and includes preparation of a detailed project execution plan, advanced conceptual design, and some detailed system design (which in the Figure 4.1 methodology is placed as the first stage of execution). FEL-3 is often divided into sub-phases that go by such terms as "facilities planning/execution planning," "feasibility," and "select/front-end engineering design (FEED)." The output of FEL-3 is a project execution plan, conceptual (ready for detail) design, basic engineering plan, and detailed project charter. By the end of FEL-3, typically 3 to 5 percent of the total project cost is spent, a relatively small amount to ensure that project risks are acceptable before committing full funding to the project.

Each FEL phase is followed by a gate: FEL-1 to assess the robustness of the business case, FEL-2 to assess the completeness of the scope definition, and FEL-3 to determine if the project is ready to execute. Since FEL-3 is the most expensive part of FEL, it is not undertaken unless the project has already been approved. The project approval decision happens at the FEL-2 gate, which means that the FEL-2 phase must be very thorough and address all factors important in the decision. Project cancellation at the FEL-3 gate happens rarely and only with changes in the project environment (sharp drop in market, business downturn, dropout of a major business partner).

Besides project definition, FEL also addresses system definition, described next.

4.4 System definition

Systems are defined from their requirements; thus, requirements are the starting point for all systems development projects and the foundation for project planning. Each requirement impacts end-item scope and complexity, which in turn impact project work effort, time, cost, and risk. Unless the requirements are clearly defined and agreed upon, it will be difficult to fully conceptualize the end-item and create a viable project plan. With the contract signed and the project about to get underway, the user requirements defined in Phase A should be reviewed, the details filled in, and any gaps and ambiguities eliminated.

User requirements revisited

For products and systems in competitive markets, user requirements are initially framed in general terms; for example, outperform the F-35, taste better than Joe's beef jerky, obtain at least a 20 percent rate of return, or upgrade to software release 10.2. General requirements such as these must be expanded before serious development work and project planning can be started. As shown in Example 4.2, a poor requirements definition can lead to project failure.

Example 4.2: User Requirements for Product Development

The marketing group for a kitchen appliance manufacturer wrote the requirements for a new food processor. The requirements specified the general size, weight, usage, price, and sales volume of the proposed product but nothing about product performance, which the engineering design group set by studying competitors' products. The food processor as developed met all the requirements set by marketing and engineering, yet it was obsolete before even launched because competitors had released products better suited to customer needs. In defining the product, both the marketing and engineering groups had ignored the *user* requirements for the food processor—that is, the requirements as specified by actual user customers.

Defining complete, accurate requirements is not easy. Among the problems are:

- Requirements must incorporate information from not only the user but also functional areas such as marketing, engineering, manufacturing, and outside stakeholders.
- The information needed to define requirements is not always available when definition occurs, so it is easy to overlook necessary requirements or include unnecessary ones.
- The requirements include vague terms that cannot be accurately measured (e.g. "modern," "enough," "comfortable," "sufficient," or "low cost").
- The user or contractor cannot adequately describe the requirements because the end result is complex, abstract, or artistic.
- The customer or contractor intentionally defines requirements in ambiguous terms to allow latitude in results later in the project.

Problems like these result in confused project planning and, later, customer-contractor disputes over whether the end result met the requirements. The following steps can reduce such disputes.[5]

- Convince both the user and contractor groups of the importance of clear, comprehensive definition of requirements. Users and contractors often are reluctant to devote the time necessary to define clear and complete requirements.
- Check for ambiguities and redefine the requirements so none remain.
- Augment written requirements with nonverbal aids such as pictures, schematics, graphics, and visual or functional models.
- Avoid rigid specification of requirements that are likely to change due to uncertainty or changing environment.
- Make each requirement a commitment to which user and the contractor both agree and sign off.
- After the project begins, monitor the requirements and resist attempts to change them.
- Use a change control system to assess the necessity and impacts of changes before deciding whether to approve them.

Detailed user requirements come from one source: users. The project manager, however, should not accept just any requirements provided by users but offer assistance in defining them. Just as users sometimes require help in understanding the problem or need, they also might need help in specifying their requirements. They may not understand the ramifications of requirements in terms of cost or schedule or what will be necessary to fulfill them.

For most projects, the list of high-level user requirements (summary or bullet points) should fit on one page for easy reference. Early in the project, the contractor will refer to the list when preparing the project's scope statement; at the end of the project, the customer will refer to it to determine the acceptability of project results and end-items.

Preliminary definition of user requirements happens during the feasibility study and proposal preparation, and a summary of user requirements is included in the contract. In simple systems, user requirements rarely exceed a few lines or a page. In big systems, however, they might fill volumes. An example of the former is user requirements for a contract to perform a 1-day management seminar; an example of the latter is user requirements for the 9-year, multibillion-dollar Delta Project to prevent the North Sea from flooding the Netherlands.

System requirements

A major thrust of Phase B is translating user requirements into *system requirements*. System requirements are oriented toward the solution; they specify the contractor's approach and objectives for satisfying the needs as spelled out in the user requirements. But beyond fulfilling user requirements, a project must also fulfill contractor needs. For example, besides being profitable, the contractor might specify requirements to keep skilled workers and costly production facilities occupied.

System requirements define the system or solution approach—including the principal functions, system architecture, and resulting end-item (system, solution, or product)—and provide a common understanding among project team members as to what must be done in the project. Whereas user requirements represent the user's perspective, system requirements derive from the contractor's perspective. They state what the end-item system must do to satisfy the user requirements. Following are examples contrasting user requirements and system requirements:

User Requirements	System Requirements Will Address
1. Vehicle must accelerate from 0 to 60 mph in 10 seconds and accommodate six people.	Vehicle size and weight, engine horsepower, kind of transmission.
2. House must accommodate a family of four.	Number and size of rooms.
3. House must be luxurious.	Quality and expense of materials and decorative features.
4. Space station must generate electricity for life support, manufacturing, and experimental equipment.	Type and kilowatt capacity of power-generating equipment; technology for primary operation and backup operation.
5. Aircraft must be "stealthy."	Design of configuration and external surfaces; types of materials; usage of existing or newly developed components.

System requirements specify what the project's designers and builders must address in designing and building the end-item. The following illustrates this for the X-Prize/SpaceShipOne project introduced in Chapter 1.

Example 4.3: High-Level System Requirements for Spaceship

Following are five user requirements for the spaceship, each followed by one or more system requirements. The former specify the user requirements, the latter what the spaceship and its subsystems and components must do to satisfy those requirements.

1. Attain altitude of at least 100 km:
    1.1 Motor must provide enough thrust (i.e., be powerful enough)
    1.2 Motor must burn long enough
    1.3 Vehicle must be lightweight
2. Capacity for three people:
    2.1 Cabin must be large enough
3. Comfortable flight:
    3.1 Cabin temperature must remain at comfortable level
    3.2 Cabin pressure must remain at comfortable level
    3.3 Vehicle acceleration force must not exceed certain level
    3.4 Cabin must have sufficient elbowroom
4. Relatively inexpensive to design, build, and launch:
    4.1 Fuel and fuel handling procedure must be economical
    4.2 Structural materials of vehicle must be economical
    4.3 Whenever possible, uses existing, off-the-shelf technology and systems
    4.4 Requires few people to maintain vehicle
5. Capable of being "turned-around" in at most 2 weeks:
    5.1 Minimum repair/replacement of parts/modules between flights
    5.2 Minimum refueling time
    5.3 Minimum cabin cleaning time

Notice, the system requirements specify "what" the system must do, not "how" it will do it. They say, for example, "the motor must generate enough thrust to propel the spaceship to 100 km before it runs out of fuel" but not how. Addressing the "how" comes later.

Defining requirements sufficiently so that designers will know what they are striving for is called *requirements analysis*. The result of the requirements analysis is a comprehensive list of functional requirements.

Functional requirements

Functional requirements specify the functions that the new system must be able to perform to meet the user requirements. For example, the functions of the spaceship include propulsion, handling and maneuverability, human habitability, safety, and support and maintenance. The common tool for identifying the functional requirements of a complex system is the functional flow block diagram (FFBD), described in Appendix A to this chapter. All significant functions for the system, its subsystems, components, and interfaces, including for support and maintenance, must be identified. Most systems perform several basic functions, each of which has numerous subfunctions.

Associated with each functional requirement are targets or *performance requirements*. These specify in technical terms—for example, physical dimensions, miles per hour, turning radius, decibels of sound, acceleration, percent efficiency, operating temperature, operating cost—the target requirements that the function must satisfy, as well as the tests, procedures, and measures to be used to prove that the targets have been met. The project team refers to these performance requirements in the design or purchase of components for the system.

In addition, other requirements might be imposed on the overall system or on specific subsystems and components. These requirements are sometimes called "non-functional" requirements (!) because they are not tied to particular functions and are desired of the entire system and all its components.

The following are typical:[6]

1. *Compatibility*. Ability of subsystems to be integrated into the whole system or environment and to contribute to objectives of the whole system.
2. *Commonality*. Ability of a component to be used interchangeably with an existing but different type of component. A "high commonality" system contains many available off-the-shelf (OTS) components; a "low commonality" one has many that must be newly developed.
3. *Cost-effectiveness*. Total cost of the system if a particular design is adopted. This includes the cost of the design, as well as the cost for implementing and operating the design to achieve a given level of benefit.
4. *Reliability*. Ability of the system or component to function at a given level or for a given period of time before failing.
5. *Maintainability*. Ability of the system to be repaired within a certain period of time (i.e. the *ease* with which it can be repaired).
6. *Testability*. Degree to which the system can be systematically tested and measured for its performance capabilities.
7. *Availability*. Degree to which the system can be expected to operate when it is needed.
8. *Usability*. Amount of physical effort, technical skill, training, or ability required to operate and maintain the system.
9. *Robustness*. Ability of the system to survive in a harsh environment.
10. *Expandability*. Ability of the system to be easily expanded to include new functions or be adapted to new conditions.

Requirements priority and margin

Two properties of each requirement are its priority and margin (sometimes also referred to as tolerance). The *priority* of a requirement is, simply, the relative importance of the requirement. When multiple requirements conflict so that not all of them can be met, priority determines which will be met and which not. Suppose a product is specified to, for example, perform in a certain way and be a particular maximum height, but performance has priority. Knowing this will be useful to the design team if later they determine that to achieve the specified performance, the height requirement must be exceeded.

Related to priority is the *margin* on a requirement—the amount by which the requirement can vary. For example, the requirement "maximum height of four feet; margin of two inches" tells designers that in case they must exceed the height requirement, they have at most two more inches.

Requirements breakdown structure

During requirements analysis, system functions are sorted and assigned to logical groups. The requirements breakdown structure (RBS) in Figure 4.5 is a simplified example showing ways of grouping requirements. The RBS should include every identified functional requirement; in large systems, these can number in the hundreds or even thousands.

The purpose of the RBS is to provide a common reference for everyone working on the project. Often a requirement will pertain to multiple system components, which means that multiple project teams will be working to meet that requirement. The RBS enables these teams to coordinate efforts and avoid omissions or duplication.

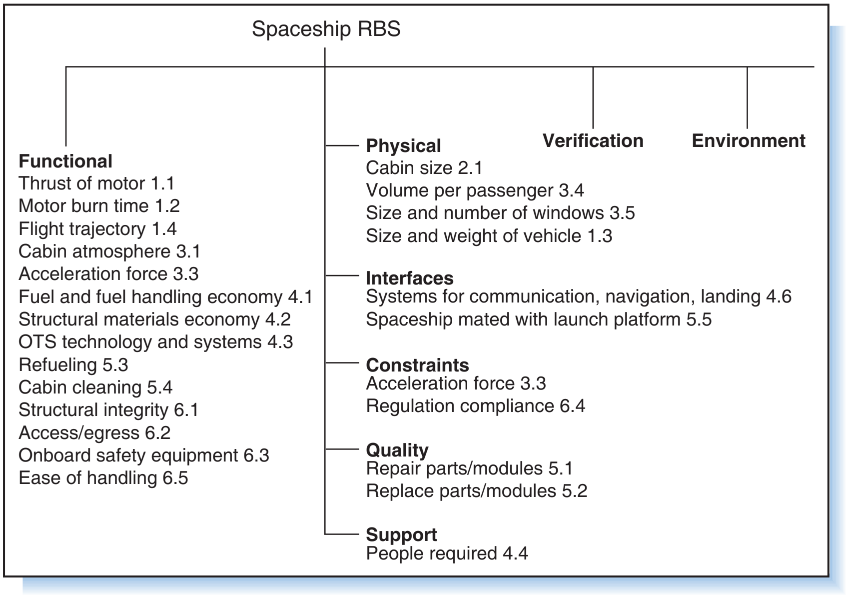


Figure 4.5
Requirements breakdown structure.

System requirements provide general direction for the project, but they are high-level and not detailed enough to tell the project team what it must design, build, or purchase to create the end-item system. Stipulations must be placed on each of the requirements; these are called *system specifications*.

System specifications

System specifications are derived from system requirements. They define the end-item and its subsystems, components, and processes in sufficient depth so that the project team will be able to design, build, and/or purchase those subsystems and components.

System specifications are the basis for specifications of lower-level subsystems, which are the basis for specifications of even lower-level subsystems. From the system specification for an automobile, for example, specifications are derived for the auto's drive train, suspension, steering system, brake system, and so on. The specifications for these lower-level components normally take the form of a drawing or, for a commercially available "off-the-shelf" item, a catalog number. The connection between user requirements and system requirements and specifications is illustrated in Example 4.4.

Example 4.4: System Specifications for Spaceship

The progression from user requirements to system requirements and from system requirements to system specifications is illustrated in Figure 4.6. At the top, the system requirement "Motor must provide enough thrust" is derived from the user requirement "Spaceship must reach 100 km"; in turn, the system specification "Motor must provide ≥88 kN thrust" is derived from the system requirement "Motor must provide enough thrust." (Note, kN, or kilonewton, is a measure of force.) System specifications tell the project team what it must do and targets it must meet. For example, besides the motor having a specific thrust, another specification, 4.1.1, says the motor will burn nitric oxide and rubber. Since there are no OTS motors that do this, this says the team will have to design and build one from scratch. The multiple arrows to each specification in the last column indicate that each specification must satisfy multiple requirements.

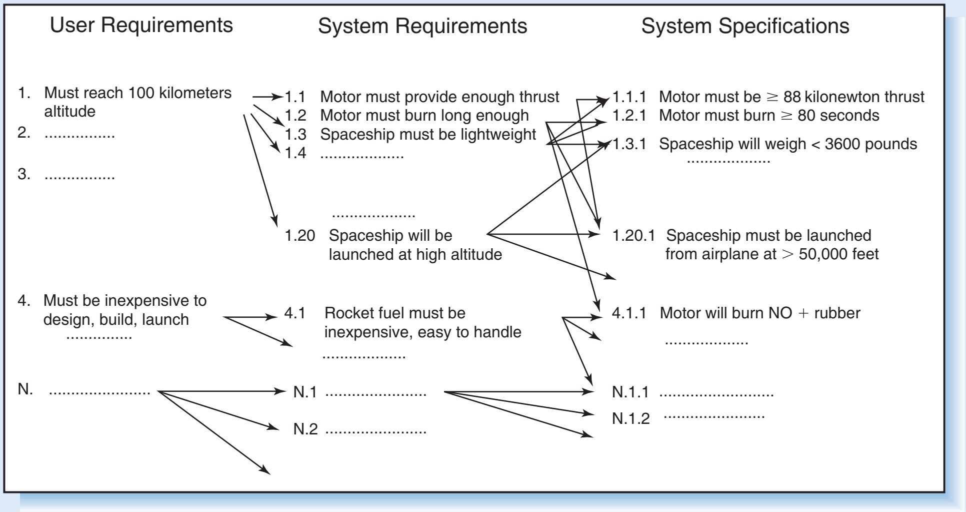


Figure 4.6
Relationships between user requirements, system requirements, and system specifications for spaceship.

Traceability

Developing clear specifications is important, but so is keeping track of their relationships to each other and to system requirements. Throughout the systems development cycle, numerous changes and tradeoffs will be made to the requirements that will each impact multiple specifications. For example, altering the spaceship weight (Figure 4.6, system requirement 1.3) will impact the spaceship's required launch altitude (specification 1.20.1) and the motor's required thrust and burn time (1.1.1 and 1.2.1). Because weight impacts so many of the specifications, a designer cannot be cavalier about doing anything that might alter it. Any decision affecting weight must be assessed for the impact it will have on the specifications for launch and rocket motor. The ability to trace the effects of changes in some specifications and requirements to others is called "traceability."

A useful tool for this purpose is the traceability matrix, described in Appendix A to this chapter. The process of managing all of this—identifying specifications, tying them to physical components, tracing the impacts of changes, and *controlling* changes so requirements are met and do not conflict—is called *configuration management* and *change control*, discussed in Chapters 10 and 13.

See Chapters 10 and 13

System specifications are the criteria that will guide actual project work; they are written by and for project subject-matter specialists—systems analysts, programmers, engineers, product and process designers, consultants, and so on—and they address all areas of the project—design, fabrication, installation, operation, and maintenance. System specifications should be set so as to meet but not exceed *customer baseline specifications*, which are high-level specifications the customer can understand. This is one way to prevent "scope creep," that is, the growth of project requirements that causes project budgets and schedules to also grow.

Iterative design-testing and rapid prototyping

The definition of requirements and specifications and the design and testing of the system usually happen iteratively, particularly when the project end-item is complex. The requirements cannot be completely defined without some amount of prior design work, and the design work cannot be completed without some amount of prior fabrication and testing. The overall process generally cascades down as illustrated in Figure 4.7, with occasional loops back and repeated steps. Work that flows from stage to stage like this is called the *waterfall process*. To assess and modify specifications, often a *prototype* is used. A prototype is an early running model of a system or component built for purposes of demonstrating performance, functionality, or proving feasibility. It is built according to initial specifications and then tested; if, based upon tests, the specifications are changed, then the prototype is modified and tested again. This process ensures that the basic system design supports the system specifications.

It can be difficult to conceptualize the system when no system exists like the one to be developed. The system that the customer "sees" might be very different from the one the developer envisions, yet without a physical or working model, the difference might not be apparent. Requiring the customer to specify and sign off on requirements early in the project only intensifies the problem. It forces the customer and developer to commit to decisions before they reach a mutual understanding about the requirements.

In a process called *rapid prototyping*, a rudimentary, intentionally incomplete model of the product that is initially somewhat simple and inexpensive is produced.[7] The rapid prototype (RP) model represents *key parts* of the system but *not* the complete system and is somewhat easy to create and modify. The customer experiments with the RP to assess the system's functionality and determine any necessary modifications or additions. After iterations of experimenting and modifying requirements, the final requirements and design concept are firmed up. In software development, the RP might be a series of screens or windows with queries to allow a user to "feel" what the system would be like. Architects use physical scale models

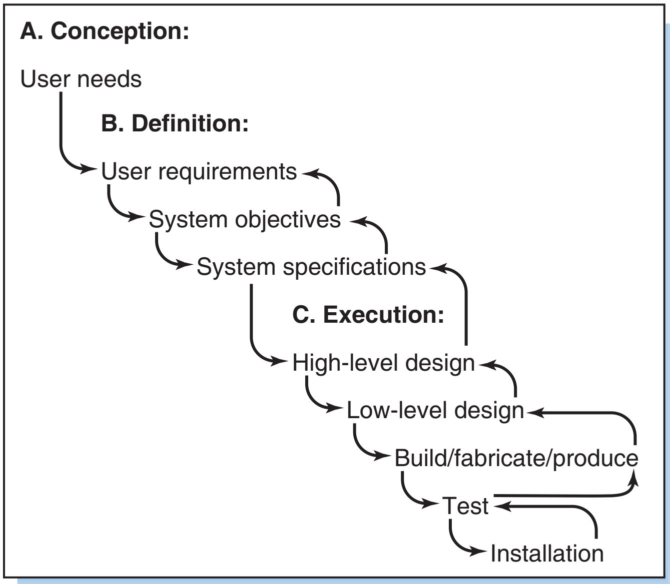


Figure 4.7
Iterative development cycle (waterfall process) for complex systems.

of buildings for the same purpose. They know that a physical model is always better than a drawing or lists of requirements for conveying the look, feel, and functionality of a design. Drawings and requirements tell the development team what is expected, but the RP process ensures that drawings and requirements are finalized only after the customer has accepted them as represented by the RP model.

Ordinarily, the RP process will not speed up the definition phase; instead, it might lengthen it. The first RP model will likely be incorrect, though it will enable the customer and developer to experiment, learn, and eventually select optimum requirements. RP models and mockups are used, for example, to demonstrate the form and functionality of the shapes and sizes of control panels used in plants and equipment and to design the interior layouts of automobiles and aircraft cabins.

Agile project management

The waterfall approach in Figure 4.7 (and, generally, the phases of A, B, and C in Figure 4.1) applies to projects where the requirements can be defined early in the project and will not change afterward. Such situations are like a waterfall: the projects move “down” from one stage to the next. But, also like a waterfall, it is hard to go the other way, which is analogous to what happens when the stages of a project must be repeated. When the requirements in a project cannot be completely defined early on or will change significantly, then steps in the project have to be repeated. The waterfall process is able to accommodate this (the back-arrows in Figure 4.7), although not very effectively, because altering the requirements midstream is costly and time consuming. Waterfall applies to projects where requirements can and must be defined early (e.g. designing and constructing a new building or airplane); for projects where the requirements cannot be defined or will certainly change (e.g. some software projects), so-called *agile* methods are better.

In *agile project management*, the project is divided into a sequence of small, iterative efforts, each conducted by a team devoted to meeting a limited set of requirements and releasing a partial result or solution. In the fashion of rapid prototyping, the end-item is developed in a series of quick iterations, where, in effect, the stages of definition, design, development, and testing are repeated. Each iteration (called a “sprint” because it is short—a month or less) delivers a partial yet stand-alone, fully functional result. At whatever time the project is terminated, the customer has usable results as produced up to that point. Agile project management is the topic of Chapter 14.

See Chapter 14

Team involvement in definition

As requirements and the project plan are being developed, questions arise: “How do you know when the requirements definition is complete?” and “How do you keep everyone in the project focused on those requirements?” The problem is especially tricky when the project involves numerous people and teams and spans months or years. Part of the answer is: make the system and project definition a *team effort* incorporating the perspectives of everyone who has or will have a significant stake in the project—customers; users and operators; suppliers; and functional areas such as engineering, marketing, manufacturing, customer service, and purchasing. The more these individuals and groups have a hand in defining requirements and the project plan, the better the plan will account for the requirements and the needs and interests of all stakeholders throughout the system life cycle. Everyone in the project should be working to the same set of requirements—a master requirements document, RBS, or equivalent. Any additional necessary requirements should be derived from and compatible with this master document.

In product development projects, a good way to generate product requirements is at an offsite workshop for all the key project stakeholders, including functional groups, users, and suppliers. Beginning with a list of customer needs or requirements, the team develops the system requirements (or, lacking adequate user requirements, develops them). For complex systems, a better approach is to create a team composed of all key stakeholders for the purpose of defining requirements. The term for this is *concurrent engineering*, which implies the *combined* efforts of key stakeholders to define requirements to the satisfaction of everyone. The term is somewhat misleading, because concurrent engineering involves not just engineering but marketing, purchasing, finance, quality, and more.

Concurrent engineering teams are sometimes called *design-build teams* because they combine the interests and involvement of designers and builders into a single effort.

Example 4.5: Design-Build Teams at Boeing[8]

At one time in the Boeing factory, the production plant was located on the main floor, and the engineering group was upstairs. Whenever a problem occurred in the plant, engineers just walked down to take a look. Today, Boeing employs many thousands of people at several locations, and such easy interaction isn't possible. Similar to other large corporations, as Boeing grew, its finance, engineering, manufacturing, and planning units evolved into "silos," each with strong self-interests and little interaction with the others. In the development of the 777 commercial aircraft, Boeing wanted to change that and implemented the "design-build team" concept, or DBT. Each DBT includes representatives from all involved functional units, customer airlines, and major suppliers. The concept emerged from one question, "How do we make a better airplane?" The answer required not simply a good understanding of aircraft design and manufacture but also knowledge of aircraft operations and maintenance. To capture such knowledge, customers, manufacturers, and designers joined together early in the project to discuss ways of incorporating all their objectives into the aircraft design.

The formation of DBTs mirrored the physical breakdown of the major subsystems and subcomponents of the airplane. For example, the wing was divided into major subsystems such as wing leading edge and trailing edge and was then further broken down into components such as inboard flap, outboard flap, and ailerons; responsibility for each subsystem and component was handled by a DBT.

The project required 250 DBTs, each with 10 to 20 members and run like a little company. The teams each met twice weekly for a few hours, following a preset agenda coordinated by a team leader. The concept of having so many people at design meetings—people from airlines, finance, production, and quality—was totally new, but with so many people representing so many interests, there were actually few conflicts.

Since most components in an airplane interact (interface) with numerous others, most participants in the program had to be assigned to multiple DBTs (to ensure their components would work with other DBTs' components). The manufacturing representative, for instance, belonged to 27. His duty was to tell engineers what would happen when their elegant designs met with the realities of metal, manufacturing processes, and assembly line and maintenance workers, and he offered suggestions that would improve the airplane's maintenance. One suggestion concerned the cover on the strut-faring that holds the engine to the wing. The faring would contain a lot of electrical and hydraulic components that maintenance personnel would need to access, but design engineers hadn't noticed that repairing the components would require removal of the entire faring. The manufacturing rep noticed, however, and suggested adding two big doors, one on each side of the faring. This improved access to the components inside and greatly simplified the repair work of maintenance personnel.

See Chapter 15

Concurrent engineering teams are discussed more fully in Chapter 15. Another practice for defining requirements and keeping the project focused on them is *quality function deployment* (*QFD*), which is covered in Appendix B to this chapter.

At the conclusion of Phase B, companies and governmental agencies sometimes employ a phase gate, that is, a formal review or checklist to ensure that the project is ready to move on to Phase C. Assuming all the requirements of the definition phase have been met, the project is given the green light to proceed to the next phase, execution.

4.5 Summary

There are good reasons the project life cycle approach is used in so many kinds of projects. First, it emphasizes continuous planning, review, and authorization. At each stage, results are examined and used as the basis for decisions and planning for later stages. Second, the process is goal oriented—it strives to maintain focus on user requirements and system objectives. Third, in each phase, the risks are assessed and reduced: knowledge gaps are filled in; mistakes and problems are caught early and corrected before they get out of control; if the environment changes, timely action can be taken to modify the system or terminate the project. Finally, user requirements and system requirements are always in sight, and activities are done so that they are coordinated and occur at the right time and in the right sequence.

The front-end phases of a project—conceptualization and definition—are important to the viability and success of the project. What is surprising is that in many projects, user and systems requirements definition receive relatively little attention. The impetus is to begin preparing the project plan—without even having clearly defined what the end result of the project is supposed to be! Project definition and system definition go hand in hand; only in cases where there is much latitude in terms of what the customer wants, when he wants it, and how much he is willing to pay can a project succeed in the absence of good requirements. In the more usual case (the customer is more demanding and the schedule and budget are constrained), success is predicated on a well-defined description of what the end result must be and do—the user requirements and the system requirements.

APPENDIX A: STAGES OF SYSTEMS ENGINEERING[9]

The systems engineering methodology described in Chapter 2 follows a series of stages that closely parallels that of the project life cycle and systems development cycle. A misnomer, really: systems engineering is not “engineering” in the same context as other engineering disciplines. Rather, as described earlier, it is a logical *process* employed in the evolution of a system from the point when a need is first identified through the system’s planning, design, construction, and ultimate deployment and operation by a user. The process, outlined in Figure 4.8, has two parts, one associated with the system’s *development and production* (Stages 1 through 4), the other with the system’s *utilization* (Stage 5).

See Chapter 2

Stage 1. Needs identification and conceptual design[10]

The main tasks of this stage, analogous to those in project life cycle Phase A, are to define stakeholder needs and requirements; perform feasibility analysis; and perform high-level requirements analysis, system-level synthesis, and system design review. The result of this stage is a “functional baseline” design—a list of high-level requirements and high-level functions of the intended end-item system.

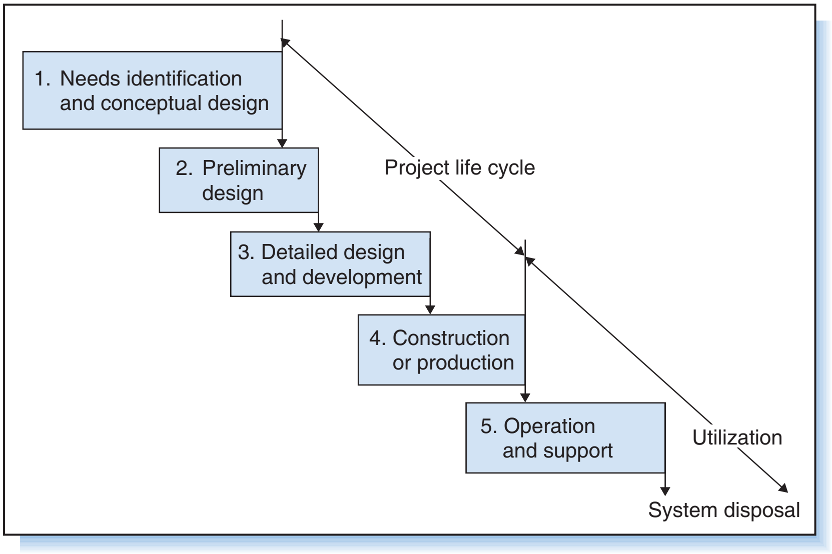


Figure 4.8
Stages of the systems engineering process.

Stakeholder and needs identification

Systems engineering deals with poorly defined problems. The customer may feel that something is wrong or something new is required but be unclear about the source of problem or need or what the system should look like or do. Sometimes it is not clear who has the problem or need. The first step is identifying the stakeholders who will be affected by or able to impact the system. Identifying the "customer" is not trivial. The customer might be an organization, but within the organization, only certain parties will have the authority to make decisions relating to the system or will use, operate, or be impacted by it. These parties must be singled out and their needs identified.

Developing a clear concept of the need or problem begins by asking basic questions:[11]

1. How did the problem or need arise?
2. Who believes it is a problem or feels the need?
3. Is this the root problem or need, or is it a manifestation of a deeper problem?
4. Why is a solution important? How much money (or time, etc.) will it save?
5. How important is the need? Would resources be better applied to another need?

Answers to these questions lead to a preliminary description of a system that addresses the need or problem, including its expected performance, cost, and schedule. The customer reviews the description and perhaps redefines the need, in which case the contractor must redefine the system description. The process continues back and forth until parties agree on the need definition and proposed system.

Requirements definition

High-level requirements specify everything important about the system—its objectives, life cycle, operational modes, constraints, and interfaces with other systems. As discussed earlier, they should also address all the stakeholders—producers, suppliers, operators, and others who will ultimately use and benefit from, manage, maintain, and otherwise impact or be impacted by the system—and reflect their interests and perspectives: for example, corporate customers who are interested in the system's market, capacity, and operating and capital costs; operators who are interested in its performance, durability, reliability, and parts availability; and users who care about its comfort, safety, and usability.

In systems engineering practice, the initial requirements are stated in the language of the stakeholders and compiled in a list called the *stakeholder (or user) requirements document* (SRD). Anyone reading the SRD should be able to readily understand the mission and application of the intended system. The project should not be started until the principal stakeholders have reviewed and endorsed the SRD.

Example A4.1: SRD for the Spaceship[12]

As an example, let's revisit the X-Prize/SpaceShipOne project described in Chapter 1. The criteria of the competition were to send a reusable vehicle capable of carrying three people into space twice within 2 weeks. Besides winning the X-Prize, a goal of developer Burt Rutan and customer Sir Richard Branson was to develop technology that would enable low-cost space tourism. Among the constraints were a relatively small budget and a small development company with limited resources. Hence, the SRD would include developing a spaceship with the following requirements:

1. Can minimally attain 100 km altitude.
2. Carries three people.
3. Provides comfortable flight.
4. Is relatively inexpensive to design, build, and launch.
5. Can be turned around in 2 weeks or less.
6. Is inherently safe to operate.

Feasibility

The next step is to identify high-level (system-level) alternative ways to meet the needs, objectives, constraints, and requirements. The alternatives are evaluated in terms of costs, risks, effectiveness, and benefits using studies and models; the most feasible solutions are recommended to customers and supporters.

Requirements analysis

With approval of the project and system-level alternatives, the next step is to specify what *the system must do* (the functions the system must perform) to be able to meet the requirements in the SRD. For example, the stakeholder requirement that the spaceship "provide comfortable flight" implies system requirements that the spaceship's cabin temperature, humidity, and pressure all function at "comfortable" levels throughout the flight. This implies that the spaceship will be equipped to perform the necessary functions to make this happen. Whereas the SRD specifies the system in terms of stakeholder wants or needs, the system requirements tell the designer the *functions* the system must perform and the physical characteristics it must possess to meet the SRD. This process of defining requirements, called *requirements analysis*, results in a document called the *system specification*, described later. Requirements analysis for physical systems addresses three kinds of requirements: *functional*, *performance*, and *verification*.

Functional requirements

Functional requirements specify the functions that the new system (its hardware, software, and related services, etc.) must perform to meet all the requirements in the SRD, including those for system support,

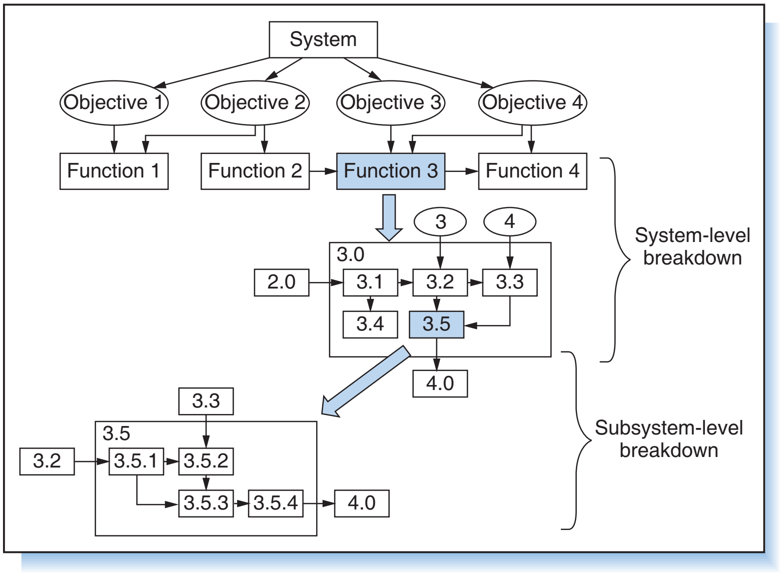


Figure 4.9
FFBD for decomposing system-level functions into lower-level functions.

operation, and maintenance. A popular tool for analyzing and defining functional requirements is the *functional flow block diagram*, illustrated in Figure 4.9. Each block represents a function that the system must perform to satisfy requirements. As illustrated, each function is defined in greater detail by decomposing it into subfunctions; for example, as shown, function 3 is logically composed of five subfunctions, 3.1 through 3.5. In the conceptual design stage, the decomposition of functions into smaller, better-defined subfunctions proceeds only to the next level (e.g. subdivides function 3 into 3.1–3.5). Later, in the preliminary design stage, the decomposition will resume and continue to whatever level necessary to arrive at the best possible requirements definition. In the figure, this is shown by decomposing function 3.5 into functions 3.5.1–3.5.4.

Notice the numbering scheme used in Figure 4.9: each and every function has a unique identifier that enables it to be traced to the original system-level function; for example, function 3.5.4 contributes to function 3.5, which contributes to function 3. This "traceability" of functions is essential because throughout the system development cycle, numerous changes will be made to components and functions, and for each change, it is necessary to know the impact on higher-level and lower-level functions. This helps prevent mistakes that could lead to later problems. For example, the cryogenic tanks in the Apollo 13 spacecraft were originally designed to operate at 28 volts. Later on, the spacecraft design required that certain controls be changed to 65 volts. This involved changes to numerous components, including to the cryogenic tanks, but somehow the linkage between tanks and controls was missed, and the changes were never made. During the mission, this mistake caused a tank to explode, which ruined the mission and nearly cost the lives of the three Apollo astronauts.

Example A4.2: Functional Requirements Breakdown for the Spaceship

Figure 4.10 shows a portion of the FFBD for the spaceship and decomposition of the system-level functions that address stakeholder requirements 3 and 5. The other system-level functions would be decomposed as well.

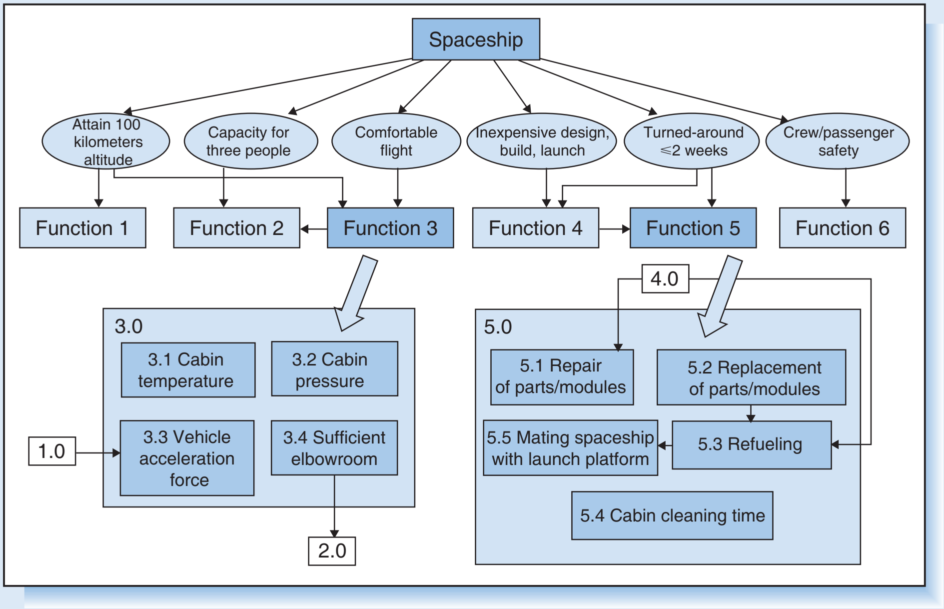


Figure 4.10
System-level breakdown of functions for spaceship.

Performance and verification requirements

Associated with each functional requirement are performance requirements and verification requirements. Whereas a functional requirement states *what* the system must do, a *performance requirement* states *how well* it must do it. Performance requirements are usually specified in physical parameters such as speed, acceleration, weight, accuracy, power, force, or time. They are the targets on which designers set their sights. For example, the stakeholder requirement "provide comfortable flight" has many functional requirements, including some for cabin temperature and pressure. The associated performance requirements for these might be:

1. Cabin temperature: 75–85 degrees F.
2. Cabin pressure: 4.2–3.2 psi.

Accompanying each performance requirement is a set of *verification requirements*; these specify procedures and tests to verify that the performance requirement has been met. For example, verification requirements would specify the kinds of tests to prove that cabin temperature and pressure will remain at the required performance levels during all phases of space flight.

Synthesis

Up until now, the systems engineering process has been focused on *top-down analysis*, resulting in a big list of functional, performance, and verification requirements. The next step, *synthesis*, looks at *relationships among the system-level requirements* and alternative ways of satisfying the requirements. One question is: Can these requirements be satisfied using existing, "off the shelf" designs and products, or will it be necessary to employ new and different designs or technologies? An OTS item is one that can be readily purchased or built; if it meets the requirements, an OTS item is often preferable to a newly designed one because it is readily available and usually less costly. Sometimes there is no OTS item and to create a new design that meets the requirements would be overly costly, risky, or time consuming; in such cases, the requirements must be revised.

The result of synthesis is called the "system specification," which is a comprehensive list of all the functions the new system must satisfy plus a firm or tentative solution (to be developed or bought) for each function. The system specification serves as a guide for designers in the later stages of preliminary and detailed system design.

Example A4.3: System Specification for Spaceship Motor

A decision must be made about the kind of rocket motor the spaceship will have. Among the functional requirements for the motor are:

1.1 Must provide thrust of *x*
4.1 Cost of fuel and fuel handling must be economical
5.3 Refueling procedure must be simple
6.1 Fuel and fuel system must be inherently safe

A check of existing OTS rocket motors used to launch satellites shows that none fit the requirements; all are too costly to fuel and operate and are somewhat dangerous. Hence, a new rocket motor must be developed—one that will be safe, simple, and inexpensive to fuel and operate and provide the necessary thrust. Experiments reveal a promising solution: a motor that uses ordinary rubber as the fuel and nitrous oxide (laughing gas) as the oxidant; both materials are stable, safe, inexpensive, and easy to handle. The decision is made to adopt the technology and design and build a completely new motor. Thus, one system specification for the spaceship (of many hundreds) is that the rocket motor burn nitrous oxide and rubber.

The system specification is reviewed and checked against the functional requirements at a formal meeting. When approved, it becomes the "*functional baseline*," or template for all subsequent design work.

Stage 2. Preliminary design[13]

The purpose of the preliminary design stage is to translate system-level functional requirements into design requirements for the subsystems. This stage roughly corresponds with Phase B. Studies are performed of the high-level elements comprising the system, and the system-level requirements are *allocated* among the subsystems.

Functions of subsystems

The FFBD process as illustrated in Figure 4.10 is now repeated to decompose the system-level functions into subsystem-level functions and, as before, to define functional, performance, and testing requirements for each functional block. The functions are decomposed to whatever level necessary to completely define each subsystem and permit decisions about whether each function can be met with an OTS design or product or it must be designed and built from scratch. In preliminary design, there is a subtle shift in focus away from *what* the system will do to *how* it will do it. It is a shift from *functional* design to *physical* design. Example 4.4 illustrates.

Example A4.4: Decomposing Functions into Subfunctions

Figure 4.11 shows the FFBD for function 5.5, mating (attaching) the spaceship with the launch vehicle. This requirement is derived from the system-level requirement of "turnaround in 2 weeks or less."

Suppose the performance requirement for mating the spaceship to the underbelly of the mothership is set at 10 hours. Having decomposed the function into all of the subfunctions in the procedure, planners are then able to set time requirements for the subfunctions such that the overall mating procedure will not exceed 10 hours.

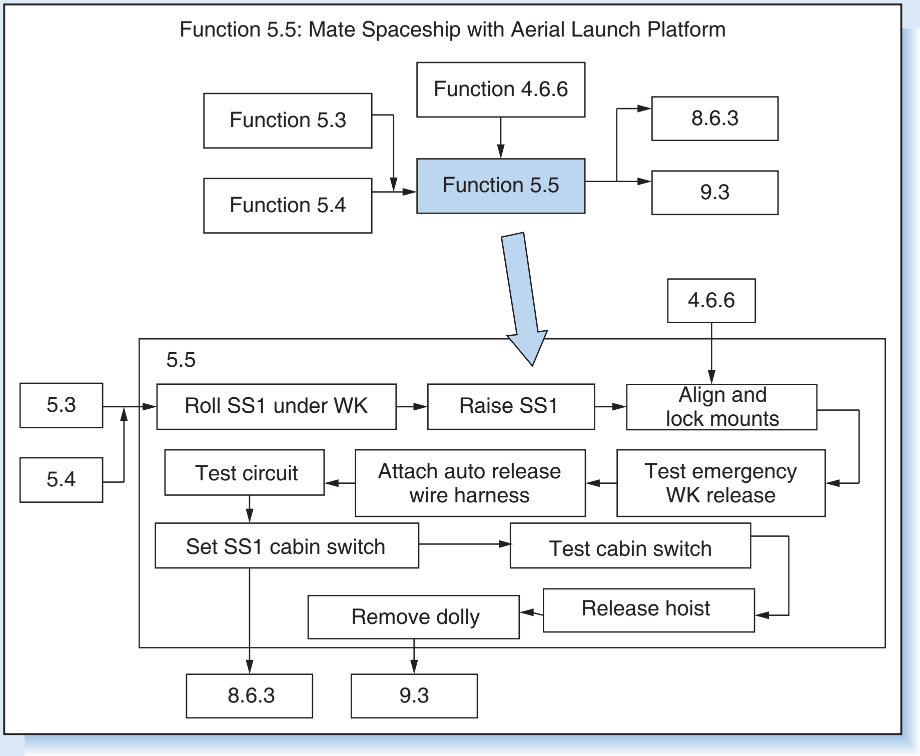


Figure 4.11
FFBD for mating SpaceShipOne and White Knight.

Grouping of functions: architecture and components

The next step is to group the identified functions and requirements according to the physical *architecture* of the system. In general, the term "architecture" refers to the major components in a system and how they are configured or arranged to satisfy the functions of the system; for example, the architecture most people have in mind for a bicycle is:

- *Major components*: two wheels, frame, seat, pedals and chain, handle bar.
- *Configuration*: wheels attached at ends of frame; front wheel pivots on frame; seat mounted on frame between wheels; pedals attached to frame, linked by chain to rear wheel; and so on.

Another case is Example A4.5.

Example A4.5: Architecture of the Spaceship

The spaceship will have airplane features of a fuselage and wings but also spacecraft features of a rocket motor and ability to maneuver in space. Unlike an airplane, where the cabin and fuselage walls are the same, the cabin in a spaceship is a separate "pressure vessel" fitted inside the fuselage. The spaceship architecture will include the following subsystems:

- Fuselage: structure containing or attached to other subsystems (cabin pressure vessel, hydraulics, avionics, motor, fuel system, wings, etc.).
- Cabin pressure vessel: contains seats, storage space, instruments and flight controls, and environmental control system.
- Rocket motor: main propulsion system, fuel system, motor controls.
- Avionics: aviation electronics; computers, subsystems for communication, navigation, flight controls, auxiliary power system, and so on.
- Wing/aerodynamic surfaces: main wings, tail, and hydraulic/electronic actuators.
- Landing gear: gear doors, braces, skids or tires, brakes.

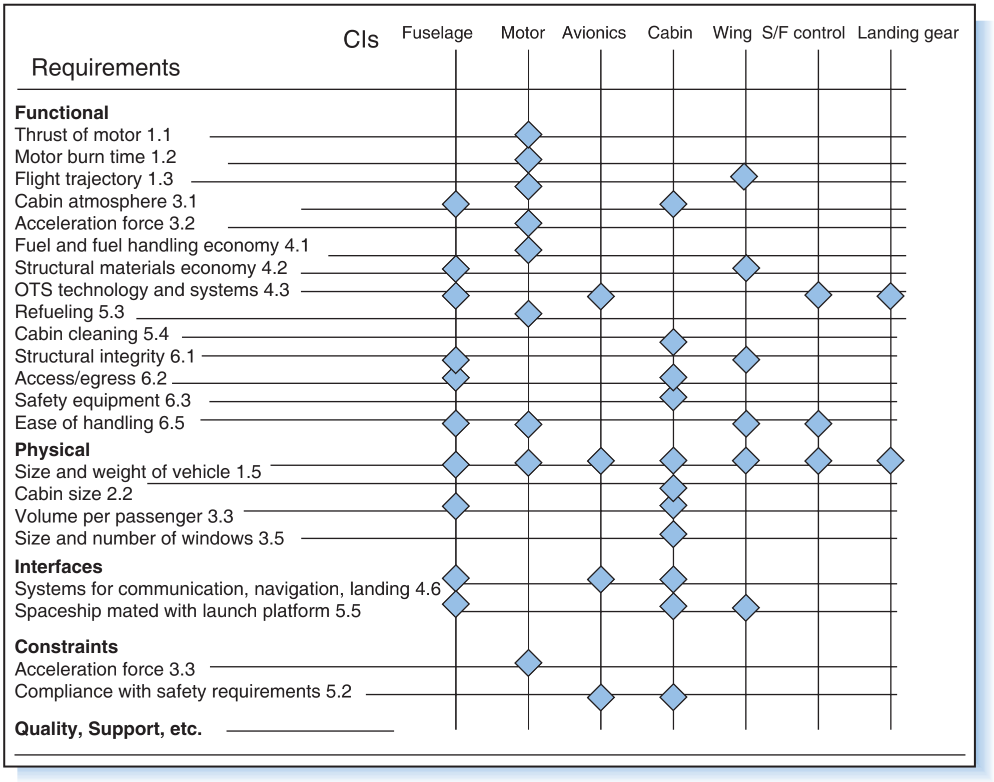
Sometimes the architecture "looks right," sometimes not. Often, in order to satisfy unique requirements, designers are forced to stray from the commonplace architecture, the result being a "funny-looking" architecture. Each major component will perform a major function or set of system-level functions as listed in the functional baseline.

A large system will have numerous components, all of which must be documented and monitored throughout the system development cycle of design, production, and usage. This documenting and tracking, referred to as *configuration management*, is necessary to ensure that any changes in the design, production, or usage of the components do not alter or degrade the end-item system's ability to meet the functional requirements. Configuration management utilizes "traceability" to prevent snafus such as the voltage change that caused the Apollo 13 accident mentioned earlier. It pertains not only to major subsystems but any items identified as risky, costly, or critical to performance. Every major subsystem or component that will be documented and tracked throughout the system's life cycle is referred to as a *configuration item* or CI.

Requirements allocation among the components

As of this point, the design consists of (1) a list of the functional requirements and (2) a high-level design of the system—the major subsystem or components (the CIs). The next step is to "allocate" the functional requirements to the CIs, which means to assign responsibility for each functional requirement to one or more of the CIs. The purpose here is to ensure that every functional requirement will be addressed (and hopefully satisfied) by at least one of the subsystems or CIs. The resulting allocations are shown in an "allocation matrix" or "traceability matrix": shown in Figure 4.12, the matrix columns are the subsystems responsible for meeting the requirements; the matrix rows are the requirements that the subsystems must fulfill.

With this allocation, the transition from functions to physical items accelerates. Since each of the CIs represents something that will ultimately be a physical item—a piece of hardware, software, or both,



Requirements / CIs	Fuselage	Motor	Avionics	Cabin	Wing	S/F control	Landing gear
Functional							
Thrust of motor 1.1		◆					
Motor burn time 1.2		◆					
Flight trajectory 1.3		◆			◆		
Cabin atmosphere 3.1	◆			◆			
Acceleration force 3.2		◆					
Fuel and fuel handling economy 4.1		◆					
Structural materials economy 4.2	◆				◆		
OTS technology and systems 4.3	◆		◆			◆	◆
Refueling 5.3		◆					
Cabin cleaning 5.4				◆			
Structural integrity 6.1	◆				◆		
Access/egress 6.2	◆			◆			
Safety equipment 6.3				◆			
Ease of handling 6.5	◆	◆			◆	◆	
Physical							
Size and weight of vehicle 1.5	◆	◆	◆	◆	◆	◆	◆
Cabin size 2.2				◆			
Volume per passenger 3.3	◆			◆			
Size and number of windows 3.5				◆			
Interfaces							
Systems for communication, navigation, landing 4.6	◆		◆	◆			
Spaceship mated with launch platform 5.5	◆			◆	◆		
Constraints							
Acceleration force 3.3		◆					
Compliance with safety requirements 5.2			◆	◆			
Quality, Support, etc.							

Figure 4.12
Allocation (traceability) matrix.

Source: Adapted from Falconbridge R. and Ryan M, *Managing Complex Technical Projects*. Boston: Artech, 2003:78.

assigning functional requirements to CIs represents a transition in thinking from *what* must be done (e.g. travel 100 km above the Earth) to *how* it will be done (with a spacecraft that has a fuselage, cabin, wings, and engine, configured in a certain way).

Notice in Figure 4.12 that responsibility for some requirements is shared by more than one CI. For example, the weight of the system (requirement 1.5) is shared by all the CIs. That is to say, the spacecraft weight is the sum of the weights of all the CIs, and if the weight of any one is changed, so is the weight of the spacecraft. If the maximum loaded weight of the spacecraft is set at 3,600 kg, the CIs must be designed so that all of them combined will not exceed that weight.

Example A4.6: Allocation of Weight Among CIs

Question: How do you design and develop all of the CIs such that in the end the total weight (shared requirement) does not exceed 3,600 kg? Answer: estimate the percentage of the total spaceship weight that each configuration item should account for, and set that as the "target" design weight for the CI.

For example, allocate, say, 30 percent of the total system weight to the fuselage and contents, 20 percent to the motor, 20 percent to the wings, 10 percent to avionics, and 10 percent for everything else. Hence, the fuselage target weight would be 0.30 × 3,600 kg = 1,080 kg, the motor target weight 0.20 × 3,600 kg = 720 kg, and so on. Since achieving targets is critical, each is designated as a *technical performance measure,* or TPM, which means that as the CIs are being designed, their estimated and actual weights are carefully compared to the targets. If during the project it becomes clear that a target cannot be achieved (as will surely happen), then the allocations are readjusted. If, say, the weight of the motor cannot be held to its target but must be increased by 30 kg, then either the allotted weights for other subsystems must correspondingly be reduced by or the target spaceship weight increased by 30 kg. Throughout the design process, it will be necessary to adjust the CI targets and allocations as guided by the TPM process. This process is described in Chapter 13.

See Chapter 13

Interfaces

None of the subsystems function independently; all rely on the outputs of other functions and, in turn, provide inputs to still others; in a word, they *interface*. Part of the preliminary design process is to identify all interfaces in the system and establish requirements for the interfaces. A main source of information about interfaces is FFBDs. For example, the FFBD in Figure 4.11 shows that function 5.5 *receives* input from functions 5.3, 5.4, and 4.6.6 and *provides* input to functions 8.6.3 and 9.3. Each arrow represents an interface—a connection or "flow" between functions. The connection can be:

- Physical—mechanical connections, physical joints and supports, pipes.
- Electronic—analog or digital signals.
- Electrical—electric energy.
- Hydraulic/pneumatic—liquid or gas.
- Software—data.
- Environment—temperature, pressure, humidity, radiation, magnetism.
- Procedural—completion of a procedural step so another next step can begin.

Identifying the interfaces is necessary for setting requirements on the inputs and outputs of every subsystem and element. For example, since the fuselage of the spacecraft contains the motor and also supports the wings, neither wings nor motor can be designed without also considering the design of the fuselage, and vice versa. The requirements for each interface (e.g. allowable maximum or minimum flow or physical strength) are set by a design team that includes representatives from subsystems or functions at both sides of the interface.

Synthesis and evaluation

Designing each of the CIs and its subsystems and elements involves choosing among design alternatives and, again, deciding whether to buy or modify an OTS design or product or to develop a new design from scratch. An OTS design or product that meets all or most of the requirements for a CI and is not too costly will be purchased; otherwise, the CI must be designed from scratch.

The selection of alternatives in the preliminary design stage must consider the synthesis of components—the impacts of each design decision on other components and the overall system. Following is an example.

Example A4.7: Tradeoffs in Designing Cabin Size

The weight requirement for a spacecraft is a big deal because the greater the weight, the more thrust (power) required of the rocket motor to propel the vehicle into space and the greater the load-carrying capacity of the mothership to carry it aloft. At some point early in the conceptual design, the maximum weight will be set, and thereafter every effort will be made to find ways to reduce it.

Consider some tradeoff decisions that designers face. For example, how big should the cabin be? In general, the cabin should be roomy enough to hold three people, instruments and controls, and stowage; a bigger cabin would be more comfortable for the occupants but would also weigh more. Suppose a cabin of volume *m* is chosen, which will result in an estimated weight of *w* for the spaceship. Suppose also that to propel a vehicle of weight *w* into space will require a rocket motor with thrust of *y* (Figure 4.13, top diagrams). Note that if the cabin size is increased, then the thrust of the rocket motor must also be increased—unless weight somewhere else in the spaceship can be reduced.

Now consider the impact of vehicle weight on another decision: landing gear. The more the vehicle weighs, the stronger the required gear, but all else being equal, the stronger the gear, the heavier the gear. If the weight of a typical wheeled landing gear strong enough to support the vehicle is deemed too high, then an alternative must be considered, such as a skid (Figure 4.13, bottom). The skid has no wheels and weighs less than a wheeled gear. If the skid meets other functional requirements, then it would be chosen over a wheeled landing gear.

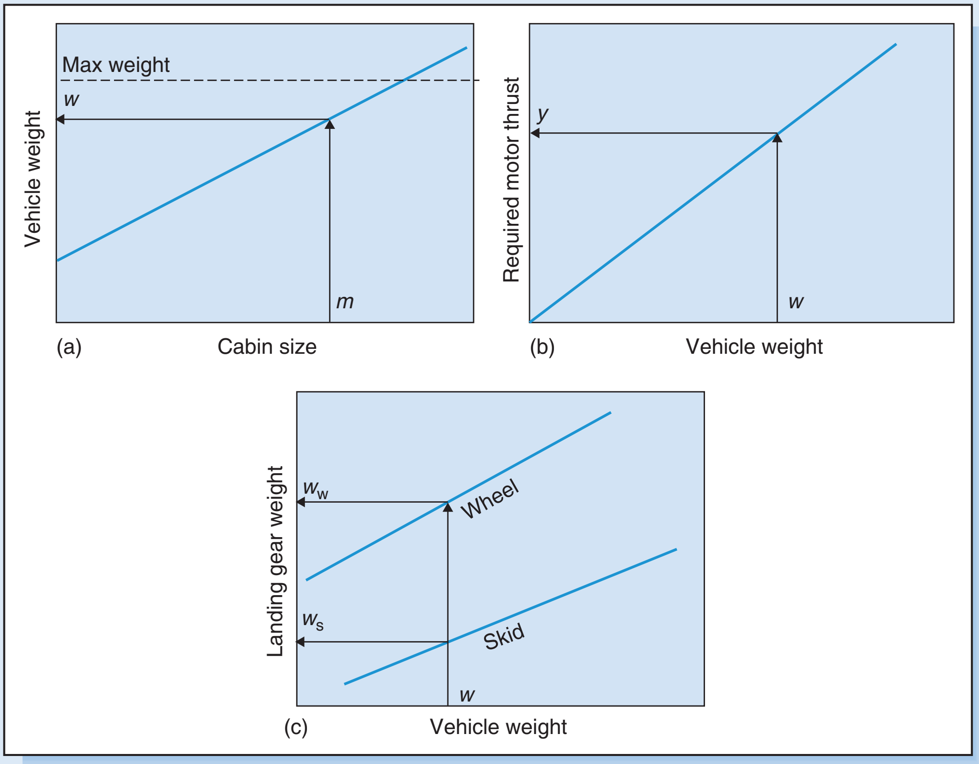


Figure 4.13
Impact of cabin size on vehicle weight, rocket thrust, and landing gear.

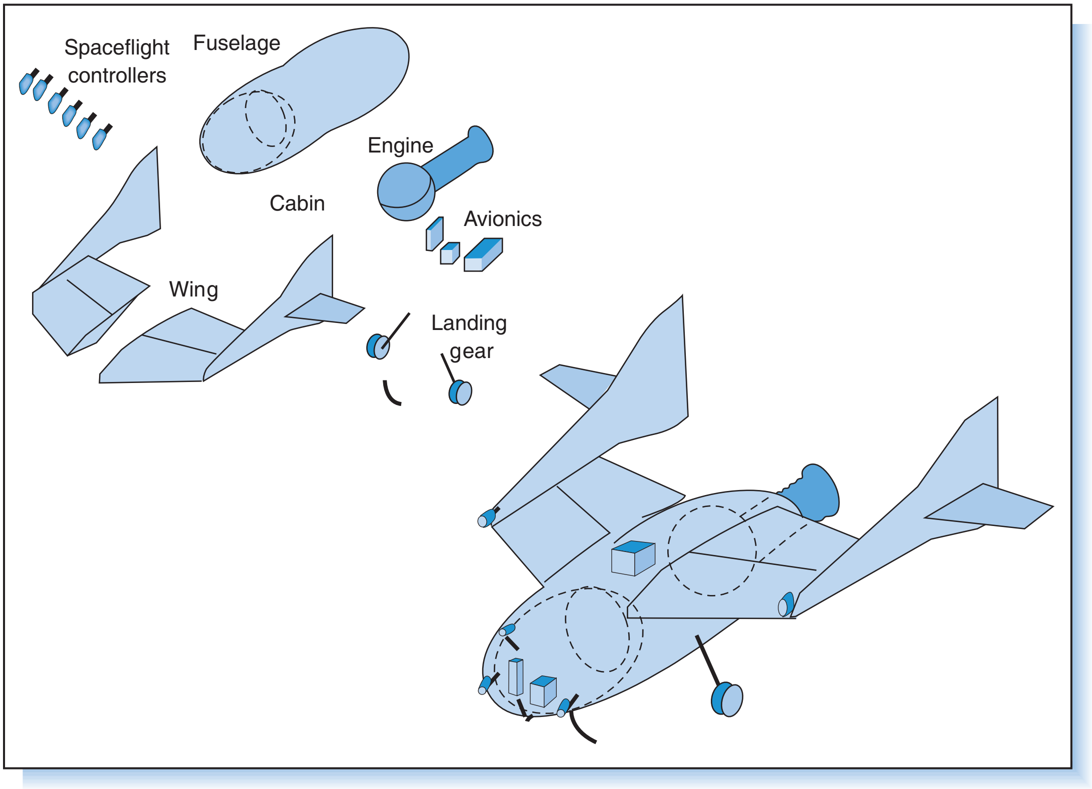


Figure 4.14
Pictorial representation of major subsystems (CIs) and allocated baseline design. (The "funny looking" architecture derives from the spaceship having to meet many requirements. On re-entry, the wings rotate upward, making the spacecraft one big airbrake that floats to earth like a shuttlecock, thus avoiding high speed and high temperature. Nearer to the ground, the wings tilt back and the ship glides to a landing.)

Such tradeoff decisions will be necessary for all the CIs and other components. As decisions are made, a design evolves that meets the requirements. The form and configuration of the CIs is set, and the physical appearance of the system begins to take shape. By the end of the preliminary design stage, the system architecture will have been established, and all system-level requirements allocated among the major subsystems (CIs). Combined, the architecture and allocated requirements form the "allocated baseline" design (see example, Figure 4.14).

Stage 3. Detailed design and system development

The detailed design stage involves further description of subsystems, assemblies, components, and parts of the main system and support items. It roughly corresponds to tasks performed in Phase B and early Phase C in the project life cycle.

Everything up to this point has been analytical in nature. With detailed design, the development process moves from "concepts on paper or computer"—the SRD, system specifications, FFBDs—to *a* *design that is ready to build*. Decisions are made about whether subsystems and components will function manually or automatically; whether components will be electronic, mechanical, or hydraulic; whether input-output will be manual, mechanical, electronic; and so on. Available OTS components are selected on the basis of surveys or laboratory tests, and newly developed components are tested experimentally using models that enable designs to be verified by trial and error. Models or mockups for components ("breadboards") are used to develop pieces of equipment that will subsequently be mated and integrated into the overall system. A prototype (nearly complete system) is assembled for purposes of developmental testing and evaluating the overall system in terms of satisfying requirements. Different type models and mockups for testing are described in Chapter 10.

See Chapter 10

System development and design testing and evaluation includes:[14]

1. Checking the operation of subsystems when combined in the complete system.
2. Evaluating the validity of design assumptions.
3. Paying close attention to the interfaces:
    a. feedback and "cross talk" among subsystems.
    b. adjustments and calibrations.
    c. serviceability and maintenance.

The system is checked under a variety of conditions and operational modes. Problems previously overlooked often come to light during these tests. Designs are modified to eliminate deficiencies and improve the system.

Example A4.8: Testing SpaceShipOne

Numerous ground and flight tests of SpaceShipOne resulted in changes; for example:

- In one test flight, the spacecraft began to pitch wildly, and only with great difficulty was the pilot able to regain control. Engineers diagnosed the cause as being a too-small tail, which they quickly redesigned. (Problem was, the small company did not have a wind tunnel in which to test it. Undeterred, they mounted the tail assembly on a Ford pickup truck and checked it by racing up and down the runway.)
- The nose skid showed excessive wear after tests and had to be replaced by one with a stronger material.

When there is not enough time or money to build test mockups, then the first few manufactured models are subjected to testing and design evaluation. Gradually, as modifications are made and the design is approved, full-scale production begins. Design and development testing is phased out and replaced with quality control to ensure the end-item system as produced will conform to design specifications.

At this time, the methods, resources, and capability to *produce the system* (process design) are also addressed. This involves the design of new (or redesign of old) facilities and manufacturing processes; selection of specific materials and pieces of equipment; and preparation for production control, quality testing, manufacturing tooling, product transportation, personnel hiring and training, and data collection and processing.

Stage 4. System fabrication, construction and/or production

Analogous to the latter part of Phase C, in Stage 4, the system is (1) mass produced, (2) produced in limited quantities with different features, or (3) built as a single item. This stage begins as soon as the design is approved and "frozen." The stage involves acquiring materials and controlling production/construction to uphold performance, quality, reliability, safety, and other requirements.

Stage 5. System operation and support

Stage 5 completes the systems engineering process. Analogous to Phase D, the customer maintains and operates the system until it wears out or becomes obsolete. The system developer might continue to support the system in any of several ways: assisting in deploying, installing, and checking out the system; assisting in day-to-day operation or field service and maintenance support; modifying or enhancing the system to ensure continued satisfaction; or providing support in closing, phasing out, and disposing of the system at the end of its life cycle. The last way, system closeout and disposal, is a consideration in the design and operation of systems that have potential to degrade the surrounding environment. The design of nuclear reactors and mines for metals and coal, for example, must account for the way each will be shut down. Their closeout must include measures to restore the land, clean up wastes, and remove toxins from soil and water, which can be expensive and time consuming and take years or decades.

Example A4.9: Product Launch of SpaceShipOne

Preliminary development of SS1 and its support systems began in 1999, and full development began in April 2001, albeit in total secrecy. Exactly 2 years later, Dick Rutan announced intentions to capture the X-Prize, and flight-testing began (Figure 4.15).

In May 2004, Mike Melville piloted the craft on a test above 100 km, making him the world's first civilian astronaut. On October 29, he again flew SS1 into space, and less than 2 weeks later, so did pilot Brian Binney, winning the $10 million X-Prize for the SS1 team (Figure 4.16). Today SS1 hangs in display at the Smithsonian Air & Space Museum in Washington, D.C. A bigger spaceship, SS2, and a bigger

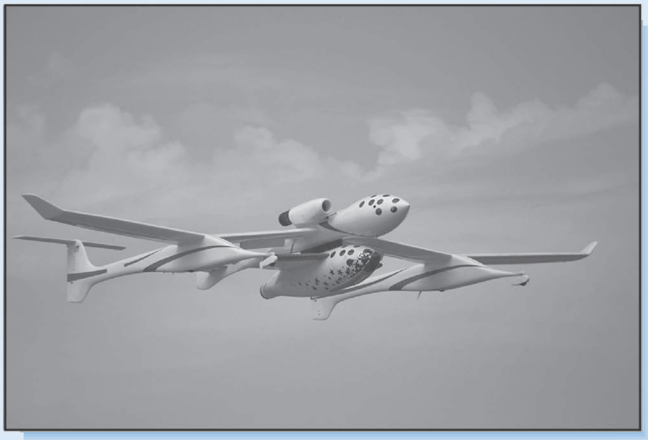


Figure 4.15
SS1 beneath mothership White Knight.

Photo courtesy John Nicholas.

mothership, WK2, have since been developed for use by Sir Richard Branson's commercial "spaceline," Virgin Galactic, which hopes soon to operate a fleet of them.

Figure 4.16
Designer Burt Rutan (center) and pilots Mike Melville (left) and Brian Binney.

Photo courtesy John Nicholas.

APPENDIX B: QUALITY FUNCTION DEPLOYMENT[15]

QFD is a methodology for defining requirements and, specifically, for translating customer needs into system or product characteristics and specifying the processes and tasks needed to produce the system or product. As demonstrated in numerous applications, QFD not only yields end-item results that meet customer needs, but it does so in less time and at a lower cost than traditional development methodologies. QFD was developed by Mitsubishi's Kobe Shipyards in 1972, adopted by Toyota in 1978, and has since been implemented by companies throughout the world.

House of quality[16]

QFD mandates that the project team articulate the means by which the product or system being designed will achieve customer requirements. The process starts with customer requirements or market needs and then uses a planning matrix called the *house of quality* to translate the requirements and needs into technical requirements. The structure of the house is shown in Figure 4.17.

- The left side of the matrix lists "what" the customer needs or requires.
- The top of the matrix lists the design attributes or technical requirements of the product; these are "how" the product can meet customer requirements.
- Additional sections on the top, right, and bottom sides show correlations among the requirements, comparisons to competitors, technical assessments, and target values.

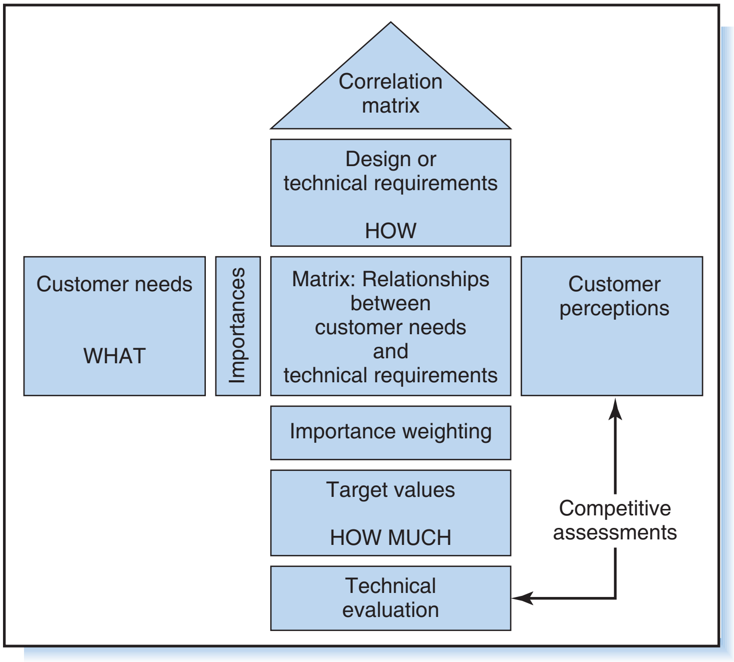


Figure 4.17
Structure of the house of quality.

Features of the house of quality are illustrated subsequently in Example A4.10.

Example A4.10: House of Quality for a TV Remote-Control Switch

Figure 4.18 is a portion of the house of quality matrix for the design of a television remote-control (RC) switch. The house is interpreted as follows:

- Rows (customer requirements): These show what customers think is important about the product. They are the product "whats."
- Importance to customer: The requirements have been rank-ordered 1–6 by customer preference; "multifunction buttons" is rated the highest; "RC easy to see/find" the lowest.
- Columns (technical requirements): These are the *requirements or attributes* of the product, the ways that the product meets customer requirements. They are the product "hows."
- Central matrix: Contains symbols that show the strength of the relationship between the whats and the hows (strong positive, positive, negative, strong negative). For example, "buttons easy to see" has a strong positive relationship to the size and color of the buttons and a positive relationship to the size of the remote-control chassis. Note that each relationship has a numerical weighting (small = 1, medium = 3, strong = 9).
- Importance weighting: The weights of the symbols in each column are summed to determine the relative importance of the technical attributes. Thus, the most important technical attribute is "dimensions of the RC" (weight = 9 + 3 + 1 + 9 = 22), followed by "size of buttons" and "color of RC chassis" (9 + 3 = 12 each).
- Gabled roof: This contains the correlations among the technical attributes. For example, "dimensions of the RC chassis" has a strong positive correlation with "size of buttons" and "number

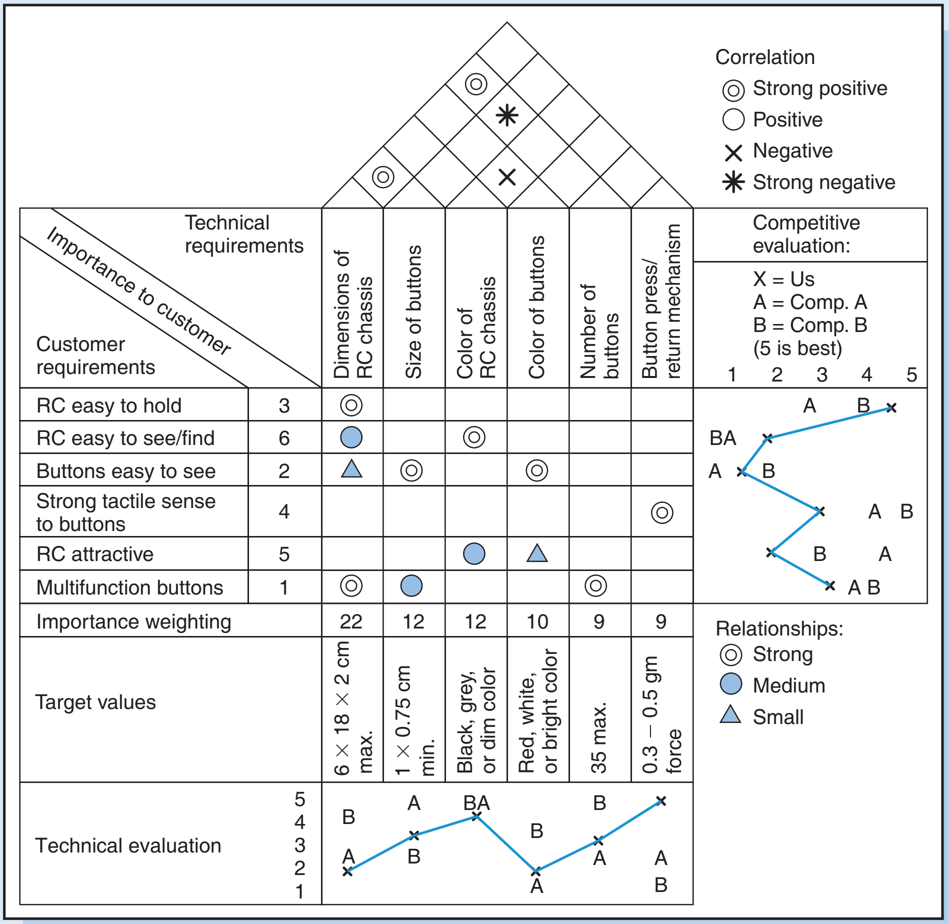


Figure 4.18
House of quality for television remote-control switch.

of buttons"; "size of buttons" has a strong negative correlation with "number of buttons" (smaller buttons allow more buttons; larger buttons allow fewer).

- Target values: The numerical or qualitative descriptions (in the "basement" of the house) are design targets set for the technical attributes. One target of the design, for example, is to keep the dimensions of the RC within "6 × 18 × 2 cm."
- Technical evaluation: The graph (in the "sub-basement") compares the company (x = "us") against two of its competitors, A and B, on the technical attributes. For example, the company's current product does relatively poorly on the attributes of RC dimensions and button color but fares well on chassis color and return mechanism. These evaluations are based on test results and opinions of engineers.
- Competitive evaluation: The graph on the right rates the company and its competitors in terms of customer requirements. These ratings are based on customer surveys. For example, customers think the company does best in terms of the RC being "attractive" but worst in terms of it being "easy to hold."

The house of quality suggests areas in which designers might focus to gain a market niche. For example, the rating on the right in Figure 4.18 indicates that no company does particularly well in terms of "buttons easy to see," even though that customers rank that requirement second in importance. A requirement that customers rank high, yet on which all companies rank low, suggests a feature that could be exploited to improve a company's competitive standing. The company making the RC, for example, might try to improve the button visibility by increasing button size and/or using bright colors.

The house provides a systematic way of organizing, analyzing, and comparing the hows with the whats and prevents things from being overlooked. It justifies where to devote time and money and where to refrain from adding resources. Still, the results of QFD are only as good as the data that go into the house. At minimum, the competitive evaluations require two perspectives: the customers' viewpoints regarding how the product compares to the competition and the engineers' and technicians' views regarding how well the product meets technical requirements. The data come from sources such as focus groups, tests of competitors' products, and published reports.

An important aspect of requirements definition is to determine priorities—to distinguish between the *critical few* and *trivial many* aspects of the end-item system so as to ensure that the critical ones are done correctly. As an example, a computer printer might have as many as 30 different design features that affect print quality, but the most important feature is the fusion process of melting toner on the page, which is a function of the right combination of temperature, pressure, and time. Focusing on temperature, pressure, and time narrows the design emphasis to the relatively few most important technical parameters. These parameters become the ones for which designers seek the "optimum" values. Once these values have been set, the analysis moves on to identify important factors in the manufacturing process necessary to achieve those values.

QFD process[17]

The QFD process employs a series of matrices in a multiphased approach to project planning. The process, shown in Figure 4.19, utilizes four matrices that correspond to four project phases: project planning, product design, process planning, and process control planning. The phases (circled numbers) are as follows.

1. Create the "house of quality" matrix (A). This matrix converts customer needs or requirements into technical requirements.
2. Develop an initial version of the project plan based upon the house of quality requirements. The house matrix does not have to be completed; start with a rudimentary plan using information available from the matrix, then expand the plan as new requirements emerge in the updated matrix.
3. Create the design matrix (B). This matrix converts technical requirements from the house matrix into product design features and requirements.
4. Create the process matrix (C). This matrix converts design features and requirements from the design matrix into process steps or production requirements.
5. Create the control matrix (D). This matrix converts process steps or production requirements from the process matrix into process tracking and control procedures.
6. Refine the project plan to incorporate aspects of the design, process, and control matrices.

The matrices highlight the information needed to make decisions about product definition, design, production, and delivery, and they link work requirements in the four phases so that customer needs

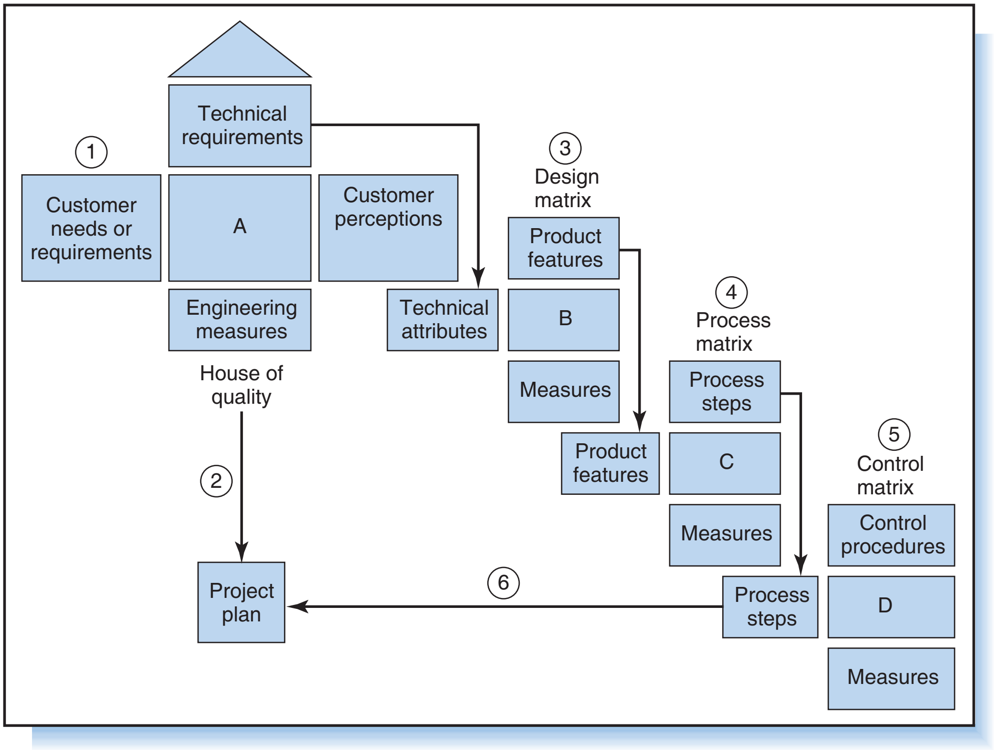


Figure 4.19
QFD multiphase, multimatrix approach.

and technical requirements, as defined early in the process, are translated undistorted into design features and production requirements. Shown in Figure 4.19, the link happens by taking the requirements or steps from the top of one matrix and putting them on the left side of the matrix in the next phase. This linking of matrices ensures traceability (that word again)—that any project activity can be traced to the customer need or requirement that it fulfills, and, conversely, that every customer need and requirement can be traced to the necessary project activities. Put another way, QFD ensures that every activity serves a requirement and every requirement is served by at least one activity. The result is a plan where every task in the project is integrated with the technical requirements listed in the original house matrix.

The additional time required by the QFD process to produce a project plan and an initial product design is offset by the reduced time to produce the *final* design because less redesign and fewer engineering changes are needed after the product goes into production.

Example A4.11: Chrysler Development of the LH Car Line[18]

Chrysler first applied QFD in the design and development of its LH-platform cars (Chrysler Concorde and Dodge Intrepid). Early in the product concept stage, a program team was formed to establish overall design guidelines. The program team allocated responsibility for the different major automobile systems to different design groups (as did Boeing in its design-build teams), and each group set up a

QFD matrix to determine system-level requirements. Once requirements were set, smaller groups were formed to focus on designing the components within the system.

The QFD methodology was part of a broader concurrent engineering effort that yielded impressive results: The total LH design cycle took 36 months versus the historical 54 to 62 months, prototype cars were ready 95 weeks before production launch versus the traditional 60 weeks, and the program required 740 people compared to the usual 1,600 people. The cars received numerous awards and magazine citations for design excellence.

Review Questions

1. When does the project manager become involved in the project?
2. What is the purpose of the kickoff meeting? When is the meeting held, and who runs it?
3. How is the project team created?
4. Describe briefly the contents of a project execution plan.
5. Describe phased project planning.
6. What are user requirements, system requirements, and system specifications? Give examples. How are they related?
7. What are functional requirements? What are performance requirements? Give examples.
8. What are "non-functional requirements"? Give examples.
9. Describe the process of developing user requirements and system specifications.
10. What problems are associated with requirements definition? What are ways to minimize these problems?
11. What is the purpose of specifying priorities and margins in defining requirements?
12. Describe concurrent engineering.
13. Describe the stages of systems engineering in Figure 4.8. Think of some projects and describe the stages of systems engineering in these projects.
14. Distinguish the following: functional requirements, performance requirements, and verification requirements. Give an example of a functional requirement and its associated performance and verification requirements.
15. What is meant by the term "traceability"?
16. Think of a simple system like a mousetrap, tape dispenser, or can opener. Draw a simple high-level functional flow block diagram for it. If possible, decompose each of the functions into subfunctions.
17. Briefly define the purpose of quality function deployment (QFD).
18. What is the source of customer needs or requirements that appear in the house of quality?
19. Think about the following or use whatever consumer research material available to you to define customer needs or requirements for the following:
    a. A "good" college course.
    b. Toaster (or other home appliance of your choosing).
    c. Cell phone.
    d. Coffee mug for your car.

    For each, define a corresponding set of physical or technical characteristics. Using the format of Figure 4.20, construct a house of quality matrix and show the relationship between the technical characteristics and customer requirements. Use the matrix in each case to "design" or suggest what the ideal product or service would be like or look like.
20. What is the purpose of the project charter? What is included in the charter?
21. To what situations does agile project management apply? How does agile differ from "waterfall"?

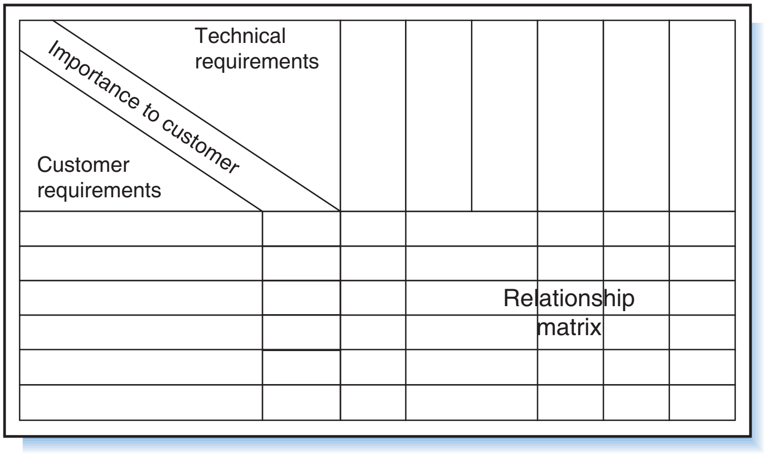


Figure 4.20
QFD matrix for Question 19.

Questions About the Study Project

1. Did the project have a kickoff meeting? What happened there?
2. How did the project manager become involved in the project? Was she selected as project manager before or after the proposal was completed?
3. How was the project team formed?
4. Were there user requirements? How were they defined? Were they "well-defined" requirements?
5. Were there any system requirements? Were they clear and utilized by the project team?
6. Were there any system specifications and performance requirements? If not, how did the project team know what was required of the end-item?
7. Did the project have a project execution plan? If so, describe the contents. If not, how did the team know what they were supposed to do (tasks, schedules, responsibilities, etc.)?
8. Describe the process of creating the project plan.
9. Did different stakeholders participate in defining the requirements and creating the project plan?
10. Was QFD or a similar process used to define requirements and/or create the project plan?
11. What is your overall impression about how well the definition phase was conducted in the project and of the quality of the system requirements and project plan?

CASE 4.1 STAR-BOARD CONSTRUCTION AND SANTARO ASSOCIATES: REQUIREMENTS SNAFU

Star-Board Construction (SBC) was the prime contractor for a large skyscraper project in downtown Manhattan. SBC worked directly from drawings received from the architect, Santaro Associates (SA). Robert Santaro, owner and chief architect of SA, viewed this building as similar to others he had designed, although one difference he failed to notice was the building's facing, which was to consist of large granite slabs—slabs much larger than anything with which he or SBC had prior experience.

Halfway into the project, Kent Star, project manager for SBC, started to receive reports from his site superintendent about recurring problems with window installation. The windows were pre-manufactured units made according to SA's specifications. The granite facing on the building was to be installed according to specifications that allowed for dimensional variations in the window units. The architect provided the specification that the tolerance for each window space should be 1/2 inch (that is, the window space between granite slabs could vary as much as 1/4 inch larger or smaller than the specified value). This created a problem for the construction crew, which found the granite slabs too big to install with such precision. As a result, the spacing between slabs was often too small, making it difficult or impossible to install window units. Most of the 2,000 window units for the building had already been manufactured, so it was too late to change their specifications, and most of the granite slabs had been hung on the building. The only recourse for fitting window units into tight spaces was to grind away the granite. It was going to be very expensive and would certainly delay completion of the building.

QUESTION

What steps or actions should the architect and contractor have taken before committing to the specifications on the window units and spacing between granite slabs that would have prevented this problem?

CASE 4.2 REVCON PRODUCTS AND WELBAR, INC.: CLIENT—CONTRACTOR COMMUNICATION

Revcon Products manufactures valves for controlling the water level in industrial tanks. It had concentrated on products for the construction industry (valves for newly installed tanks) but now wanted to move into the much larger and more lucrative replacement market. Whereas annual demand for new valves is about 100,000, it is about 1 million for replacement valves. The company envisioned a new valve, the Millennium Valve, as a way to gain a share in the tank-valve replacement market. Revcon's objective was to design and produce the Millennium Valve to be of superior quality and lower cost than the competition. Revcon decided to outsource the development and design of the new valve. It prepared an RFP with the following objectives and requirements:

Product objectives:

- Innovative design to distinguish the Millennium Valve from competitors' valves.
- Price competitive but offer greater value.

Market (user) requirements:

- Ease of installation
- Non-clogging
- Quiet operation
- Ease in setting water level
- Adjustable height.

Revcon sent the RFP to four design companies and selected Welbar, Inc., primarily based on it being the lowest bidder. Welbar's proposal was written by its sales and marketing departments and revised by senior management but with no input from industrial designers, engineers, or anyone else who would work on the project. Welbar had no prior experience with industrial water valves, but its sales team saw Millennium as an opportunity to earn profits and align with a major equipment manufacturer. The marketing department prepared time and cost estimates using standard tasks and work packages from proposals for old projects.

The Welbar design team for the Millennium Valve project was headed by Karl Fitch, a seasoned engineer, and included two industrial designers and two engineers. His first task was to research the valve market and talk to contractors, plumbers, and retailers. Karl reviewed Welbar's proposal and concluded that it had omitted several critical steps and that its cost was substantially underestimated.

Karl divided the project into small work packages and prepared a Gantt chart. During the project, the design concept, work tasks, and schedule had to be changed many times. Welbar engineers were frustrated at Revcon's constant harping that the valve be low priced and have functional superiority and that the project be speedy and low cost. During the project, Welbar engineers learned that to design such a valve required more resources than had been budgeted for. Because of all the changes, Welbar exceeded the budget and had to request additional funds from Revcon four times. A major problem occurred when Welbar delivered a prototype to Revcon. Because the prototype description in the proposal was vague, Revcon expected the prototype to be an almost-finished product, whereas Welbar understood it to be a simple working model to demonstrate functionality. Welbar had to spend extra time and money to bring the prototype up to Revcon's expectation. To compensate, Welbar crammed project stages together. When the design stage fell behind because of the prototype, it went ahead and prepared production-ready models. The finished prototype later demonstrated that the production models could not be produced.

Eventually Welbar did design a truly innovative valve; however, the design would require substantial retooling of the factory and cost 50 percent more to produce than expected. In the end, Revcon spent twice as much time and money on development as expected. Because of that, the product could not be priced low enough to be competitive.

QUESTION

What happened to this project? What are the factors that contributed to Revcon's failure to get the product it wanted? For each factor, discuss what might have been done differently.

CASE 4.3 LAVASOFT.COM: INTERPRETING CUSTOMER REQUIREMENTS

Lavasoft Company is developing new website software for a corporate client. The project starts out when a few Lavasoft staffers meet with the client to create a list of user needs and requirements, which they then turn over to the Lavasoft design team.

The project manager, Lakshmi Singh, feels that the kind of system best suited to the user's needs is more or less obvious, and to address the needs, she creates some bullet points and flowcharts. She then presents these to the design team and asks if anyone has questions. Some people are concerned that the approach as stated by the bullets and charts is too vague, but Lakshmi assures them that the vagueness will subside as details of the system are defined.

To reduce outside interference, the team works in relative isolation from other development teams in the company. Daily, the team is forced to interpret the bullet points and high-level charts and to make design decisions. Whenever there is disagreement about interpretation, Lakshmi makes the decision. The team creates a list of detailed system specifications, and the project is considered on schedule. Upon working to the specifications, however, issues arise concerning the system's compatibility with the client's existing site. Further, some of the specifications call for technical expertise that the team lacks. Also, in a review of the original user needs, the team discovers that some specifications are unrelated to the needs and that for some needs, there are no specifications.

The team drops some specifications and adds new ones. This requires eliminating some of the existing code, writing new code, and retesting the system, which puts the project behind schedule. Resistance grows to changing the specifications further, since that would require even more recoding and put the project further behind. Lakshmi adds people to get the project back on schedule. Eventually the system is ready for installation, although it is 2 months late. Because of the additional people added to staff the project, Lavasoft does not make a profit. Because the specifications were incorrect, the system is not fully compatible with the client's website, and Lavasoft must continue to work on it and introduce "fixes."

QUESTIONS

1. What went wrong with the project?
2. Where were mistakes made in the project initially?
3. How were problems allowed to persist and go uncorrected for so long?

CASE 4.4 PROPOSED GOLD MINE IN CANADA: PHASED PROJECT PLANNING

July 12, 2006: Peter's firm acquires the rights to an ore body in the Canadian Shield region. The firm is considering developing a new mine there, and Peter is responsible for proposing a project plan to the board in September. The mine will take a few years to reach full production, and there is much uncertainty as to the price of gold when that happens. Peter includes in his proposal a history of the gold price (Figure 4.21).

August 2, 2006: Peter meets with Bruce, a mining engineer with 20 years of experience in Australian gold mines, and Sam, a geologist who a few years back did exploratory work on gold deposits in the Canadian Shield region. They discuss known facts about the ore body, the likelihood of unforeseen geological phenomena that could jeopardize mine development, production figures that might be achieved, and production costs and technical problems that might arise in extracting gold from the ore. A quick calculation shows that 300,000 ounces of gold per year at $700 per ounce would be very lucrative, but a figure of 150,000 ounces at $400 per ounce, 3 years from now, would lead to large losses that could ruin the company. Current information about the ore body is inadequate, however, and it will be necessary to drill exploration holes to learn more about the general geology of the area.

Peter summarizes: "To the best of our knowledge, we could produce anywhere between 150,000 and 300,000 ounces a year. The capital cost for developing the shaft will be US$150 million to $260 million, and annual operational costs could be $60 million to $100 million. Exploration to provide information on the ore body would require drilling 200 exploration holes at a cost of between $1.2 million and $1.6 million. Rock samples from these holes will be analyzed in a laboratory to determine the gold content."

Peter instructs Sam to review the data from his previous exploration work and to prepare a report of his recommendations concerning the future exploration. He is authorized to spend no more than $25,000 on this "paper exercise." They agree that, should the exploration holes yield good results, a "demonstration shaft" will be sunk to haul out a sample of 30,000 tons of ore to be processed to extract gold. Results from this demo would increase confidence about the amount of

Figure 4.21
Gold price.

gold present, reduce uncertainty about processing the ore, and provide a good indication of potential yields. They estimate that the demo shaft and analysis would cost $18 million to $25 million, some of which, however, could be deducted from the cost of the full-fledged mine—should it go ahead. Only if these results are positive—and the gold price is relatively high and stable as of that stage—would full-fledged shaft development be authorized.

QUESTIONS

1. List the phases of the project and indicate the minimum and maximum cost of each phase as foreseen in August 2006.
2. "While estimates for the distant future are very 'broad brush', it is always possible to make relatively accurate estimates for the imminent phase of a project." Explain.
3. Describe how each of the proposed project phases will help reduce the risk of the project.
4. Comment on the problem that, once money has been allocated to the process, people might become "hooked" into the project and be tempted to go ahead regardless of high risks.
5. How would you determine the value of accurate estimates for the number of ounces that could be mined and for costs?
6. Would you trust any internal rate of return or net present value estimates at this time?

REFER TO CASE 2.4, SANTA CLARA COUNTY TRAFFIC OPERATIONS SYSTEM AND SIGNAL COORDINATION PROJECT

Question

The INCOSE Transportation Working Group determined that a requirements traceability matrix, which was not used in the project, could have—were it used—aided in technology-related decision-making during construction and reduced the number of change requests. Based on the limited information provided in the case, discuss the applicability of the traceability matrix to this project.

Notes

1. For advice for naming projects, see Gause D. and Weinberg G. *Exploring Requirements: Quality Before Design*. New York, NY: Dorset House; 1989, pp. 128–134.
2. *APMP Syllabus,* 3.1 edn. Buckinghamshire, UK: Association for Project Management; 2012.
3. Kay R. *An APMP Primer*. Lul.Com Self Publishing; 2010.
4. This section is adapted from Merrow E. *Industrial Megaprojects*. Hoboken, NJ: John Wiley; 2011.
5. See Frame J.D. *Managing Projects in Organizations*. San Francisco, CA: Jossey-Bass; 1988, pp. 146–151.
6. Hajek V. *Management of Engineering Projects,* 3rd edn. New York, NY: McGraw-Hill; 1984, pp. 35–37; Whitten N. *Managing Software Development Projects,* 2nd edn. New York, NY: John Wiley & Sons; 1995, pp. 250–255.
7. Connell J. and Shafer L. *Structured Rapid Prototyping*. Upper Saddle River, NJ: Yourdan Press/Prentice Hall; 1989.
8. Portions adapted from Sabbagh K. *Twenty-First Century Jet: The Making and Marketing of the Boeing 777*. New York, NY: Scribner; 1996.
9. Sources: (1) Falconbridge R.I. and Ryan M. *Managing Complex Technical Projects: A Systems Engineering Approach*. Boston, MA: Artech House; 2003, pp. 9–93; (2) Blanchard B. and Fabrycky W. *Systems Engineering and Analysis*. Upper Saddle River, NJ: Prentice Hall; 1981, pp. 18–52; (3) Chestnut H. *Systems Engineering Methods*. New York, NY: John Wiley & Sons; 1967, pp. 1–41; (4) Jenkins G. The systems approach. In Beishon J. and Peters G. (eds), *Systems Behavior,* 2nd edn. London, UK: Harper & Row; 1976, pp. 78–101.
10. Falconbridge and Ryan. *Managing Complex Technical Projects*, pp. 29–65.
11. Jenkins. The systems approach, p. 88.
12. The SpaceShipOne examples in this book illustrate concepts. While there is much factual information about the project available from published sources, information about the actual design and development of the spaceship is confidential. SS1, the X-Prize, and the stakeholders described are all true life; however, for lack of information, portions of this and subsequent examples are hypothetical. Information for this and other examples of SS1 are drawn from news articles and the SS1 website at Scaled Composites, www.scaled.com/projects/tierone/index.htm.
13. Adapted from Falconbridge and Ryan. *Managing Complex Technical Projects*, pp. 67–96.
14. Chestnut. *Systems Engineering Methods*, p. 33.
15. Sources for this section: Bounds G., Yorks L., Adams M. and Ranney G. *Beyond Total Quality Management*. New York, NY: McGraw-Hill; 1994, pp. 275–282; Hauser J. and Clausing D. The house of quality. *Harvard Business Review*; May–June 1988: 63–73.
16. Portions of this section adapted from Nicholas J. *Competitive Manufacturing Management*. Burr Ridge, IL: Irwin/McGraw-Hill; 1998, pp. 428–434.
17. See Bicknell B. and Bicknell K. *The Road Map to Repeatable Success: Using QFD to Implement Change*. Boca Raton, FL: CRC Press; 1995, pp. 97–110.
18. Lockamy A. and Khurana A. Quality function deployment: A case study. *Production and Inventory Management Journal* 36(2); 1995: 56–59.

Chapter 5

Project execution and closeout

Don't tell people your plans. Show them your results.

—Anonymous

If you build it, they will come.

—*Field of Dreams*

So much effort goes into the definition phase—preparing the project plan and defining the end-item—all of it in preparation for what is to come next: the execution phase.

Project execution is what most people—project outsiders—witness or read about: It is a building being constructed, a new website being developed, a new rocket engine being test fired, or employees and facilities being moved to a new corporate headquarters. To them, the word "project" means doing *the physical work* of creating an end-item. Of course, project insiders also recognize the many things that had to happen first—*before* execution, the necessary pre-work in the conception and definition phases—without which there would be no project execution and, for that matter, no project!

Execution is generally the longest and most expensive phase of a project (for a megaproject, it can cost over a billion dollars and last for several years). For many a project, the start of execution is the tipping point—the point of no return.

What happens during execution and the stages and details of work depend entirely on the end-item—skyscraper, space vehicle, pharmaceutical drug, software application, and so on. This chapter provides an overview of what happens in *many* projects during execution, especially projects aimed at delivering physical end-item systems. It describes the most common stages and steps, although with a little imagination, you might see how these stages and steps occur in other kinds of projects as well—for example, in research programs, corporate audits, motion-picture productions, or large-scale litigations. In a sense, however, all of these projects course through the stages of execution as described in this chapter.

5.1 Phase C: execution

The execution phase typically includes the stages of *detail design*, *production/build*, and *implementation*, though, as mentioned, in actuality, the stages will differ depending on the project. The typical

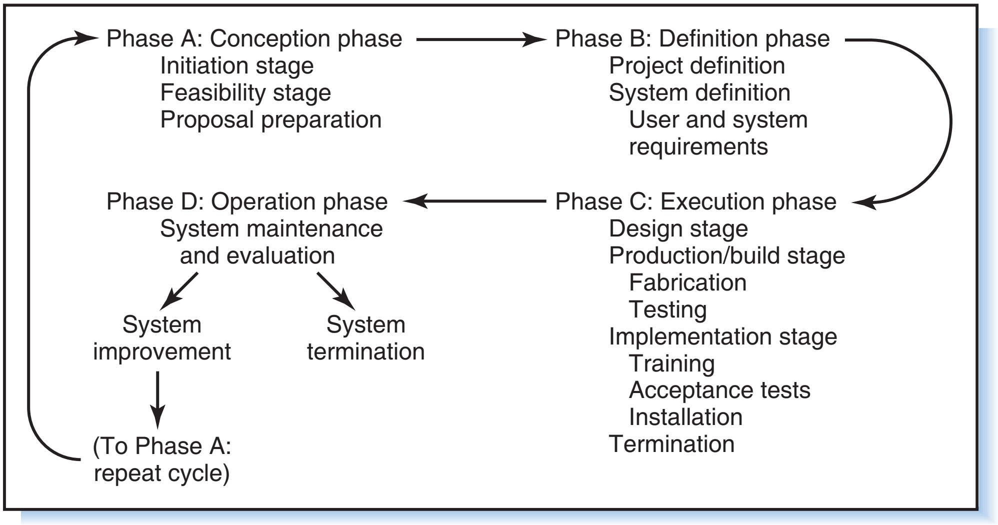


Figure 5.1
Phase and stages of systems development life cycle. Phases A, B, C = Project life cycle.

See Chapter 18

stages in a hardware development project are design, development, and production; in construction projects, they are design and build; and in consulting projects, they are background research and investigation, report compilation, and presentation. Many companies have customized project methodologies with their own unique project phases and stages; these are discussed in Chapter 18. All projects that produce a physical end-item—a product, building, or system—also include an implementation stage wherein the end-item is handed over to the user. This chapter looks at the stages of detail design, production/build, implementation, and project closeout/termination (Figure 5.1).

See Chapter 4

Given its importance and the significant resources devoted to it, execution often initiates with a formal kickoff meeting and, in many cases, a project charter document to authorize expenditures; both of these topics are discussed in Chapter 4.

5.2 Detail design stage

In the detail design stage, system specifications are converted into plans, graphics, or drawings. The outputs of this stage are pictorial forms—blueprints, flow charts, schematic diagrams—or models showing the end-item system's components, dimensions, relationships, and configuration.[1]

See Chapters 2,3, and 6

During this stage, the system is divided into tiers of subsystems, components, and parts. Various design possibilities for elements at each tier are reviewed for compatibility with each other and with elements at higher-level tiers and ability to meet system specifications and cost, schedule, and performance requirements. The breakdown into tiers and components uses tools mentioned elsewhere (block diagramming, Chapter 2; requirements breakdown structure, Chapter 3; and work breakdown structure, Chapter 6).

The design process is composed of two interrelated activities. First is preparation of a *functional* (or logical) design that shows the functions of system components; their relationships; and flows of information, electricity, fluids, and so on: whatever moves among them. The purpose of this design activity is to ensure that the system's components individually and collectively provide the functionality necessary to satisfy the system's performance requirements. It is the thrust of systems engineering (Chapter 2) and system definition/FEL-3 (Chapter 4).

Second is preparation of a *physical* design that represents what the actual system and its components will look like and be made of—their sizes, shapes, relative positioning, and materials. This design activity results in engineering, manufacturing, architectural, and other types of drawings and models that reveal details necessary to later fabricate, assemble, and maintain the system. The physical design sometimes reveals limitations in the functional design because of space, cost, materials, appearance, or other considerations, in which case the functional design must be redone.

See Chapters 2 and 4

Design often follows an evolutionary, trial-and-error process, as illustrated in Figure 2.7 in Chapter 2 and Figure 4.7 in Chapter 4. A trial design is prepared, modeled, and tested against system requirements. If it fails, the design is modified and retested. This design-build-test iteration happens in virtually all projects for developing new systems.

See Chapters 2 and 4

When the end-item system is complex, the iteration occurs in many places for elements and subsystems throughout the system, and necessary changes in one have a ripple effect on the others. For instance, one subsystem might have to be enlarged, which robs space from another subsystem, which then has to be moved to elsewhere, and so on. Uncontrolled, the result is an almost never-ending series of redesign iterations, as illustrated next.

Example 5.1: Design Complexity in the Chunnel[2]

One of the mandated requirements for the English Channel Tunnel (Chunnel) project was that trains running through it must be resistant to fire damage for at least 30 minutes; this would enable every train car to be capable of making it out of the tunnel with a fire raging inside. But the frame of a normal train car would deform from the heat, and the train soon would become immobile, so special metal alloys would have to be used. This, however, would make the trains heavier, 2,400 tons instead of 1,600 tons, and would require heavier locomotives needing six axles instead of four. The locomotives would have to be specially designed, and because they needed more power, the tunnel's power system would have to be changed, too.

Design and production/build do not always occur as discrete, sequential stages but sometimes overlap. In other words, building a portion of the system commences as soon as *some* of the design is completed, then building another part begins as soon as more of the design is completed, and so on. The system is built while it is being designed—a practice referred to as *fast-tracking*. Fast-tracking is common in the construction industry: the foundation is being dug and steel raised even though the roof and interior are still being designed. The practice speeds up work and can save up to 1 year on a major construction project, but it can be risky. Design problems often surface only after the details have been worked out, but by then, portions the building will have been fabricated and might have to be rebuilt—increasing costs and schedules. The usual sequential or "slow-tracking" method takes longer but allows more time to discover and resolve design problems before construction begins.

Interaction design[3]

Why is it that so many software-based products are difficult to use and contain obscure or irrelevant features that most people don't need or want? Examples are software products for home computers, cell phones, and entertainment systems—all of which contain numerous features and functions that most people do not need and never learn to use. Yet in an effort to continuously "improve" the product, developers keep adding more features, a process that leads to "bloatware." Compare, for instance, all the things you presumably *could do* with word-processing software or your cell phone with the few features you actually use. Not only do such products contain too many features, they intermix seldom-used features with often-used ones, making the whole product more difficult to understand and use. In the eyes of customers, they are too complex.

Complex systems have always existed, but in the past, they were operated by *trained* personnel. Farm and construction equipment, aircraft, trains, and electrical turbine generators are complex, but they are used by trained personnel, not the average person. Commercial products (software, automobile console, cell phone, etc.) are complex, too, but they are used by amateurs, not skilled operators.

Complexity and bloatware happen when product goals and user requirements are poorly defined, no one ensures the design meets user requirements, and user-system interaction is not a key design issue. They also happen when design is *controlled* by engineers and programmers, people who are technically astute but tend to be ignorant of "interaction design"—an aspect of design that addresses how the product's functions and the user interact. Whenever programmers or marketing managers insist on adding another product feature, they are contributing to bloatware and ignoring the impact on the average end-user.

The project manager and systems engineer must retain control over the design process, particularly the interaction design. This starts with knowing the end-users and their wants, aptitudes, and skill levels; incorporating these when defining user requirements; and thereafter considering how every decision that influences the function and operation of the product will affect the end-user.

Controlling design

See Chapters 10 and 13

Project reviews, discussed in Chapters 10 and 13, are scheduled to occur at key milestones. Ideally, they are attended and headed by experts to ensure that the functional design satisfies requirements and the final design meets the users' needs and budget.

See Chapter 13

Throughout the design stage, changes to earlier designs might be necessary due to new technology, technical obstacles, or new requirements. Since these inevitably require alterations to planned work, the project manager must monitor the project for changes; determine their impacts on work plans, schedules, and budgets; and relay these impacts to stakeholders for approval. All this is handled through a *change control system*, as described in Chapter 13.

Design changes tend to increase project costs, but, as shown in Figure 5.2, design costs are typically but a small fraction of production costs. Consequently, prolonging this stage to get the design right (the first time) tends to be far less costly than continuously changing the design or fixing design-related problems that crop up later in the project. But the design stage cannot be allowed to continue indefinitely,

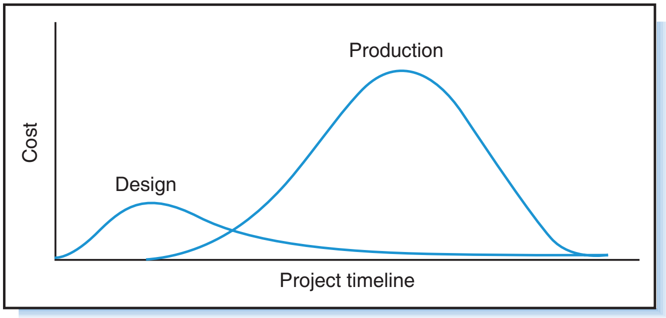


Figure 5.2
Relative costs for design and production.

and sometimes the project manager imposes a "freeze date" after which no discretionary design changes are allowed.

Project management is responsible for ensuring that design efforts and outcomes are adequately documented. Success in the production/build and subsequent stages depends in part on everyone knowing the end-item design and its features, functions, configuration, strengths, and limitations, which is the purpose of good documentation (specification, drawings, etc.).

Planning for production/build and later stages

Throughout the design stage, the project manager is looking ahead and planning for the next stage: production/build. This planning addresses all aspects of production/build—the needed tools, equipment, and materials; procedures for assembly, testing, and packaging—and includes preparing a detailed production/build schedule. If production/build is to begin before the design stage is fully completed, the production/build planning will have to be done in stages.

Important to note is that the plan for production/build must account for all the systems, activities, and resources necessary to *produce, operate,* and *maintain* the end-item system. This includes "side items" (so called to distinguish them from the main end-item of the project) such as special tools, instruments, spare parts, reports, drawings, courses of instruction, and manuals. Side items are no less important than the main end-item; in fact, without them, it would be impossible to produce, operate, or maintain the end-item. Although side items are usually developed and produced by other companies, the manager of the overall project is responsible for ensuring they have all been identified, that contractors are developing and producing them, and they will be ready for usage when the main end-item has been completed. This is discussed later.

5.3 Production/build stage

Detailed designs in hand, the project team is ready for production/build. For mass-produced items, this means the system is ready for production/manufacture; for one-of-a-kind items, it means the system is ready to build/assemble. The main activities in this stage are system fabrication, testing, and planning for implementation.

System fabrication and testing

System fabrication, another word for assembly, building, or construction, begins as soon as design work has been sufficiently completed. Components prepared by contractors and suppliers are assembled into the final end-item. As in earlier stages, the project manager monitors the work; coordinates efforts among departments/subcontractors; and tracks progress against project plans, budgets, and schedules. During this stage, the project manager and manager of manufacturing, construction, or fabrication share responsibility for the principal management tasks of releasing work orders; monitoring, inspecting, and documenting progress; comparing planned versus actual results; and taking corrective action.

During system fabrication, work quality is constantly assessed. As with most tasks in the production/build stage, quality control is not, per se, the responsibility of the project manager; nonetheless, because the project manager *is* responsible for the quality of the final system, she must ensure that other managers in the production/build stage have implemented a quality plan (discussed in Chapter 10) that ensures meeting the project's quality objectives.

See Chapter 10

Throughout production/build, numerous tests might have to be performed on the components, subsystems, and final end-item to ensure everything conforms to requirements (aspects of testing are discussed in Chapter 10). The project manager oversees test plan preparation; includes test plans in the production/build plan; and ensures that the necessary test resources are available, tests are performed as scheduled or necessary, and test results are documented and filed for later reference.

Planning for implementation

See Chapter 4

With phased project planning, discussed in Chapter 4, details of the project plan are filled in as the project progresses and more information becomes available. During each project stage, a detailed plan for the next stage is prepared. Although planning for implementation should start very early in the project, usually it is not until the production/build stage that details of the implementation plan can be completed. The implementation plan must be such that upon or before completion of the production/build stage, implementation can begin.

Implementation is the process of turning the system over to the user. Two main activities in implementation are installing the system in the user's environment and training the user to operate the system; thus, the plan must ensure that needed side items will be available in time for both sets of activities.

In projects where a new system is to replace an existing system, the plan must address the strategy to be used for orchestrating the replacement, including the:

1. Approach for converting from the old system to the new system.
2. Approach to phasing out the old system and reassigning personnel.
3. Sequencing and scheduling of implementation activities.
4. Acceptance criteria for the new system.

An initial implementation plan might have been developed as part of the initial project execution plan. Now, a more detailed implementation plan is prepared with the participation of customers and other stakeholders. As this plan is being prepared, the project team accumulates materials for preparing the user to operate and maintain the system. For complex systems, these materials include manuals for system operation, repair, testing, and servicing; training materials and simulators; manuals for training the trainers; and schematic drawings, special tools, and equipment for servicing and support. These are among the side items mentioned previously.

Agreement must be reached with the customer about how and when the project can be closed out—that is, how and when the customer will consider the system acceptable and the project completed. Misunderstandings about this, such as "acceptance only after modification," can cause a project to drag indefinitely; to prevent this, user requirements defined early in the project should include conditions or criteria for customer acceptance of the system. This is discussed next.

5.4 Implementation stage

In the implementation stage, the end-item system or other deliverable is turned over to the user for operation. Sometimes implementation happens in an instant; sometimes it takes much longer. Take a clock. If the clock is simple, you just plug it in and set it. If it is a digital alarm clock with a radio, you might first need to read the instructions. If it is a nuclear clock such as the one used by the US Naval Observatory, you might need to attend several weeks of training. If the clock is to replace an existing clock connected to a timing device that controls lighting in a large skyscraper, you will need to develop a strategy for swapping the new/old clocks so as to minimize inconveniencing people in the building. There can be many issues associated with implementation, starting with user training and acceptance testing.

User training

User training informs the user how to operate, maintain, and service the system. At one extreme, training is a simple instruction pamphlet; at the other, it is an extensive, ongoing program with a hefty annual budget. User training starts with determining the training requirements—the type and extent of training required. This will dictate the kinds of training materials needed (manuals, videos, simulators), personnel to be trained (existing or newly hired personnel), training techniques to be used (classroom, online, independent study, role plays), training schedule (everyone at once, in phases, or ongoing), and staffing (contractor, user, or subcontracted training personnel). Users should review and approve all training procedures and documents before training begins and provide feedback afterward to improve the training. Often the user takes over training after the contractor's trainers have trained the user's trainers.

User training should address the issue of how the new system will fit into the user's environment. It should provide an overview of the system's objectives, scope, and operation and how the system interfaces with the user organization. This will enable users to understand the new system within their environment and integrate it with existing systems. New systems create fear, stress, and anxiety; one aim of training should be to reduce or eliminate these.

User acceptance testing

Among tests performed on the end-item before or during installation are the user acceptance tests. The results of these tests determine if the system can be adopted or installed as is, needs modifications or adjustments, or should be rejected.

User acceptance tests differ from tests conducted by the contractor project team during the design and production/build stages, although those tests should anticipate and be rigorous enough to exceed the user acceptance test requirements. Nonetheless, the contractor should be prepared to make modifications pending the results of the user's tests.

Ideally, users perform acceptance tests with minimal assistance from the project team. In cases where they cannot, the project team must act as surrogate users and make every effort to test the system just as the user would, which means assuming the role of someone who—in many cases—is devoid of system-related technical expertise. Lack of user participation in these tests can lead to later problems, so the project team should insist that, minimally, the user be on hand to witness the tests.

System installation and conversion

System installation and conversion is conducted according to the implementation plan. During this stage, equipment is installed, tested, fine-tuned, and deemed operable to the fulfillment of requirements.

Virtually all new systems are, in a sense, designed to substitute for existing systems, so picking the strategy for replacing the old system with the new is of major importance. This process is called *conversion*. Three possible strategies, illustrated in Figure 5.3, are

Parallel installation: both new and old systems are operated in parallel until the new system is sufficiently proven.

Pilot operation: the new system is operated in a limited capacity until proven and then is fully phased in as the old system is phased out.

Cold turkey (big bang—immediate replacement): in one fell swoop, the new system is moved in and the old one is moved out.

Selecting a conversion strategy is no simple matter; it involves considerations of costs, risks, and logistics. The first strategy, parallel installation, seems safest: if the new system fails, the old one is still

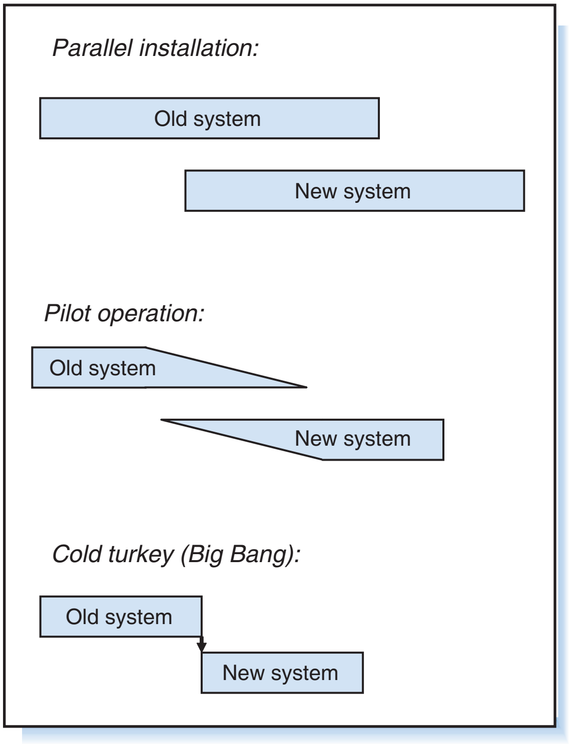


Figure 5.3
Three strategies for system conversion.

there. But it is also the most expensive because two complete systems must be operated simultaneously and fully staffed. With the second strategy, pilot operation, the costs and risks are low, and staff can be trained in stages. The drawback is, pilot operation is not necessarily representative of full system operation, and only after the new system has been completely phased in (and the old one phased out) will problems become apparent. The last strategy is the fastest and potentially least costly, but it is also the most risky and raises issues about when the staff will be trained to operate the new system and what will happen if the new system fails.

Prior to installation, the project manager updates all plans and schedules, gains approvals for revisions, and renews commitments from the contractors and customer. Implementation is a high-stress stage, and the project manager and team must be patient with users and sensitive to their questions, concerns, and fears.

After the new system has been installed, the contractor continues to monitor and perform tests on it to ensure it was installed properly, operates as expected, and interfaces smoothly with other systems in the user environment.

Side items

The installation, operation, maintenance, and monitoring of the contract end-item is often contingent upon availability of numerous necessary ancillary articles—*side items*. Side items are usually provided by subcontractors and can range from the simple and mundane to the complex and innovative. The former is exemplified by an operating manual for a network server, the latter by a high-fidelity computer simulator for training operators on a large chemical processing facility. Simple or complex, successful completion of side items is important to successful completion of the project.

Side items are deliverable contract items, and their cost may contribute to a significant percentage of total project cost. Yet perhaps because they are deemed "side" items, the time and effort required to develop and produce them is often underestimated. The result is delay in implementing the end-item and closing the project.

Side items should be included in all aspects of project planning and control. The project manager must make certain that the scope of side-item work is well understood and qualified personnel or contractors are assigned in advance to fulfill their requirements.[4] They must be considered part of the contracted work, not afterthoughts or project extensions, and included in the WBS, project schedule, and budget.

5.5 Project termination and closeout

By the time the end-item has been installed, members of the project team will be eager to move on to something new. Managers eagerly shift emphasis to upcoming projects and, as a result, might give little attention to termination/closeout. Yet, as common sense would indicate, the way a project is concluded should receive no less attention than any other project activity. In fact, the method of termination can ultimately determine the project's success or failure.

Termination can occur in a variety of ways, the best way being in a planned, systematic manner. The worst ways are abrupt cancellation, slow attrition of effort, or siphoning off of resources by higher-priority projects. Some projects are allowed to simply "limp along" until they fizzle out. Unless *formally* terminated, a project can drag on indefinitely, sometimes from neglect or insufficient resources, sometimes intentionally for lack of follow-up work. In the latter case, workers remain on the project payroll even after work has been completed. Unless the project is officially terminated, work orders remain open and labor charges continue to accrue.

Reasons for termination

The seeds of project success are sown early: since success depends in large part on customer acceptance of the project results, the project manager must make sure during project definition that the acceptance criteria are clearly defined, agreed upon, and documented and any changes made during design or production/build are approved by the contractor and customer.

There are many reasons projects do not reach successful completion. A project might be aborted because the financial or other losses from early termination are considered less than the losses expected from completing the project. The project might be perceived as a "white elephant" with low payoff or likelihood of success. The customer might simply change his mind and no longer want the project end-item.

Projects are also terminated because of changing market conditions or technology, unsatisfactory technical performance, poor quality of materials or workmanship, violation of contract, or customer dissatisfaction with the contractor. Many of these reasons are the contractor's fault and could have been avoided had project management exercised better planning and control, respected the customer more, or acted in a more ethical manner. Both sides suffer financially and otherwise: the user requirements are left unmet, and a pall is cast over the contractor's technical competency and managerial ability.

Termination and closeout responsibilities

As with all other project work, the project manager is responsible for planning, scheduling, and controlling termination and closeout activities. Much of this activity falls under the heading of contract administration, discussed more fully in Chapter 12.

See Chapter 12

Archibald lists the following responsibilities.[5]

A. Planning, scheduling, and monitoring closeout activities:
- Obtain and approve termination plans from involved functional managers.
- Prepare and coordinate termination plans and schedules.
- Plan for transfer of project team members and resources to other projects.
- Monitor completion of all contractual agreements.
- Monitor the disposition of any surplus materials and project equipment.

B. Final closeout activities:
- Close out all work orders and contracts with subcontractors for completed work.
- Notify all departments of project completion.
- Close the project office and all facilities occupied by the project organization.
- Close project books.
- Ensure delivery of project files and records to the responsible managers.

C. Customer acceptance, obligations, and payment activities:
- Ensure delivery of end-items, side items, and customer acceptance of items.
- Notify the customer when all contractual obligations have been fulfilled.
- Ensure that all documentation related to customer acceptance as required by contract has been completed.
- Expedite any customer activities needed to complete the project.
- Transmit formal payment and collection of payments.
- Obtain from customer formal acknowledgment of completion of contractual obligations that release the contractor from further obligation (except warranties and guarantees).

Responsibility for group C, particularly for payment and contractual obligations, is shared with the project contract administrator, who is responsible for company–client negotiations and contracts. The final activity, obtaining the formal customer acknowledgment, may involve claims by the contractor in cases where the customer failed to provide agreed-to data or support or requested items beyond contract specifications. In such cases, the contractor is entitled to compensation.

Before the project is considered closed, the customer reviews the results or end-item with the contractor to make sure everything is satisfactory. Items still open and in need of attention, and to which the contractor agrees, are recorded on a list, sometimes called a "punch list." The contractor checks off the items on the list as they are rectified.

Example 5.2: Punch List for the Chunnel[6]

Five months before the scheduled completion date of the Chunnel, the punch list still contained over 22,000 items. Incredibly, by one day before scheduled handover of the Chunnel to its owner/operator, that number had been whittled down to only 100. Problem was, the contract allowed for *no* (zero) items on the punch list; any open items at the handover would void the agreement and stop payment. A simple solution would be to delay the handover until the remaining items were fixed, which was estimated to take only a week. But few things associated with the Chunnel were simple. Invitations for the handoff ceremony had already gone out, and preparations for the big gala celebration had been completed. Besides, a syndicate of some 200 banks located around the world had financed the project, and any proposed delay in the handover would require their approval.

What followed was a series of frenzied, harried negotiations via telephone and fax that lasted throughout the night. By dawn, the bank syndicate had agreed to amend the contract. The gala signoff ceremony went off as planned, complete with fireworks, champagne, a choral group, and a Dixieland jazz band. The ceremony—attended by corporate executives and project managers from the Chunnel's ten prime contracting companies plus a thousand other guests—was a minor project in itself.

The importance of doing a good job at termination cannot be understated; neither can the difficulty. In the rush to finish the project and the accompanying confusion, it is easy to overlook, mishandle, or botch. The termination responsibilities listed previously should be systematically delegated and checked off as completed.

Delivery, installation, and user acceptance of the main contract end-item (hardware, software, or service) does not necessarily mean that the project is closed. As mentioned, project completion might be dependent on the availability of necessary side items, without which the customer would not be able to effectively operate or maintain the main end-item.

Closing the contract and negotiated adjustments

In many projects, the contractor receives payment up front for only a portion of the total project cost, say 80 to 90 percent; the remainder is contingent upon the performance of the end-item, the contractor's compliance with contractual agreements, or the quality of the working relationship with the contractor.[7] The contractor might have to repay the customer for any advances received; alternatively, the customer might have to pay the contractor for work underway but not completed/accepted.

These payment adjustments are considered *post-acceptance* issues because they occur after the customer has accepted the major end-item. If the delivered end-item is satisfactory but found to not perform fully to the contracted specifications, to be defective after a trial period due to design or production inadequacies, or is delivered late, the contractor might have to pay a negotiated compensation to the customer. If the final end-item is found to be deficient after installation or delivery, the contractor might be obligated to provide on-site user support, at no additional fee, to remove any operating deficiencies.

Sometimes the customer or contractor seeks to negotiate aspects of the contract price or completion date *after* the project is completed. The US government retains the right to negotiate overhead rates *after* it receives the final price on cost-plus contracts. Likewise, a contractor sometimes seeks to negotiate a revised completion date on the contract *after* the project is completed—usually because it overran the scheduled date and wants to salvage its reputation.

It should be noted that all of the previous applies not only to contractor–customer agreements, but to contractor–subcontractor agreements as well.

5.6 Project summary evaluation

Among final activities of the project team after project closeout is to perform a formal evaluation. This final *summary evaluation* gives project and company management the opportunity to learn from past successes and mistakes. Without a summary review, there is a tendency to mentally suppress problems encountered and to understate the impact of errors or misjudgments—“Things weren't really so bad, were they?” Project summary evaluation reviews and assesses the performance of the project team and the end-item system. It addresses the questions “What happened, what were the results, and what if anything remains to be done?” Decidedly, its purpose is *not* to find fault or place blame on anyone. It is the central theme of the “post-project” and “confirm benefits” stage of the PRINCE2 project methodology. Two forms of summary evaluation are the *post-completion project review* and the *post-installation system review*.

Post-completion project review

The *post-completion project review* (perversely also called the *postmortem*) is a summary review and assessment of the *project*, conducted by the project team immediately after project closeout—early enough so that project team members are still around to participate and remember what happened.[8] It is an important task for which funds and time should be included in the project budget and schedule. Post-completion reviews are one way companies try to continuously improve future projects through lessons learned from past projects—an opportunity that many companies forego.

The post-completion project review should evaluate

1. Initial project objectives in terms of technical performance, schedule, and cost and the soundness of objectives given the needs and problem the end-item system was to resolve.
2. Changes in objectives and reasons for changes, noting which changes were avoidable and which not.
3. The activities and relationships of the project team throughout the project life cycle, including the effectiveness of project management; relationships among top management, the project team, functional departments, and the customer, as well as customer reactions and satisfaction.
4. The involvement and performance of all stakeholders, including subcontractors and suppliers, the client, and outside support groups.
5. Expenditures, sources of costs, and profitability.
6. Areas of the project where performance was particularly good, noting reasons and identifying processes that worked especially well.
7. Problems, mistakes, oversights, and areas of poor performance and the causes.
8. A list of lessons learned and recommendations for incorporating them into future projects.

The review happens in a half- or day-long meeting with representatives from *all* functional areas that substantially contributed to the project. To encourage openness and candor, the managers of these areas should *not* be at the meeting. An outside facilitator might be selected to guide the review and to ensure it is comprehensive and unbiased. At the meeting, participants independently make notes on what went right and wrong with the project; they then share their notes and create lessons-learned lists and recommendations for future projects. These are formally shared with stakeholders; others on the project team; and project, functional, and senior managers.

The review seeks to determine lessons that may be applied to future projects, not to criticize or place blame. The results are documented in a *project summary report*, which becomes the authoritative document on the project. The report describes the project, its evolution and outcomes, the project plan, and what worked and what did not. Because projects affect different parties in different ways, opinions of the customer, project team, and upper management should be listed separately.

The project summary report becomes the reference for project-related questions that might arise later. Thoroughness and clarity are essential, since people who worked on the project usually will not be available later to answer questions. The report is retained in a project library, and its lessons learned and recommendations are promoted in other projects, sometimes by the project management office. The post-completion review is a way to capture and reapply knowledge to future projects—a tool for project *knowledge management*, discussed in Chapter 18.

See Chapter 18

Example 5.3: Microsoft Postmortems[9]

Product development projects at Microsoft often conclude with a written postmortem report that is circulated to team members; senior executives; the directors of product development, coding, and testing; and the highest levels of management, which for major projects includes the company president. A report can take as much as 6 months to prepare and range from under 10 pages to over 100 pages in length. Its purpose is to describe what worked well in the project, what did not, and what could be done to improve future projects. Descriptive information is also included, such as *the size of the project team, duration of the project, aspects of the product* (size in thousand-lines-of-code [KLOC], languages and platform used), *quality issues* (number of bugs per KLOC, type and severity of bugs), *schedule performance* (actual versus planned dates), and the *development process* (tools used, interdependencies with other groups). Functional managers prepare the initial draft and then circulate it via e-mail to other team members for comment.

Post-installation system review

The post-completion project review focused on the *project*. Several months after installation, a review of the performance of the *end-item system* in the user environment and under normal operational conditions should also be done. This *post-installation system review* serves multiple purposes, such as revealing potential or necessary enhancements to the system or providing information related to the system's operation and maintenance. Based upon the original user requirements, the post-installation system review attempts to answer the questions:

- Now that the system is fully operational, is it doing what it was intended to do—is it meeting user requirements?
- Is the user getting the benefits expected from the system?
- What changes, if any, are necessary for the system to better fulfill user needs?

It is important that the evaluated system be *unaltered* from the one delivered. Frequently the user makes modifications and improvements to the system after installation; although there is nothing wrong with this per se, the system will have been physically or functionally altered from the one installed, a fact that must be considered when evaluating its performance.

During the review, the evaluation team might discover elements of the system in need of repair or modification. Design flaws, operating problems, or necessary enhancements that could not have been foreseen earlier sometimes become obvious once the system has been in routine operation.

Results of the review are summarized in a report that describes the system's performance versus the requirements, any maintenance problems, and suggested possible enhancements. The post-installation system review and the project summary review are filed together and retained as references for planning future projects.

5.7 After the project—Phase D: operation

Beyond project termination, what happens next depends on whether the end-item or deliverable is a physical system that must be operated and maintained (e.g. a product, machine, or operating procedure) or is a service or event for which there is nothing physical to operate (e.g. a rock concert, company relocation, corporate merger, or audit). In the former case (i.e. the project results in a physical system or product), the systems development cycle enters Phase D, operation.

The contractor can remain involved with the customer and the system in the operation phase in two ways: (1) through ongoing evaluation, maintenance, or repair to the system or (2) through initiating a new project to enhance or replace the original system.

System evaluation, maintenance, and repair

The contractor may perform evaluation of the end-item system as part of the original contract agreement, either as a one-time scheduled activity in the form of a post-installation review, described previously, or as a warranty arrangement whereby the contractor reviews and maintains the system for a pre-specified time period. The contractor might sign an "extended" agreement with the customer to provide preventive maintenance and system repairs, upgrades, and overhauls on a continuing basis and assign *system representatives* and technicians to the customer site to perform these services on a scheduled basis or as requested by the user. Providing services for system maintenance, repair, and overhaul is commonly referred to as MRO.

Enhancing or replacing the system

When the customer wants to enhance or replace the originally contracted system, a new project emerges; from the original contractor's perspective, this is an *extension* to the original project, although it typically involves a whole new contract.

There are two kinds of project extensions: discretionary and essential. *Discretionary extensions* are requested by the customer or proposed by the contractor for the purpose of improving the operation, performance, or convenience of the original project end-item. The environment remains the same, but new and better ways now have appeared that can improve the system. The other kind, *essential extensions*, are compulsory; without them, the system will cease to operate effectively or become obsolete. An end-item that is no longer adequate because the environment has changed or the design has become deficient *must* be enhanced or replaced.

The decision to expand, enhance, or replace a system marks the beginning of a new systems development cycle, one that might be initiated with a new request (e.g. an RFP) or a new proposal from the contractor. The extension itself becomes a new project. Humankind engages in few dead-end projects; each spurs others, and the systems development cycle keeps rolling along—hence the term "cycle."

5.8 Summary

The execution phase includes the stages of *detail design*, *production/build*, and *implementation*. During the design stage, the system concept is subdivided into tiers of subsystems, components, and parts, and for each of these, designs, schematics, and models are created. The result is twofold, a *functional* design that represents the functions of the end-item system and its components and a *physical* design that shows the configuration, dimensions, materials, and other physical aspects of the end-item system and its components. During design, the emphasis must remain on meeting requirements of the end-users and avoiding ancillary, mostly unneeded features that result in bloatware, that is, overly complex and user-unfriendly products. In most projects, design costs are a small fraction of production/build costs; thus, prolonging this stage to get the design right is usually less costly than changing the design later in production/build to get it right. System design logically precedes production/build, although in a practice called fast-tracking, the two stages are overlapped: building begins after only some of the design has been completed. Throughout the execution phase, a major responsibility of the project manager is to control the project—that is, keep it on track and moving toward meeting requirements and targets as specified in the project plan.

In the production/build stage, the main activities are fabrication and testing. Components and the end-item system are assembled and tested to ensure that requirements for the system are met. The project manager is responsible for coordinating activities and controlling changes and ensuring quality of the end-item by its conformance to the design and system requirements. Throughout this stage, the project manager is preparing for the next stage: implementation.

Implementation is when the end-item system or other deliverable is completed and turned over to the user. Among the principal tasks during implementation are user training, user tests of acceptance, and system installation and conversion. The user is trained to operate, maintain, and service the system and then performs tests on the end-item system to determine if it is acceptable. Actual implementation of the end-item system and conversion from the old system to the new system requires following a strategy; the three main strategies are parallel, pilot, and cold turkey. Side items necessary for the operation and upkeep of the end-item system, often provided by other contractors, must be planned for and fully available upon or before implementation.

The last stage of execution is project termination and closeout. Every project should be terminated through a formal closeout procedure overseen by the project manager; this includes the closing of all work orders, project facilities, and project books and ensuring delivery of and customer acceptance of all end-items. The project is not considered closed until the customer has reviewed and approved everything promised about the end-item.

Following project close-out, a summary evaluation should be conducted. This evaluation has two parts: a post-completion project review (postmortem) to assess the effectiveness of the project organization and identify lessons learned and recommendations for future projects, and a post-installation system review to assess the end-item system's performance and determine possible maintenance or enhancement needs. The documented results of the project review and the system review are filed together as reference for planning and conducting future projects.

Project termination/closeout marks the end of the project and the end of the project life cycle. But in terms of the system development cycle, there might be one more phase, operation, which is that phase where the system is operated and maintained by the user. The contractor of the system can remain involved with the customer during the operation phase in two ways: (1) by agreeing to ongoing monitoring and upkeep of the system or (2) by conducting a new project to enhance or replace the system. In the former, the contractor continues to work with the customer in the assessment, maintenance, and/or repair of the system, either on a scheduled basis or as requested by the user. In the latter, the customer hires the contractor to enhance the end-item system or replace it with something entirely new—the beginning of a new end-item and a new project.

Review Questions

1. What is the practice of "fast tracking" or "design/build?" What are the associated potential benefits and dangers?
2. What happens during the design stage? Who is involved? What do they do? What is the role of the project manager? How are design changes monitored and controlled?
3. What is the role of interaction design in product design and development?
4. What does the plan for production/build include?
5. What happens during the production/build stage? How is work planned and coordinated? Who oversees the work?
6. What is the distinction between the project end-item and project side items? What role does the project manager have regarding each?
7. How is the system implemented? Describe the important considerations for turning the system over to the user.
8. Discuss user training and why it is sometimes included in the implementation stage.
9. How is the project end-item tested and checked out for approval?
10. Describe the different strategies for installing or converting over to the new system.

11. What are the reasons for project termination? How can termination for reasons other than achievement of project goals be avoided?
12. What is involved in planning and scheduling the project termination?
13. What is the role of the project manager and contract administrator in receiving customer acceptance of the work and final payment?
14. What are side items? Give examples not used in this book. How can they delay project completion?
15. What kinds of negotiated adjustments are made post-acceptance to the contract? Why would a user or contractor want to specify the terms of a contract *after* the project is completed?
16. What is a punch list?
17. What are project extensions, and how do they originate? How is a project extension managed?
18. What are the differences between the two kinds of project summary reviews: the post-completion project (or postmortem) review and the post-installation system review? Describe each.
19. Describe what happens during the operation phase. What role does the systems development organization (contractor) play in this phase?

Questions About the Study Project

As appropriate, answer the previous review questions 2, 5, 7, and 9 with regard to the study project. Also answer the following questions:

1. How was the project terminated? Describe the activities of the project manager during the final stage of the project and the steps taken to close it out.
2. If the end-item is a building or other "constructed" item, how was it turned over to the user? Describe the testing, acceptance, training, and authorization process.
3. How was the contract closed out? Were there any side items or negotiated adjustments to the contract?
4. Did any follow-up projects grow out of the project being investigated?
5. Describe the project summary review (postmortem). Who prepared it? To whom was it sent? How was it used? Where is it now? Show an example (or portion of one).
6. Was there a post-installation review of the product or project output? When? By whom? What did they find? Did the client request the review or was it standard procedure?
7. What happened to the project team after the project was completed?
8. Did the contractor or project manager remain involved with the customer and end-item through an extended agreement?

CASE 5.1 SLU INFORMATION CENTRAL BUILDING

Construction of the new Information central building at South Land University (SLU) is completed on time and on budget. Administrators at SLU and managers at Finley Construction Company, the building's prime contractor, are very pleased with the results. Besides meeting schedule and cost targets, the building and its equipment, including a variety of computer and technical gadgetry intended to augment learning, appear to have met all of the technical requirements. Much of the technology is leading edge, and some of it is being applied for the first time ever in a learning/teaching environment by SLU. By all accounts, the project is a success.

After reviewing and confirming that all of Finley's obligations for the project have been met, Jack Klackower, the project manager, meets with Sharon Holden, SLU's vice president of finance, and Ramat Ghan, SLU's vice president of facilities, to finalize details of project termination and payment. The meeting goes well and ends with discussion of future projects at SLU and possible involvement of Finley. After the meeting, Jack returns to his office, whereupon the director of Finley's PMO asks him if he planned to do a post-completion project review. "Nope," quipped Jack, "no need to. The project was a success and everything went just as planned."

A few months later, Sharon and Ramat give a final presentation on the project to SLU's president, reporting that it met all the technical and building requirements, the schedule, and the budget. In fact, they say, given the positive outcome of the project, some of the new technology in the building should be installed in other campus buildings and Finley hired to oversee it. "Not so fast," says the president. "I've heard reports that students and faculty find the new technology confusing, difficult to use, and maybe irrelevant. In fact, some rooms in the building are vacant for lack of use. Other rooms are crowded, but students go there to socialize or relax, not to take advantage of any sophisticated learning technologies. I don't know what the problem is—if it's with the technology or with the way Finley handled it."

QUESTIONS

1. Comment on Jack's neglect to conduct a post-completion project review. Is a review unnecessary whenever a project is considered a success?
2. Is the project really a success? What kind of follow-up steps should Finley and SLU have done after the project was completed?

Notes

1. Design output is normally catalogued in a master record index or data pack that lists all drawings, material specifications, and process specifications, for example, for materials heat treatment, welding, and so on. One guide for specification practices is MIL-STD 490A.
2. Fetherston D. *The Chunnel*. New York, NY: Times Books; 1997, pp. 198–199.
3. Cooper A. *The Inmates Are Running the Asylum: Why High-Tech Products Drive Us Crazy and How to Restore the Sanity*. Indianapolis, IN: Sams; 1999.
4. Hajek V. *Managing Engineering Projects*, 3d edn. New York: McGraw-Hill; 1984, pp. 233–240 describe monitoring and supporting side items for both engineering hardware and computer software projects.
5. See Archibald R. D. *Managing High-Technology Programs and Projects*. New York, NY: John Wiley & Sons; 1976, pp. 235–236, 264–270, for a complete checklist of closeout activities.
6. Fetherston. *The Chunnel*, pp. 372–375.
7. Hajek. *Managing Engineering Projects*, pp. 233–240 describes monitoring and supporting side items for both engineering hardware and computer software projects.
8. Williams T. *Post-Project Reviews to Gain Effective Lessons Learned*. Newton Square, PA: Project Management Institute; 2007; Whitten N. *Managing Software Development Projects*, 2d ed. New York: John Wiley & Sons; 1995, pp. 343–357.
9. Cusumano M. and Selby R. *Microsoft Secrets*. New York: Free Press; 1995, pp. 331–334.

Part III

Systems and procedures for planning and control

Project management extends beyond defining project objectives and requirements; it involves forming a project organization, identifying the necessary tasks and the resources to do them, and providing leadership to get the tasks done. Overall project objectives and system requirements need to be articulated into detailed plans, schedules, and budgets to accomplish the objectives and requirements. Methods are then needed to make sure the plans and schedules are carried out as intended.

Over the years, an impressive collection of methods has been developed to help project managers define, plan, and direct project work. The next nine chapters describe these methods, which include techniques and procedures for specifying, scheduling, and budgeting project activities; assessing risks; monitoring and controlling work; and organizing and keeping records to achieve project quality, time, and cost requirements.

Procedures should be conducted within a framework to ensure that everything to be done is accounted for, properly organized, and executed. These frameworks and the structures, activities, and systems that constitute them—work breakdown structures, cost accounting systems, information systems, and many others—are described in this section of the book.

Chapter 6

Basic project planning techniques

The journey of a thousand miles begins with one step.

—Lao Tzu

What is once well done is done forever.

—Henry David Thoreau

Every project is somewhat unique because it is aimed toward a result or end-item that is, in some way, unique. Because of its uniqueness, basic questions about the project must be answered before work can begin. Answering these questions so that the project will achieve its goals is the function of *project planning*. This chapter gives an overview of the project planning process and covers the topics of project scope and work definition and elementary scheduling.

6.1 Planning process

Once a project has been approved and the contract signed, the project work can begin. The first steps are to define the system requirements and prepare the project plan. For internal projects, a project charter is sent to announce the project and describe it to stakeholders.

The project manager, if not already assigned or involved, is now identified to oversee the planning process and produce a plan that elaborates on any earlier plans as prepared for the proposal, business case study, and/or charter.

Because of the uniqueness of each project, there is never an a priori, established way a project should be done. Each project poses new questions, and the purpose of planning is to answer them. In general, the planning process involves answering these questions, roughly in this order:

1. **What is the desired end result?**
   Define the project *objectives*, *scope*, and *system requirements*. These specify the project deliverables, end-items, and other sought-after results, as well as the time, cost, and performance targets.

2. **How will the result be achieved?**
   Define the *work activities*, tasks, or jobs to be done to achieve the objectives and requirements. These activities include everything necessary to create and deliver the end-item or deliverables, including planning, control, and administration activities.
3. **Who will do it?**
   Specify the *project organization*—the individuals or departments, subcontractors, and managers that will perform and manage the work—and specify their *responsibilities*.
4. **When and in what order?**
   Create a *schedule* showing the timing of work activities, deadlines, and milestone dates.
5. **How much?**
   Create a *budget* and *resource plan* to fund and support the project.
6. **How well?**
   Specify a method for *tracking and controlling* project work, which is necessary to keep the project conforming to the planned work, schedule, budget, and user and system requirements.

The result is the project plan or project management plan. Since the plan specifies what will happen in Phase C, project execution, we will refer to it as the *project execution plan*. This and the next eight chapters will discuss this plan in detail.

6.2 The project execution plan

Project planning begins early in the project life cycle—in most cases with preparation of the proposal. During proposal preparation, a proposal team or rudimentary project team is organized, and the team prepares a brief summary plan for inclusion in the proposal. They prepare this plan using the same, albeit more abbreviated, procedures as used later to develop a more elaborate and detailed project execution plan. The difference between a proposal summary plan and a project execution plan is that the former is aimed at the customer, while the latter is aimed at the project team.[1]

See Chapter 4

The plan in the proposal includes estimates for the project duration, cost, and needed resources—just enough information about the project and its price to enable the customer to make a decision. In contrast, the project execution plan lays out details of what will happen in the project, to be used as a roadmap to *guide* the project team throughout the project execution. As discussed in Chapter 4, the plan might contain details only for the immediate upcoming phase of the project, about which the most is known, with additional details for later project phases being filled in as the project progresses and more information becomes available.

Contents of execution plans

See Appendix C

Contents of execution plans vary depending on the size, complexity, and nature of the project. Figure 6.1 shows a template for a typical plan as outlined in Chapter 4.[2] Depending on the customer and type of project contract, the plan might require additional items not shown here;[3] in small, low-cost projects, it might be possible to bypass some of the items, being careful not to overlook the crucial ones. It is good practice to carefully review every item in the template, even if only to verify that some are "N/A" (not applicable). An example of the project execution plan is the plan for the LOGON project at the end of the book in Appendix C.

See Chapter 3

You might notice similarities between sections of the project plan and contents of the proposal, as displayed in Chapter 3, Figure 3.6. That's because the proposal, after revisions to reflect updates,

Project Execution Plan

I. Scope, Charter, or Statement of Work

Overview description of the project oriented towards management, customer, and stakeholders. Includes a brief description of the project, objectives, overall requirements, constraints, risks, problem areas and solutions, master schedule showing major events and milestones.

II. Management and Organization Section.

Project organization, management and personnel requirements.

A. Project management and organization: key personnel and authority relationships.
B. Manpower: Workforce requirements estimates: skills, expertise, and strategies for locating and recruiting qualified people.
C. Training and development: Executive development and personnel training necessary to support the project.

III. Technical Section. Major project activities, timing, and cost.

A. High-level **user requirements** and **system requirements**.
B. **Work breakdown structure**: Work packages and detailed description of each, including resources, costs, schedules, and risks.
C. **Responsibility assignments**: List of key personnel and their responsibilities for work packages and other areas of the project.
D. **Project schedules**: Generalized project and task schedules showing major events, milestones, and points of critical action or decision.
E. **Budget**: Control accounts and sources of financial support: Budgets and timing of all capital and developmental expenses for work packages and project.
F. **Quality plan**: Measures for monitoring quality and accepting results for individual work tasks, components, and end-item assemblies.
G. Areas of uncertainity, and **risk plan**: Risk strategies, contingency and mitigation plans for areas posing greatest risk.
H. **Health, safety, and environmental (HSE) plan**: To address HSE and sustainability matters affecting project workers, the community, and society arising from the project and its end-results.
I. **Communication plan**: Expected meetings, reports, participants, formats—formal and informal.
J. **Human resource plan**: Project organization, roles, responsibilities, staffing, and training.
K. **Work review plan**: Procedures for periodic review of work, what is to be reviewed, by whom, when, and according to what standards.
L. **Testing plan** (may be included in work review plan): Listing of items to be tested, test procedures, timing, and persons responsible.
M. **Change control plan**: Procedures for review and handling of requested changes or de facto changes to any aspect of the project.
N. **Documentation policy/plan**: List of documents to be produced, format, timing, and how they will be organized and maintained.
O. **Procurement policy/plan**: Policy, budget, schedule, plan, and controls for all for goods, work, and services to be procured externally.
P. **Implementation plan**: Procedures to guide customer conversion to or adoption of project deliverables.

Figure 6.1
Template for project execution plan.

agreements, and contract specifications, sometimes becomes the project execution plan. More often, however, the proposal serves as only an outline project plan, and the execution plan is much more expansive. The execution plan is aimed at the project team—to tell them what has to be done in the project, who will do it, when, for how much, and so on.

As illustrated in Example 6.1, sometimes developing a project execution plan is an evolutionary, cross-functional process.

Example 6.1: Developing a Project Plan for LOGON Project at Iron Butterfly Company

Iron Butterfly Company (IBC) is a medium-sized engineering and manufacturing firm specializing in warehousing and materials handling systems. It purchases most of the subsystems and components for its product systems from vendors and then combines them to meet customer requirements. The company was awarded a large contract by the MPD Company for a system to place, store, retrieve, and route shipping containers. The system, called the Logistical Online System, LOGON, is to be developed and installed at MPD's Chicago distribution center. Iron Butterfly is responsible for design, assembly, and installation of the system. Two of its contractors, CRC and CreativeRobotics, will provide the computer and robotics systems plus assistance with their installation and checkout. Frank Wesley, the IBC project manager, is in charge of preparing the project execution plan.

Most of the project plan for LOGON originated in IBC's project proposal. In preparing the proposal, engineers from IBC, CRC, and CreativeRobotics together conceived a system that covered MPD's requirements which included schematics, operational specifications, and a bill of materials. Design managers at CRC and CreativeRobotics estimated the labor expertise needed and the costs for parts and labor. Frank and his engineers prepared a work breakdown structure and estimates for IBC's time and costs. They then combined these with CRC's and CreativeRobotics' estimates to arrive at a plan, schedule, and price for the proposal.

After winning the contract, Frank met with his project engineer and managers from the fabrication, software, and purchasing departments to review the design, plan, costs, and schedules in the proposal and prepare a detailed execution plan. This plan contained similar information to the proposal but updated and expanded to include schedules for procured materials and parts, plans for labor distribution across work tasks, a task responsibility matrix, a detailed work breakdown structure and associated budget and master schedule.

The LOGON project execution plan evolved in stages: it was initially created during proposal preparation but then was expanded and modified after contract signing. In many projects, however, particularly for large, complex systems, the proposal serves only as a reference, and the bulk of project planning happens *after* the contract is signed (i.e. in Phase B, definition). Often, project planning is a significant effort that requires substantial time and labor.

Learning from past projects

Oftentimes, organizations look at each project as being *too* unique and ignore the lessons of past projects.[4] No project is totally unique, so in developing the project plan, it makes sense to refer to earlier similar projects and their plans, procedures, successes, and failures. Ideally, the project manager receives planning assistance in the form of lessons learned, best practices, suggested methodologies, and even consultation based upon experience from past projects. In some cases, this assistance is provided through the project management office, described in Chapter 18. Lessons learned and best practices are compiled by the PMO and based upon the *post-completion project reviews* (or *postmortems*) of past projects (described in Chapter 5).

See Chapters 5 and 18

6.3 Scope and statement of work

Project planning starts with defining the objectives, deliverables, and major tasks of the project; in combination, these determine the overall size of the project and the range or extent of work it encompasses: the concept of *project scope*. Determining the project scope happens during project conception, first when the project is initiated, then during preparation of the RFP and the proposal, and then again during project definition. In each case, user needs and requirements are compared to time, cost, resource, and technology constraints to determine what the project should and can encompass. This scope-setting process is called scope definition.

Scope definition

Scope definition involves specifying the breadth of the project and the span of its outputs, end results, or deliverables. Results or end-items to be produced or delivered by the project are termed “inclusions,” meaning they are *included* in the project. To ensure clarity, any result, items, or conditions *not* to be included in the project, called “exclusions,” are also defined. For example, a building construction project might exclude the building’s landscaping and interior decorating, and distinguishing such exclusions (possible customer responsibilities) from inclusions (contractor responsibilities) prevents misunderstanding and false expectations.

Scope definition focuses primarily on determining outputs and deliverables, not time and cost. Of course, time and cost delimit or dictate the potential deliverables; as such, they might be accounted for as “constraints” in the scope definition.

The outcome of scope definition is a *scope statement* that describes the main results, end-items, or deliverables of the project. The scope statement might also include: criteria for acceptance of the deliverables, assumptions and constraints (to provide rationale for why the project has these deliverables and not others), functions to be fulfilled by the deliverables, brief background about the problem being addressed or the opportunity being exploited, project objectives, user requirements or high-level specifications, and high-level project tasks or major areas of work. The input information needed for scope definition includes a set of user needs and requirements, a business case or other expression of needs, and assumptions and constraints; ideally, the principal subsystems and components of the end-item will have been identified and also serve as inputs. Besides everything to be included in the project or contract, including support and side-items (inclusions), plus work or deliverables not to be included (exclusions), the scope statement sometimes also lists outcomes or consequences to be *avoided*, such as negative publicity, interference with other systems, pollution, or damage to the natural environment. Rather than repeat the detailed requirements and specifications, the scope statement normally refers to other documents that contain them.

For a unique project, the preliminary scope statement defined during project initiation might be somewhat vague; it must, however, be expanded and clarified during project definition while detailed plans for the first phase of the project are being developed. For programs, separate scope statements are developed for the overall program and for the individual projects that make up the program.

Once the scope statement has been approved, it becomes a controlled document that can be modified only through a *formal change process*, described in Chapters 13.

See Chapter 13

Example 6.2: Scope Statement for the LOGON Project

The RFP for the LOGON project (see Appendix A, back of the ebook) sent by Midwest Parcel Distribution Company (MPD) specifies “The Contractor shall be responsible for furnishing expertise, labor, materials, tools, supervision, and services for the complete design, development, installation, checkout, and related services for full operational capability of the LOGON system." It also specifies the technical performance requirements for the system, as well as project exclusions, that is, "Removal of existing storage, placement, and retrieval equipment will be performed under separate contract."

Upon receiving the RFP, Iron Butterfly Company (IBC), one of the proposing contractors, decided that the best way to meet MPD's needs was with a system that employs robotic drone transporter units for placing and retrieving containers as instructed by a neural-network system. IBC analyzed MPD's technical and budget requirements and after a preliminary system design effort created the following scope statement for its LOGON proposal:

1. Project background: (short description of MPD's Chicago distribution facility and of the purpose and objectives of the LOGON system).
2. Description of the work to be done: design, fabrication, installation, test, and checkout of a transport, storage, and database system for the automatic placement, storage, and retrieval of standardized shipping containers.
3. Deliverables and main areas of work:
    a. Overall system: create basic design. Reference requirements A and B.
    b. Racks and storage-bucket system (termed "Hardware A"): develop detailed design. Storage-bucket system is Model IBS05 adapted to requirements C.1 through E.14.
    c. Robotic drone transporter units and tracking system (termed "Hardware B"): develop detailed design. RBU is Model IBR04 modified to meet requirements F.1 through G.13.
    d. Neural-network, database, and robotic-controller system: develop software specifications. Reference requirements H.1 through H.9 and K.3.
    e. Hardware A and Hardware B: procure software, subassemblies, and components. Reference requirements K.1 through L.9.
    f. Hardware A and Hardware B: fabricate at IBC site. Reference requirement M.
    g. Overall system: install and check-out at MPD site. Reference requirement Y.

Items 3a-g represent deliverables for different stages of the project; associated with each are specific requirements (i.e. "Reference requirements") listed in separate documents appended to the scope statement. For example, detailed design as noted in points 3b and 3c includes reference to requirements C.1–E.14 and F.1–G.13. The requirements must be comprehensive enough to enable subcontractors to produce the specified systems and components. Elsewhere the scope statement lists exclusions, either as noted in the RFP or identified by IBC.

The scope statement is the reference document for all project stakeholders; it becomes the basis for making decisions about resources needed for the project and, later, determining whether required or requested changes to work tasks and deliverables fall within the agreed-upon project scope. A common tendency in projects is *scope creep*, which means the project keeps growing due to changes in the number and/or size of deliverables. Scope creep, if not controlled, can lead to runaway project budgets and schedules.

The scope statement appears in many places—project proposals, charters, and plans. Often the scope statement is incorporated into the statement of work.

Statement of work

The statement of work is a description of the project; it includes a scope statement, but often it goes far beyond that; for example, it describes: specifications and requirements for deliverables, schedule for deliverables, management procedures for communication and handling risks and changes, project budget, and key personnel responsible for administrative and work tasks. The SOW is effectively a high-level version of the project execution plan.

The term SOW and its usage are commonly associated with *contracted* projects, and the SOW appears in documents associated with the contracting or procurement process. The RFP, proposal, contract, and project execution plan all contain SOWs, each an updated, expanded, or more refined version of the SOW in the previous document. The project charter might also contain a SOW.

6.4 Work definition

Once project objectives and deliverables have been set in the scope statement, the next step is to translate them into specific, well-defined work activities, that is, to specify the tasks and jobs that the project team must *do*. Particularly for large, unique projects, it is easy to include unnecessary activities or overlook necessary activities. To ensure that every necessary activity is identified and clearly defined and that no activities are missed, a procedure called the work breakdown structure is used.

Work breakdown structure

Complex projects consist of numerous smaller subprojects, interrelated tasks, and work elements. As described earlier in the book, the project main end result or deliverable can be thought of as a system that consists of subsystems, which themselves consist of smaller components, and so on. The method for subdividing a project into smaller elements is called the *work breakdown structure* or *WBS*, and its purpose is to divide the overall project into "pieces of work" called *work packages*. Dividing the project into work packages helps in preparing schedules and budgets and assigning work task responsibilities.

Creating a WBS begins with dividing the overall project into major categories. These categories are then divided into subcategories that, in turn, are each subdivided. With this level-by-level breakdown, the scope and complexity of work elements at each level get smaller. The objective is to reduce the project into many small work elements, each so clearly defined that the project can be easily planned, budgeted, scheduled, and monitored.

A typical WBS consists of the following four levels:

Level	Element Description
1	Project
2	Subproject
3	Work package
4	Activity

Level 1 is the total project. Level 2 is the project broken down into several (usually four to ten) major elements or subprojects. These subprojects must conform to the deliverables or work areas specified in the scope statement, and all of them when combined must constitute the *total project scope*. Each subproject is broken down into activities at Level 3. If a further breakdown is necessary, that occurs at Level 4. When the project is part of a *program*, a fifth level is added at the top, and the levels are renumbered: Level 1 is the program, Level 2 the project, and so on.

When the process is completed, tasks at the bottom levels, whatever those levels might be, are called *work packages*. In the table previously, the term "work package" appears at Level 3, but that is for illustration only. Later in the planning process, larger work packages might be subdivided into more detailed activities and the activities into still more detailed tasks.

The actual number of levels in the WBS varies by project, as do the actual names of the element descriptions at each level. Figure 6.2 shows a typical WBS. Note the different levels and descriptions for each work element.

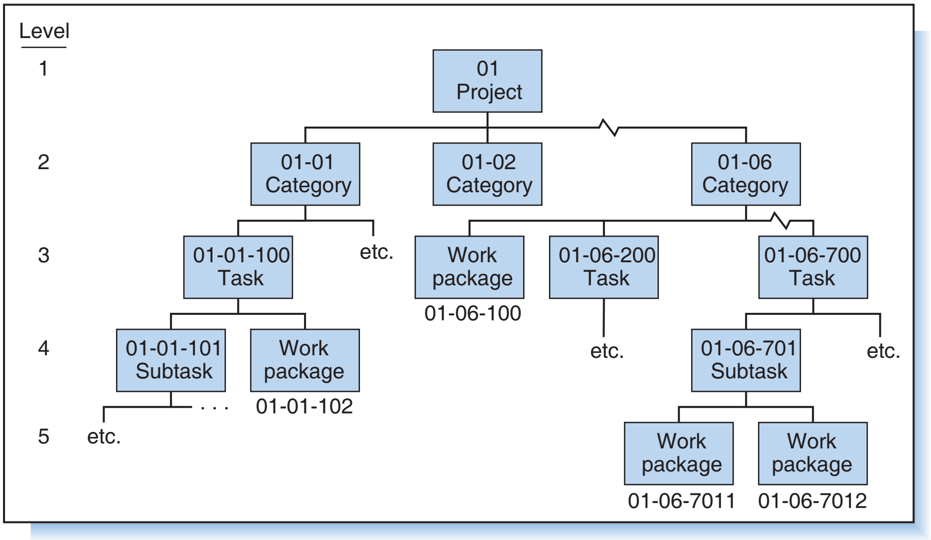


Figure 6.2
Elements of a WBS.

For a small project, it makes sense to break down the work to the activity level. For a large project, however, this would result in a WBS too big to be practical, so it makes better sense to break down the work to the work package level, then, for each work package, create a separate document that reveals details about the work package (see Example 6.4). All the work package documents can be combined into a "WBS dictionary."

The WBS process happens somewhat naturally, starting with the list of user and system requirements. These requirements suggest the main system, end-item, or deliverables of the project and the major subsystems and components; they also suggest which of these results will be met externally (by suppliers/subcontractors) and which internally. These major subsystems and components are boxes on the WBS. Those boxes are then logically subdivided into smaller components of the system and the work tasks to create or acquire them. For technical and engineering projects, the WBS should include all of the configuration items and major components of the system, as well as the work tasks to design, develop, build, and test them.[5]

The WBS becomes the basis for assigning project responsibility and contracting. For contracted work, responsibility for each subproject or activity is assigned to a subcontractor through a contract agreement between the subcontractor and the project manager. For internal projects, responsibility for each subproject is assigned to an in-house department through an agreement between the department manager and the project manager.

To avoid unnecessary complexity, the number of levels in the WBS should be limited. For a large project, a five-level WBS might be necessary, but for most small projects, a three-level WBS is adequate. To organize and help track project activities, each work element is coded with a unique identifier, where the identifier at each level is based on the identifier at the next higher level. In Figure 6.2 Project "01" has six categories numbered 01–01 through 01–06; then, for example, category 01–06 has seven tasks numbered 01–06–100 through 01–06–700. The project manager establishes the numbering scheme.

Figure 6.3 illustrates ways to create the WBS for constructing a house. The top part of the figure (*hardware, product-oriented WBS*) shows the main project end-item (Level 1) and the physical components of the house to be included (Level 2). By subdividing a project in this way—according to physical products or deliverables, it is easy to attach performance, cost, and time requirements to each item and to assign responsibility for meeting those requirements. That is, creating a WBS in this way assists in preparing the project schedule and budget. The bottom part of Figure 6.3 shows how the product-oriented WBS would be subdivided into four levels.

Sometimes the WBS or portions of it are divided by work tasks or functions (*functional-oriented* or *task-oriented*, rather than product-oriented). For example, the middle part of Figure 6.3 shows the project subdivided

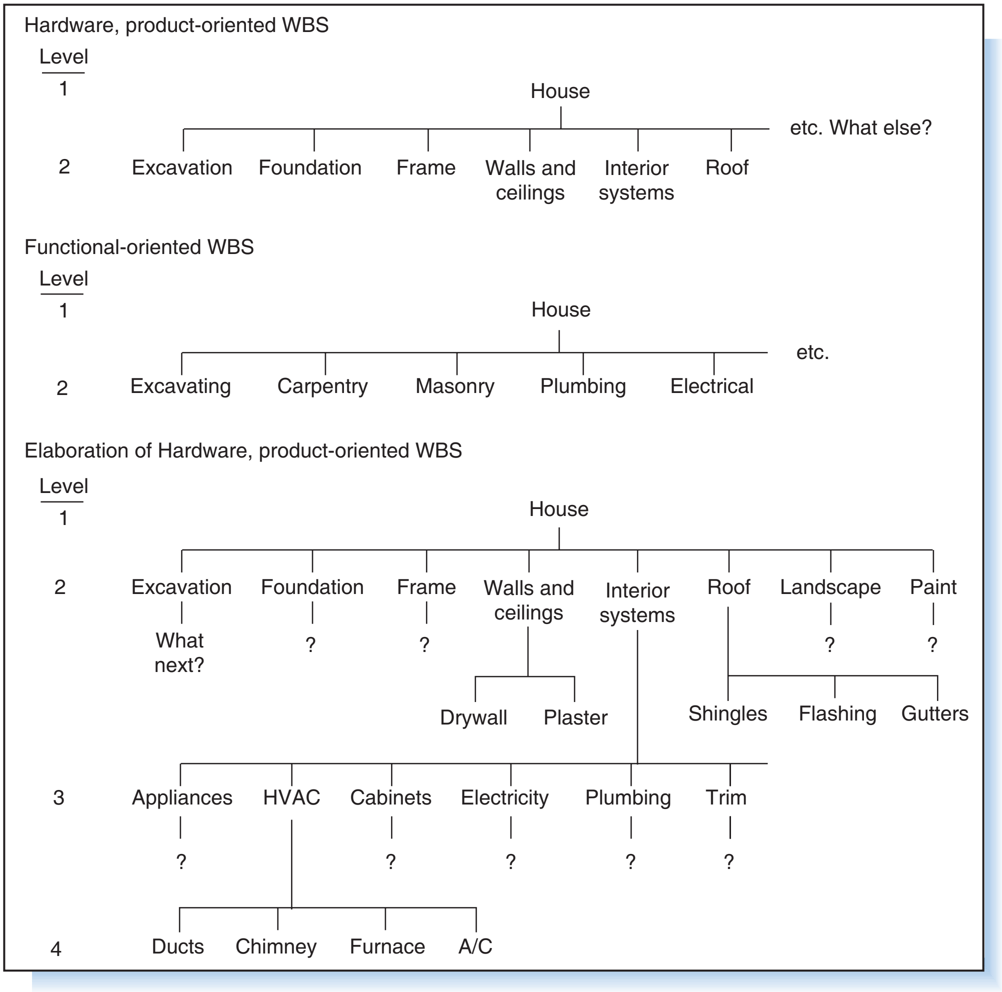


Figure 6.3
Example of WBS for building a house.

according to the work functions of excavating, carpentry, and masonry. All functions or tasks (e.g. management overhead, design, engineering, training, inspection) that apply to deliverables or to *integrating* multiple deliverables should be identified as separate work packages. Whether to use a product, functional, or other form of breakdown in the WBS is a matter of preference, sometimes as stipulated by the organization.

During the WBS process, the question "What else is needed?" is constantly being asked. Supplementary or missed elements are identified and added to the WBS at appropriate levels. For example, the bottom WBS in Figure 6.3 does not include blueprints, budgets, and work schedules, even though the house cannot be built without them. These are deliverables associated with managing the project and designing the house, which could be included in the WBS by inserting in Level 2 boxes for "design" and "project management" and then at Level 3 inserting "blueprints" under Design and "budget and work schedules" under Project Management. Somewhere in the WBS, tasks related to permits and licenses, environmental impacts, and so on must also be included. As discussed in Chapter 12, the WBS must also reflect any procured (contracted or outsourced) work and materials.

See Chapter 12

The concept of traceability, mentioned in Chapter 4, applies directly to the WBS. One test for the completeness of the WBS is to compare the list of project objectives and high-level requirements with work packages in the WBS. Every objective and requirement should be traceable to at least one work package. If an objective or requirement cannot be traced to a work package, then the objective will likely not be met. The reverse also applies: every work package should be traceable to at least one objective or high-level requirement. If it can't be, the question is, why is it in the WBS?

Figure 6.4 exemplifies the WBS for a large engineering project where the main deliverable and many of its subsystems and components must be developed, built, integrated, and tested from scratch. Notice some portions of it are hardware, product oriented (vehicle, facilities), while others are functional oriented (test/evaluation, project management/systems engineering).

As the WBS process progresses, the question always arises "Should we do this work ourselves or should we procure it (meaning buy it or contract someone to do it for us)?" Most projects involve at least some procured goods, materials, or services, and in some projects, most everything is "procured" and virtually nothing is done or produced "internally." Whether project work should be done internally or procured from outsiders is the result of a make-or-buy analysis of the project end-item and of its subsystems, components, services, or deliverables identified in the WBS. The process by which this happens and how it is integrated into project planning is the subject of procurement management and Chapter 12.

See Chapter 12

In general, the larger and less standardized the project, the easier it is to overlook something and the more valuable the WBS process is to avoiding that. In large projects, the initial WBS is usually rather coarse and shows only major products or work functions and aspects of each to be allocated to specific contractors. Before work commences, however, details of each product or function must be more fully developed in the WBS.

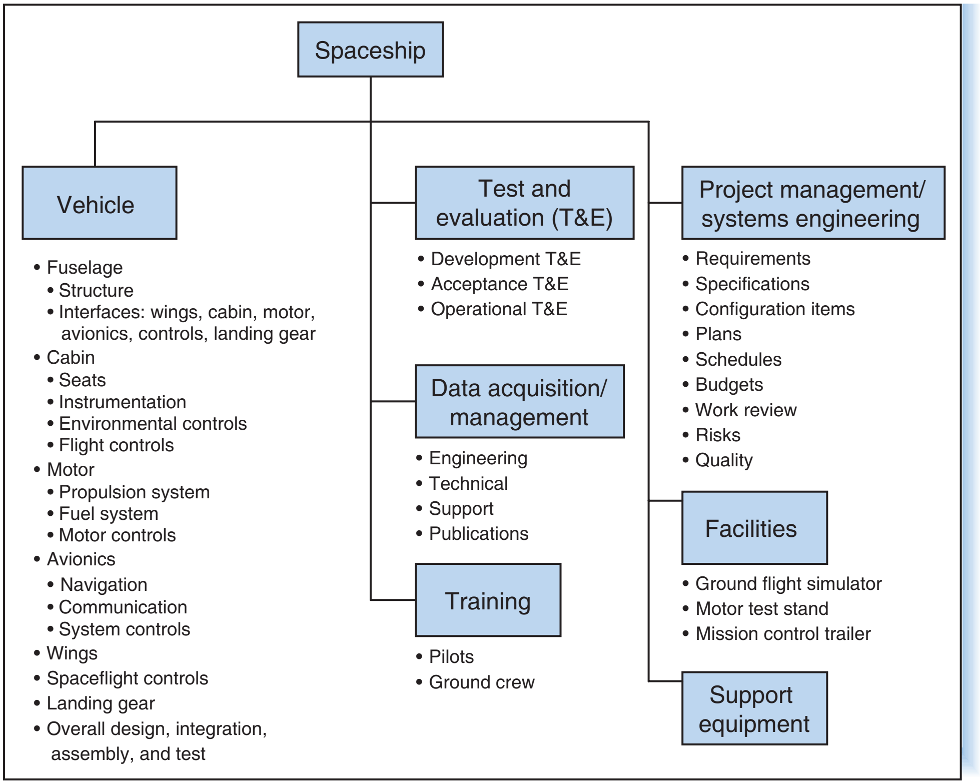


Figure 6.4
WBS for spaceship project.

Example 6.3: Process of Developing the WBS for the LOGON Project

Project manager Frank Wesley and his staff meet several times in brainstorming sessions to create the WBS for LOGON, first during proposal preparation to sort out key deliverables and define the project scope, later during project definition to update the WBS and break down the work packages into greater detail. They first "rough out" the major categories of work and deliverables in the Level 2 breakdown from the SOW and requirements (described in Example 6.2) and identify the responsible functional areas.

After contract signing, Frank meets with managers from the functional areas that will be contributing to the deliverables in the Level 2 breakdown (Figure 6.5). The managers then meet with their technical staffs to prepare Level 3 and, where necessary, Level 4 breakdowns.

The WBS in Figure 6.5 is part functional oriented (basic design, procurement, etc.) and part product oriented (Hardware Part A, Hardware Part B, software, etc.). Where necessary, Level 2 items have been subdivided into Level 3 items, and Level 3 items into Level 4 items. The boxes at the bottoms of the branches are "work packages," denoted by letters in parentheses. Notice that the designated work packages are at different levels (some at Level 2, some at Levels 3 or 4); this is because each branch of the WBS is developed separately.

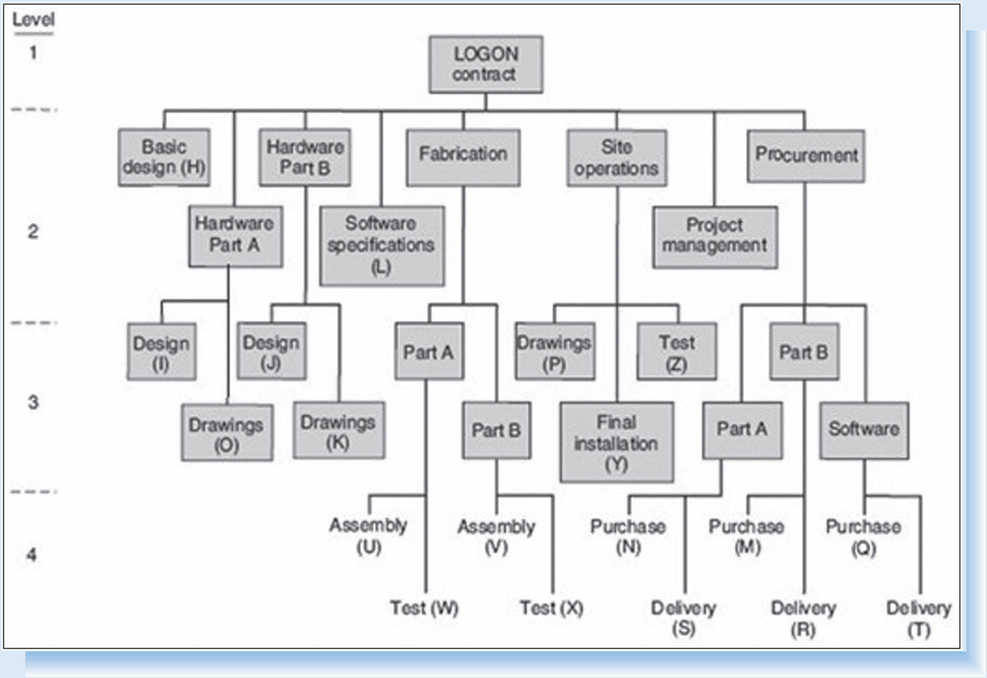


Figure 6.5
Work breakdown structure for the LOGON project. Work packages are lettered H through Z.

Work packages

How far down does the breakdown go? Simply, as far as needed to completely define all work necessary for the project. The work in each "box" or element of the WBS should be "well defined"; if it is not,

Inputs	Task	Outcomes
Predecessors	Statement of work	Deliverables
Preconditions	Time	Results
Resources	Cost	
Requirements/specifications	Responsibility	
	Quality assurance	
	Risk	

Figure 6.6
Properties of a work package.

then the box should be subdivided at the next level. For a box to be "well defined," ideally, it should include the following:

1. *Comprehensive SOW*: work task or activity to be done.
2. *Resource requirements*: labor, equipment, facilities, and materials needed for the task.
3. *Time*: estimated time to perform the task.
4. *Costs*: estimated resource, management, and related expenses for the task.
5. *Responsibility*: parties, individuals, or job titles responsible for doing and/or approving the task.
6. *Outcomes*: requirements, specifications, and associated deliverables, end-items, or results for the task.
7. *Inputs*: preconditions or predecessors necessary to begin the task.
8. *Quality Assurance*: entry, process, and exit conditions to which the task must conform, as specified in the quality plan.
9. *Risk*: uncertainty about the time, cost, and resources associated with the task.
10. *Other*: additional information as necessary, for example, safety and work environment.

These properties are summarized in Figure 6.6. If any of them cannot be defined for a given box, then the task or product in the box is too broad and must be broken down further. When all or most of the properties can be defined for a box or element, the element is considered "well defined" and, by definition, a *work package*.

But the level of work breakdown must not continue so far as to result in an unnecessarily large number of work packages. During the project, each work package becomes the focal point for planning and control and, as such, involves paperwork, schedules, budgets, and so on. Thus, the more work packages, the more time and cost needed to manage them.

Example 6.4: Work Package Definition for LOGON Project

The LOGON project was divided into 19 work packages—the boxes lettered H through Z in Figure 6.5. The following exemplifies the properties for one: Work Package X, Test of Hardware. Note how the properties correspond to those shown in Figure 6.6.

1. **Statement of work**: perform checkout, operational test, and corrections as necessary for sign-off approval of four Batman drone transporter units, Model IBR04.

2. **Resource requirements**:
   - Labor (FT commitment, 3 weeks): test manager, two test engineers, three technicians.
   - Procured materials: track for mockup; all other materials on hand.
   - Facility: test room 1405 at Iron Butterfly for 3 weeks.
3. **Time**: Three weeks scheduled; (time critical) start December 2; finish December 23.
4. **Costs** (Control account RX0522):

Labor:	Manager, 75hrs + 25% OH	=	$9,750
	Engineers, 1125 hrs + 25% OH	=	$135,000
	Technicians, 1125 hrs + 25% OH	=	$112,500
	Material:		$70,000
	Subtotal		$327,250
	10% G&A		$32,725
	Total		$359,975

5. **Responsibility**: oversee tests: B.J., manager of robotic assembly. Approve test results: O.B., manager of Fabrication Department.
   Notify of test status and results: J.M., project engineer; F.W.N., site operations.
6. **Deliverables**: four tested and approved Batman robotic transporters, Model IBR04. Refer to specifications.
7. **Inputs**: predecessor: assembly of Batman robotic transporters (work package V). Preconditions: test room setup for robotic transporter.
8. **Quality Assurance**: refer to entry, process, and exit conditions for work package X in the LOGON quality plan.
9. **Risk**: RBU will fail test requirements because of assembly/integration problems/errors. Likelihood: low. Contingency reserve: additional week included in the schedule.
10. **Specifications**: refer to test document 2307 and LOGON contract spec sheets 28 and 41.
11. **Work orders**: none, pending.
12. **Subcontracts/purchase orders**: no subcontracts; P.O. 8967–8987 for track tests.

Such details should be defined for all work packages and can be combined in a single document called the WBS dictionary.

WBS templates

Companies that routinely perform similar kinds of projects might utilize standardized WBS “templates” at Level 2 or Level 3. The template is based upon experience from having done many of a similar kind of project. Even with a template, however, it is good practice to remember that every project is somewhat unique and that such uniqueness might not become apparent until Level 3 or 4. Hence, the full WBS for a project should never be a mere template or complete copy of the WBS from another project, no matter how similar the projects might seem. Nowhere is the saying “the devil is in the details” more appropriate than in projects, and the WBS is *the* tool for identifying the details wherein the devil might be. To reduce oversights, another good practice is to have two or more teams each create a WBS and then to combine the WBSs into one.

Ideally, work packages represent jobs of about the same degree of effort and of relatively small cost and short duration compared to the total project. For example, DOD/NASA guidelines specify that work packages should be a maximum of 3 months’ duration and not exceed $100,000 cost. These are simply guidelines. Work package cost and duration depend on many factors such as project size (smaller projects have smaller work packages).

Each work package represents a contract or agreement with a subcontractor, supplier, or internal functional unit. Although several functional or subcontracting units might share responsibility for a work package, ideally, a work package has only one party with primary responsibility for it. A work package that produces a tangible deliverable or physical product should include specific start and finish dates.

Integrated execution project plan and WBS process

The execution plan is an *integrated plan* where all elements of the plan (Figure 6.1)—requirements, work tasks, schedules, budgets, risk, quality, communications, procurement, and so on—are interconnected. Once created, the plan enables managers to track the project and assess the impacts of actions or problems in some elements of the plan on the other elements.

To better describe what an integrated execution plan is, we can compare it to what it is *not*, which would be: (1) a list of work packages or tasks seemingly created without regard for user requirements, (2) a budget that does not account for the resources required in the work packages, and a (3) schedule where the tasks do not match up with the work packages in the WBS or budget. To the outsider, it would appear that five people who had never talked to each other had each come up with, respectively, a list of requirements, a list of work tasks, a list of needed resources, a schedule, and a budget. Amazingly, that sometimes happens, with the result being that requirements, work tasks, resources, schedules, budgets, and so on in the plan are seemingly independent and unrelated.

One noticeable feature about an integrated project plan is that the *same list of work packages* or tasks reappears throughout different elements of the plan. The same work tasks developed in the WBS appear in schedules, budgets, and most other elements of the plan.

In several ways, the process of creating the WBS and the resultant work packages form the basis for integrated project planning and, later, integrated project control:[6]

1. Managers, subcontractors, and others to be responsible for the project are identified during the WBS process and involved in defining the work. Their involvement helps ensure completeness of work definition and gains their commitment to that work.
2. Work packages in each phase are logically related to those in earlier and later phases; this ensures that predecessor relationships are met and no steps overlooked.
3. Work packages identified in the WBS become the basis for budgets and schedules. The project budget is the sum of budgets for the work packages plus overhead and indirect expenses. The project schedule is a composite of the schedules for the work packages.
4. The project organization is formed around the work packages, with resources and management responsibility assigned to each work package.
5. The project is managed by managing people working on the individual work packages.
6. The project is controlled by controlling the work packages. During project execution, work completed and costs accrued are compared to schedules and budgets for the work packages, suggesting which work packages are in need of corrective action.

The creation and use of an integrated project plan is a systems approach to management—recognition that a project is a system of interrelated work elements that must be defined, budgeted, scheduled, and controlled to achieve overall objectives.

6.5 Project organization and responsibilities

Integrating WBS and project organization

During the WBS process, each work package is associated with the area of the project organization that will have functional or budgetary responsibility for it. An example is the LOGON project and its contractor, Iron Butterfly Company, represented in Figure 6.7: on the left is the company organization structure; across the top is the project WBS. (For project work that is contracted, i.e. performed by external parties, the organization structure on the left would consist of contractors and suppliers instead of departments. The matrix can also include other important stakeholders who need to be notified or give approval, e.g. the customer.) The box at the intersection of each department and work package is called a *control account* or *cost account*. Each account represents assigned responsibility for a particular work package or portion of one to a department. Just like a work package, each account includes requirements, a schedule and budget, resource needs, deliverables, and a manager or supervisor responsible for it. Each control account integrates the WBS with the project organization and represents an agreement or contract with departments or contractors to fulfill work package requirements. Control accounts are described further in Chapter 9.

See Chapter 9

Responsibility matrix

The individuals holding responsibility for work packages are shown in a chart called a *responsibility matrix*. Figure 6.8 is the responsibility matrix for the LOGON project. Rows represent the work packages or major project tasks identified in the WBS. Columns represent the persons, groups, departments, contractors, or other stakeholders who are responsible for the tasks or need to be notified about project matters. Letters within the matrix symbolize the *kind* of responsibility: primary (ultimate accountability for the work package), secondary (provide assistance or help), notification (must be informed about the work package's status), and approval (authority to approve or reject work package deliverables). The matrix is also called a *RACI chart*—responsible, accountable, consulted, and informed. Note that for each task, one and *only one person* is assigned primary responsibility. The matrix can be modified to signify any other conceivable kind of responsibility.

From the matrix, everyone associated with the project can easily see who is responsible for what. This helps avoid people shirking responsibility and "passing the buck."

To ensure everyone knows what is expected of them and what they can expect from others, the parties identified in the matrix should review and consent to the responsibilities before it is finalized. The assignments can be roughed in during project conception and then firmed up during a team-building session held after project kickoff. Team building is described in Chapter 17.

See Chapter 17

6.6 Scheduling

The next logical step after work definition is to *schedule* the project work tasks. A project schedule shows the timing for work tasks and when specific events and project milestones should occur.

Events and milestones

Project plans are similar to roadmaps: they not only show you what you must do to get to where you want to go, but they enable you to see what progress you've made along the way. Work packages are

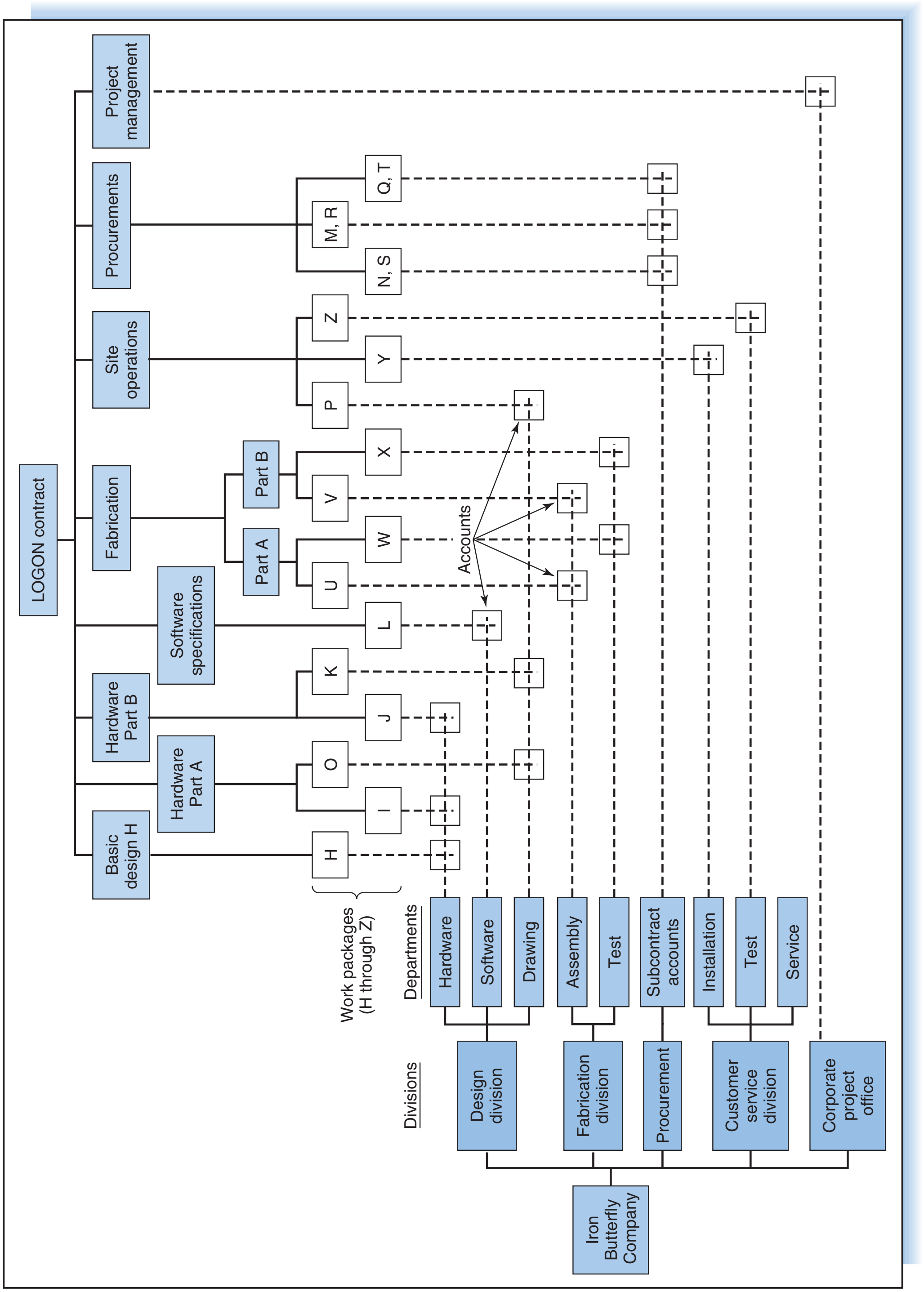


Figure 6.7
Integration of WBS and project organization.

Iron Butterfly, Corp.
Elegant design. Built to last.

Responsibility Code

P Primary responsibility
S Secondary responsibility
N Must be notified
A Must give approval

	Persons Responsible																												
	Project Manager																												
		Project Engineer																			Fabrication Manager								
			Design				Drawing					Software				Site Operations						Assembly A				Assembly B			
Project Task or Activity	F.W.	J.M.	S.E.H.	R.L.Q.	P.J.	D.V.R.	R.I.P.	O.E.M.	P.V.P.R.	D.M.N.	R.L.	L.S.F.	L.L.L.	J.R.S.	D.V.Q.	F.W.N.	J.M.M.N.	L.O.T.	A.U.A.	D.A.R.	B.O.B.	E.N.	G.G.F.	R.T.T.	B.V.L.	B.J.	T.T.Y.	H.R.D.	B.V.-Purchasing
Project coordination	P	S																			S								
Project development	A	P																											
Project design		A	P				A					N				A					N								N
H Basic design	N	A	A	P	S	S	N					N				N													
I Hardware design A			A		P	S																							
J Hardware design B			A	P		S						N																	
K Drawings B							A	S	P												N								
L Software specs		N	A									A	P	S	S														
M Parts purchase B		N																			A								P
N Parts purchase A		N																			A								P
O Drawings A							A			S	P										N								
P Installation drawings							A	P		S						N													
Q Software purchase		N																			A								P
U Assembly A		N																			N	A	P	S	S				
V Assembly B		N																			N					A	P	S	
W Test A		N														N					A	P							
X Test B		N														N					A					P			
Y Final installation		N														A	P	S	S										
Z Final test		N														A		P		S									

Figure 6.8
Responsibility matrix for LOGON project (with initials of persons responsible).

what you must do; combined with the schedule, they are the roadmap to project goals. The roadmap includes signposts called *events* and *milestones* to show how much progress you have made. Passing the last event means you've reached your destination: project completion.

Events and milestones should not be confused with work packages, activities, or other tasks. A work package or task consumes resources and time; it is the *process* of doing something (such as *driving* a car to get somewhere). In contrast, an *event* signifies one thing: a *moment in time*. In a project, events represent the *start* or *finish* of something (equivalent to beginning a trip or arriving at a destination). In project schedules, each work package or task is depicted as a line segment, and the two ends of the segment represent the events of starting and completing the task. For example, in Figure 6.9, the line segment labeled "Task A" represents that task and the time to do it; events 1 and 2 represent the moments when Task A is started and finished, respectively. In project schedules, each event is associated with a specific calendar date (day, month, and year).

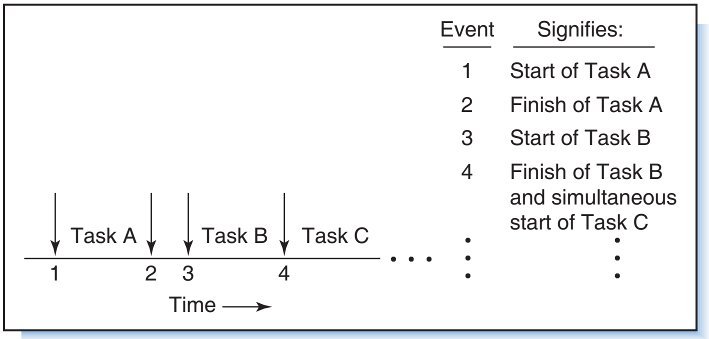
Two particular kinds of events in projects are "interface" and "milestone."[7] An *interface event* denotes the completion of one task and simultaneous start of one or more subsequent tasks. Event 4 in Figure 6.9 is an interface event: it represents the simultaneous completion of Task B and start of Task C. An interface event often represents a change in responsibility: one individual or group completes a task, and another starts the next task.

A *milestone event* represents a major project occurrence, such as completion of a phase or several critical or difficult tasks, an important approval, or availability of crucial resources. Milestone events signify progress, and, as such, they are important measures of progress. Approvals of system requirements, preliminary design, or detailed design or completion of major tests are considered milestones: they signify the project is ready to proceed to the next stage of work. Failure to pass a milestone is usually a bad omen for the project budget and schedule.

Kinds of schedules

Two common kinds of schedules are the project schedule and the task or activity schedule. Project managers and upper management use the *project schedule* (project *master* or *execution* schedule) to plan and review the entire project. This schedule shows all the major project activities but not much detail about each. It is first developed during project initiation and refined thereafter. Managers develop the project schedule in a top-down fashion, first scheduling the tasks as identified in the scope statement or WBS. Later, they refine the schedule in a bottom-up fashion, taking into account the more detailed task schedules as developed by functional managers. When the project is performed in phases, the schedule for each phase must be sufficiently detailed to enable management to authorize work on that phase to begin.

A *task or activity schedule* shows the specific tasks or activities necessary to complete a work package. It is created for those working on the activities and enables lower-level managers and supervisors to



Event	Signifies:
1	Start of Task A
2	Finish of Task A
3	Start of Task B
4	Finish of Task B and simultaneous start of Task C
⋮	⋮

Figure 6.9
Relationship between tasks and events.

focus on those activities without being distracted by other work with which they have no interaction. Task schedules are prepared by functional managers or subcontractors but incorporate the interface and milestone events shown on the project master schedule. Project and task schedules are displayed in many ways, including Gantt charts.

6.7 Planning and scheduling charts

Gantt charts

The simplest and most common scheduling technique is the *Gantt chart* or bar chart, named after the management consultant Henry L. Gantt (1861–1919). During World War I, Gantt worked with the US Army to find a way to visually portray the status of the munitions program. He realized that time was a common denominator among most elements of a program plan and that it would be easy to assess progress by viewing each element's status with respect to time. His approach, which came to bear his name, became widely adopted in industry.

The chart consists of a horizontal scale divided into time units—days, weeks, or months—and a vertical scale showing work elements—tasks, activities, or work packages. Figure 6.10 shows the Gantt chart for the LOGON project. Listed on the left-hand side are work packages; along the bottom are work weeks. The beginning and ending of each bar on the chart represent the starting and completion dates of a work package.

Preparation of the Gantt chart comes after a WBS analysis has identified the work packages or tasks to be scheduled. As each work package is identified in the WBS, estimates are prepared by the manager or others responsible for how long it will take and any prerequisites. The work elements are then listed in sequence of time, taking into account which elements must be completed before others can be started.

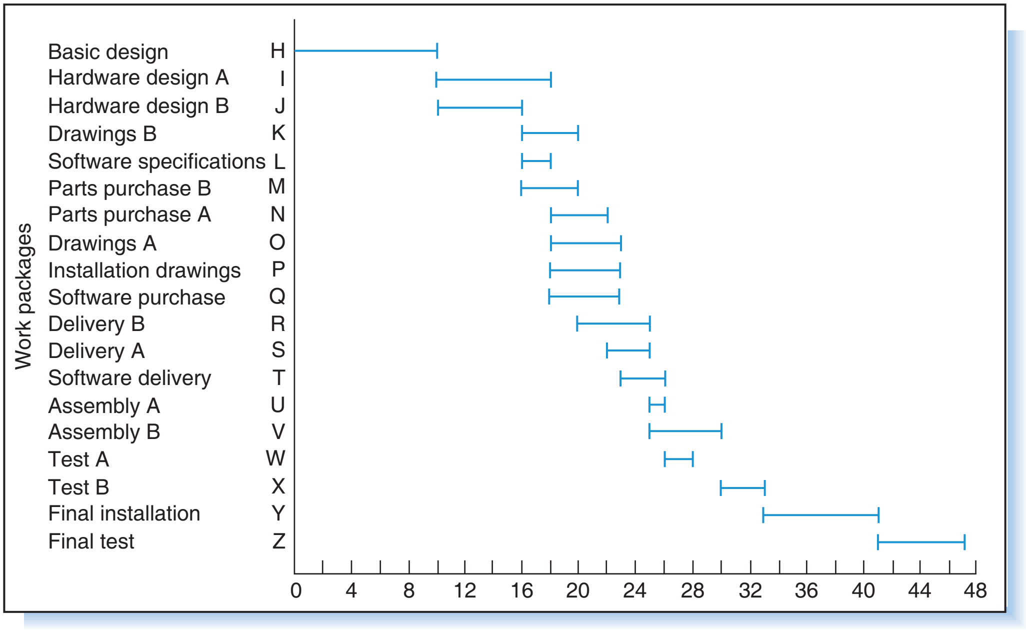


Figure 6.10
Gantt chart for LOGON project.

As an example, consider the first nine work elements in Figure 6.10 (work packages H through P). Here, as in every project, there is a "precedence relationship" between the tasks—some tasks must be completed before others can begin, and this relationship must be determined before the tasks can be scheduled. (These are the "predecessor" inputs mentioned earlier in the discussion of work package definition.) Suppose that during the WBS analysis for LOGON it was determined that: before work tasks I and J could be started, task H had to be completed; before tasks K, L, and M could be started, task J had to be completed; and before task N, O, and P could begin, task I had to be completed.

Before these can be started . . .	This must be completed
I, J	H
N, O, P	I
K, L, M	J

This sequencing logic is maintained to create the Gantt chart. Thus, as shown in Figure 6.11 (and given the times shown for the work packages), only after task H has been completed—that is, after week 10—can tasks I and J be started; only after task J has been completed—after week 16—can tasks K, L, and M be started; and only after task I has been completed—after week 18, can tasks N, O, and P be started. As each new work task is added to the chart, care is taken to locate it following completion of all of its predecessor tasks. This example uses work packages as the tasks being scheduled, but any unit of work can be scheduled.

After the project is underway, the Gantt chart becomes a tool for assessing the status of individual work elements and the project as a whole. Figure 6.12 shows progress as of week 20, the "status date." The heavy portion of the bars indicates the amount of work that has been completed. The thinner part of the bars represents work unfinished or yet to be started. This method is somewhat effective for showing which of the work tasks are behind or ahead of schedule. For example, as of week 20, task N is on schedule, task O is ahead of schedule, and tasks K, L, M, P, and Q are behind schedule; L is the furthest behind because it should have been completed but hasn't been started yet.

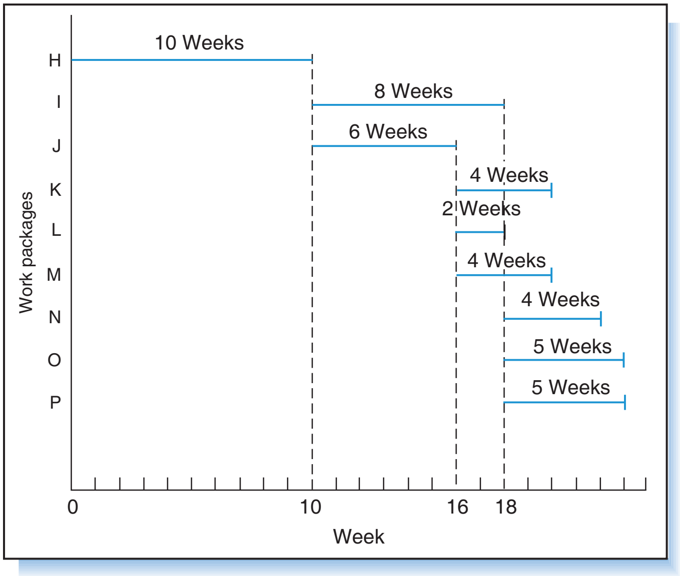
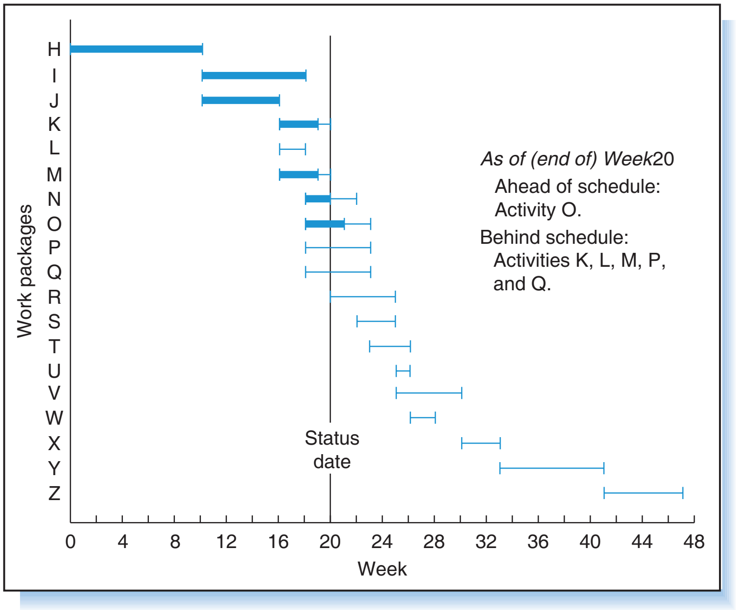


Figure 6.11 Creating a Gantt chart.



*As of (end of) Week*20
Ahead of schedule:
Activity O.
Behind schedule:
Activities K, L, M, P, and Q.

Figure 6.12
Gantt chart for LOGON project showing work progress as of week 20.

When the Gantt chart is used like this to monitor progress, the information it reflects must be the most current possible and the chart updated daily or at least weekly. Tracking progress is important for identifying and rectifying problems, and posting progress is a way to keep the team motivated.

Hierarchy of schedules

In large projects with many work elements, a *hierarchy* of schedules is used, as illustrated by the three levels in Figure 6.13. The top or project-level schedule shows subprojects within a project, the intermediate-level schedule shows major activities within a subproject, and the bottom or task level shows work packages or smaller tasks. Milestones and target dates are displayed at any level.

Each level schedule expands on the details of the schedule at the level above it. Intermediate- and bottom-level schedules are used for project and functional managers to plan labor and resource allocations. Bottom-level schedules are the most detailed, showing the daily (and even hourly) schedules of the tasks within work packages. These are used by work package leaders and correspond to the task schedules mentioned earlier. Figure 6.14 is a multilevel schedule, showing both the higher-level project activities (denoted by “summary” bars) and the detailed tasks within each activity (denoted by “activity” bars).

As a rule, lower-level, more detailed schedules are created closer to when they are needed and when such details are better known—the phased planning approach in Figure 4.3.

See Chapter 4

Disadvantages of Gantt charts

A disadvantage of the Gantt chart is that it does not necessarily show the dependencies between work elements, for example, the effects of one work element falling behind schedule on other work elements. As

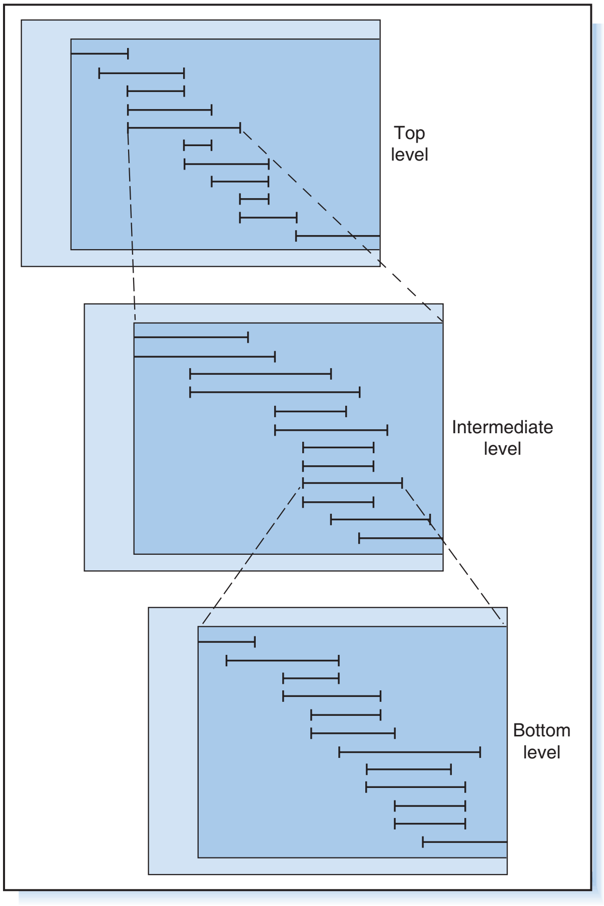
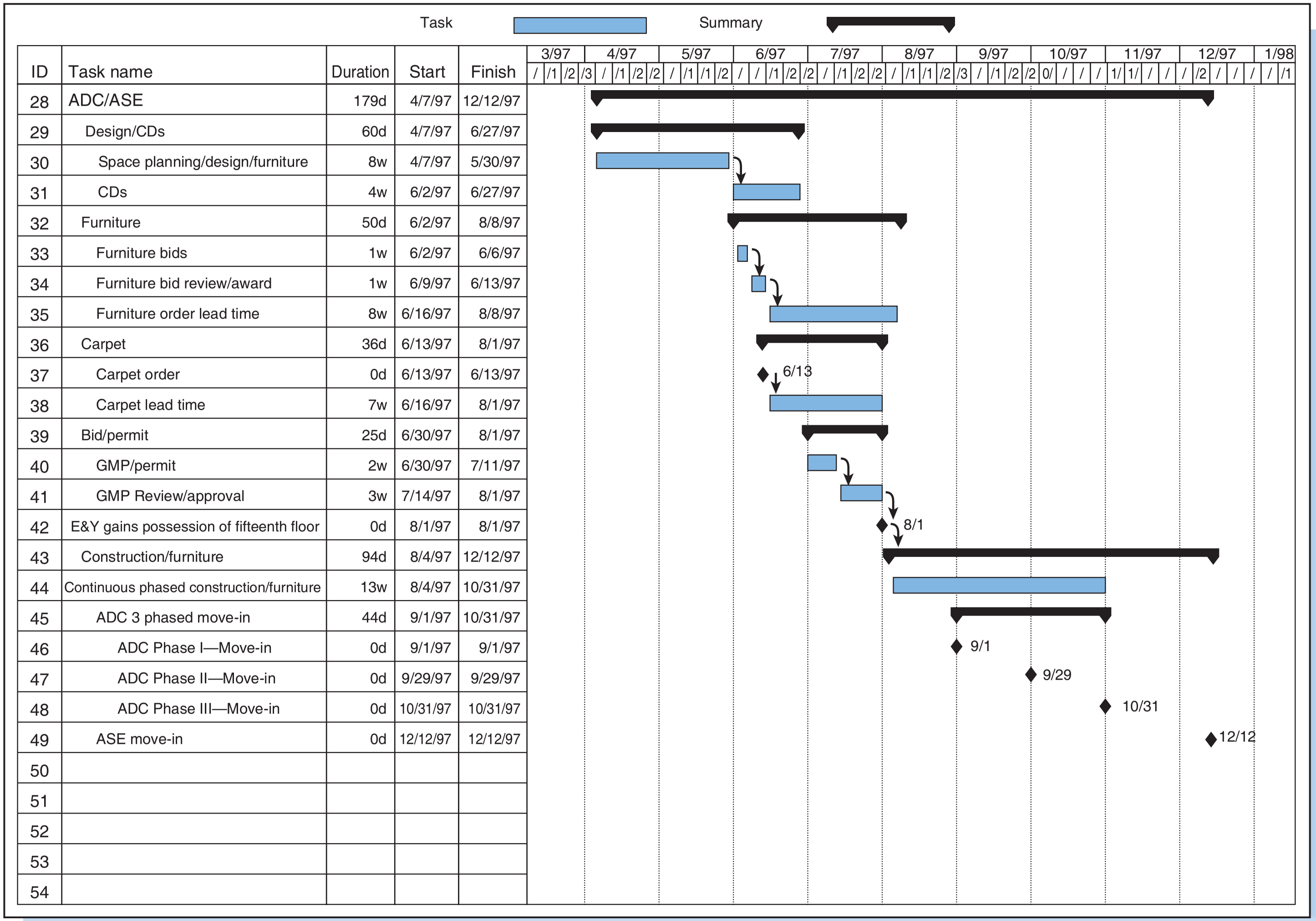


Figure 6.13
Hierarchy of schedules.

described, some work elements depend upon others before they can begin; if those others are delayed, then so will the elements that depend on them and, possibly, the entire project. Gantt charts alone provide no way of determining how delays in some work elements impact other elements and the project. This potential limitation is addressed in the next chapter.

6.8 Line of balance (linear scheduling method)

Although projects are by definition unique, one-time endeavors, they sometimes contain work tasks that are repetitive. Examples include erecting numerous towers for a new transmission line, constructing multiple largely identical housing units, and erecting a multifloor building. The towers, housing units, and floors are identical. A method for planning and controlling these repetitive activities is the *line of balance*—LOB (also called *linear scheduling method* because it is often used in "linear projects" such as highways and pipelines where the physical location of the work and progress can be represented in terms of miles or kilometers). Example 6.5 illustrates the method.



ID	Task name	Duration	Start	Finish
28	ADC/ASE	179d	4/7/97	12/12/97
29	Design/CDs	60d	4/7/97	6/27/97
30	Space planning/design/furniture	8w	4/7/97	5/30/97
31	CDs	4w	6/2/97	6/27/97
32	Furniture	50d	6/2/97	8/8/97
33	Furniture bids	1w	6/2/97	6/6/97
34	Furniture bid review/award	1w	6/9/97	6/13/97
35	Furniture order lead time	8w	6/16/97	8/8/97
36	Carpet	36d	6/13/97	8/1/97
37	Carpet order	0d	6/13/97	6/13/97
38	Carpet lead time	7w	6/16/97	8/1/97
39	Bid/permit	25d	6/30/97	8/1/97
40	GMP/permit	2w	6/30/97	7/11/97
41	GMP Review/approval	3w	7/14/97	8/1/97
42	E&Y gains possession of fifteenth floor	0d	8/1/97	8/1/97
43	Construction/furniture	94d	8/4/97	12/12/97
44	Continuous phased construction/furniture	13w	8/4/97	10/31/97
45	ADC 3 phased move-in	44d	9/1/97	10/31/97
46	ADC Phase I—Move-in	0d	9/1/97	9/1/97
47	ADC Phase II—Move-in	0d	9/29/97	9/29/97
48	ADC Phase III—Move-in	0d	10/31/97	10/31/97
49	ASE move-in	0d	12/12/97	12/12/97
50				
51				
52				
53				
54				

Figure 6.14
Multilevel schedule.

Example 6.5: Cranes for Construction

A supplier of construction cranes must deliver a total of 12 cranes according to the schedule in Table 6.1. Prior to each crane's delivery, a set of activities must be completed. These are shown as activities A–F in the Gantt chart in Figure 6.15.

Table 6.1 Delivery schedule for cranes

Week	Date	Delivery Quantity	Cumulative Delivery Quantity
1	February 7	1	1
2	February 14	2	3
3	February 21	4	7
4	February 28	5	12

Suppose we look only at deliveries on February 14; according to Table 6.1, a total of 3 cranes must be delivered by then. At this time, and throughout the project, the project manager might ask, how far along should all the other activities be at that time? For example, how many power units (Activity B) should be bought by then (assuming one power unit per crane), how many components procured, and so on?

According to Figure 6.15, a power unit must be bought 2 weeks before ("number of week prior to") the delivery of a crane. Now, look at the right-hand column of Table 6.1; moving down 2 weeks from February 14 shows the number 12: this means that 12 power units should be bought by February 14. Since Activities A and C must both be completed 3 weeks prior to crane delivery (Figure 6.15), we see, again referring to Table 6.1, that 12 sets of "other components" must be procured (Activity C) and 12 sets of structural components must be fabricated (Activity A) by February 14. In the same manner, since operators must be trained (Activity E) 1 week before delivery, moving down 1 week from February 14 in Table 6.1 shows that seven operators must be trained by February 14. Likewise, we see that seven cranes (Activity D) must be assembled by February 14. Also, since tests with operators (Activity F) involve zero lead time, three tests should be completed by then.

Figure 6.16 summarizes the LOB—the number of deliverables (completed units) per activity as of February 14. For the cost center, function, or supplier responsible for each activity, the LOB provides information necessary to estimate needed resources and plan the work.

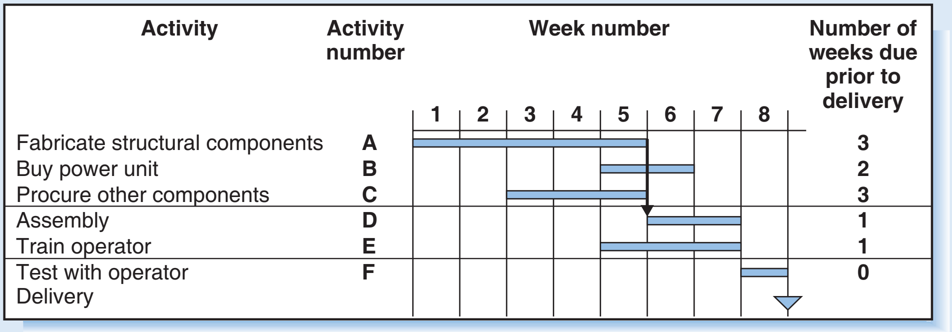


Figure 6.15
Gantt chart of tasks for delivering one crane.

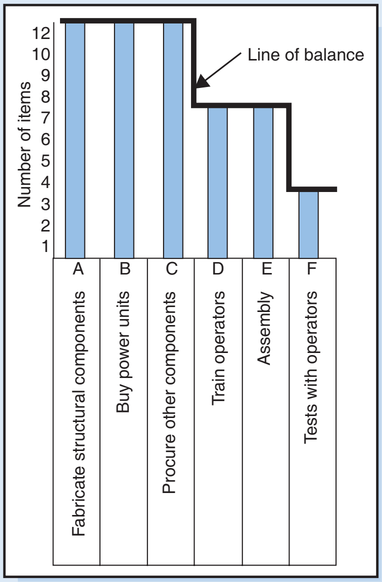


Figure 6.16
Line of balance schedule: number of deliverables required by February 14 per type of activity.

An alternative to Figure 6.16, commonly used in project management software, is a diagram that shows the number of units to be completed by a specific activity per time period. For example, Figure 6.17 shows dates and quantities for fabricated structural components (Activity A) and assembled cranes (Activity D). The same figure can be used to monitor actual units completed and track progress versus planned units.

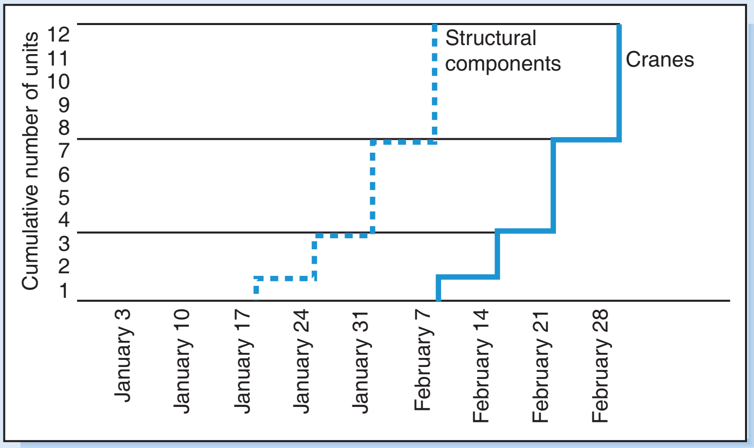


Figure 6.17
Line of balance schedule: alternative presentation.

6.9 Summary

The purpose of project planning is to determine the way in which project goals will be achieved—what must be done, how it will be done, by whom, when, and for how much.

The project scope statement and WBS are ways that managers and planners answer the question "What must be done?" The scope statement outlines the main areas of work to be done and the deliverables or end-items. It appears commonly in two places, the SOW or the project charter. The SOW is a summary description of the project used for contracted work; it appears in the RFP, proposal, contract, and project execution plan.

The WBS process subdivides the project into work packages or other work elements, each small enough to be well understood, planned, and controlled. Most all elements and functions of project management—scheduling, budgeting, resource allocation, tracking, and control—are subsequently carried out with reference to the WBS and work packages.

The responsibility matrix integrates the project organization with the WBS; it prescribes which units and individuals, both internal and subcontractors, have project responsibility and the kind of responsibility for each. It is valuable for achieving consensus, ensuring accountability, and reducing conflict among project participants.

Project schedules show the timing of work and are the basis for resource allocation and performance tracking. Depending on the amount of detail required, different types of schedules are used: project-level schedules show only high-level tasks and work packages; task-level schedules show the tasks needed to complete individual work packages. The most common form of schedule is the Gantt chart. As a visual planning device, it is effective for showing when work should be done and whether individual work elements are behind or ahead of schedule.

The concepts and techniques in this chapter are foundation tools for planning and scheduling. The next few chapters look at additional and more advanced planning and scheduling techniques. Later chapters address the role of the WBS, work packages, and schedules in cost estimating, budgeting, risk management, procurement, and project control.

Review Questions

1. What questions need to be answered whenever a new project is planned? What are the steps in the planning process that answer these questions?
2. What is the purpose of a project execution plan? At what stage of the project should this plan be prepared?
3. Can a project be undertaken without an execution plan? What are the possible consequences?
4. Which aspects of the execution plan might be eliminated for projects with small budgets? Which might be eliminated for short-duration projects (few weeks or months) with relatively few tasks?
5. A section for addressing risk and uncertainty is often left out of the project execution plan. What are the potential pitfalls of doing this?
6. What is the purpose of the project scope statement? What information is used to create the scope statement? How is the scope reflected on the WBS?
7. What is the statement of work? In what documents does the SOW appear?
8. What are similarities and differences between the SOW and the project charter?
9. Think of a somewhat complicated endeavor you are familiar with and develop a WBS for it. (Examples: wedding, high school reunion, questionnaire survey, movie or stage play, etc.) Now repeat for a complicated job you are not familiar with. At what point do you need assistance from "functional managers" or other specialists to continue the breakdown?
10. How do you know in a WBS when you have reached a level where no further breakdown is necessary?
11. Could the WBS in Figure 6.5 have started with different Level-2 elements and still result in the same work packages? In general, can different WBS approaches give similar results?

12. In what ways is the WBS important to project managers?
13. What is the role of functional managers in developing a WBS?
14. What is the impact of altering the WBS after the project has started?
15. What should a "well-defined" work package include?
16. What is the relationship between the WBS and organization structure? In this relationship, what is the meaning of a "control account"?
17. Figure 6.8 shows some possible types of responsibilities that could be indicated on a responsibility matrix. What other kinds of responsibilities or duties could be indicated?
18. Construct a responsibility matrix using the WBS you developed in question 9. In doing this, consider the project organization and the managerial/technical staff to be assigned and their duties.
19. What function does the responsibility matrix serve in project control?
20. Could a responsibility matrix seem threatening to managers and others? Why?
21. Distinguish an event from an activity. What problems can arise if people on a project confuse these terms?
22. Distinguish an interface event from a milestone event. Give some examples of each. When is an interface event also a milestone event?
23. How are project-level and task-level schedules prepared? What is the relationship between them? Who prepares them?
24. Construct a Gantt chart similar to the one in Figure 6.10 using the following data: When will task G be completed?

Task	Start Time (wks)	Duration (wks)
A	0	5
B	6	3
C	7	4
D	7	9
E	8	2
F	9	8
G	12	7

25. How must the Gantt chart you drew in problem 24 be changed if you were told that C and D could not begin until B was completed and that G could not begin until C was completed? What happens to the project completion time?
26. Is the Gantt chart adequate for planning and controlling small projects?
27. In a hierarchy of schedules, how does changing a schedule at one level affect schedules at other levels?
28. How do you decide when more than one level of schedule is necessary?
29. If a hierarchy of schedules is used in project planning, explain whether there should be a corresponding hierarchy of plans as well.

Questions About the Study Project

1. Describe the project execution plan for your project (the plan developed at the *start* of the project). What is the content? Show a typical execution plan.
2. Who prepared the plan?

3. At what point in the project was the plan prepared?
4. What is the relationship between the execution plan and the project proposal? Was the plan derived from the proposal?
5. Is there a project scope statement? Who prepared it? Do major areas of work and deliverables of the project correspond to the scope statement?
6. Is there a SOW or project charter? Describe its purpose and contents.
7. How, when, and by whom was the work breakdown structure prepared? Describe the process used in preparing the WBS.
8. Where in the WBS is project management included?
9. Was the work package concept used? If so, describe what a work package includes. How are work packages defined?
10. How were ongoing activities such as management, supervision, inspection, and maintenance handled in the WBS? Was there a work package for each?
11. How were responsibilities in the WBS assigned to the project organization (i.e. how did the functional areas become involved in the project)?
12. How were individuals assigned to the project? Describe the process.
13. Was a responsibility matrix used? Show an example.
14. How were activities in the WBS transferred to a schedule? How were times estimated? Who prepared the schedules?
15. Show examples of project-level and task-level schedules. Who prepared each? How were they checked and integrated?

CASE 6.1 BARRAGE CONSTRUCTION COMPANY: SEAN'S WBS

Sean Shawn was recently appointed project planner at Barrage Construction Company, which specializes in custom-made garages. He had worked for 2 years in the HR department while completing his MBA and now has a desk in the newly created project office. Barrage is considering branching out to building standard two-car and three-car garages as well as its usual customized garages and asked Sean to determine the feasibility of moving into this market. Skimming a book on project management, he discovered the WBS concept and decided it would be helpful for developing cost estimates for the standard garages. He had never worked on a garage construction project but felt he knew the process well enough from having talked to company employees. He sat down and drew the WBS in Figure 6.18. To estimate costs for each work category in the WBS, he reviewed company cost records from three recent two-car garage projects he thought similar to standard garages, computed the average, and then apportioned the costs among the categories in the WBS. The company had no actual cost records for a three-car garage, so as an estimate, he increased the estimate for the two-car garage by 50 percent. When he summed the costs for all the categories, he arrived at a total of $43,000 for a two-car garage and $64,500 for a three-car garage. Compared to competitors, he discovered, these costs were 10 percent higher than their prices. However, because his estimates had been based on custom garages, he believed they might be at least 20 percent higher than for standard garages. He thus reduced his estimate by 20 percent and concluded that Barrage would be able to price its garages competitively and still make a 10 percent profit.

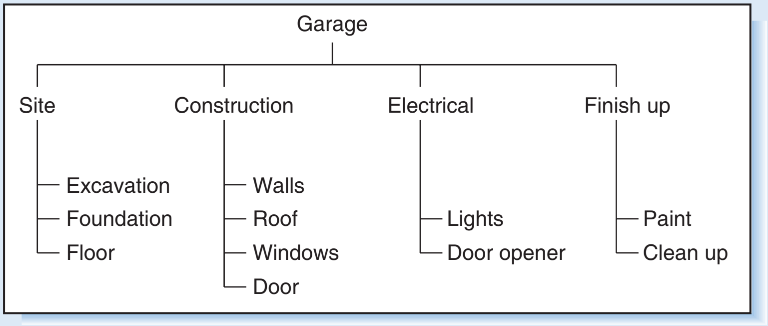


Figure 6.18
Sean's garage project WBS.

QUESTION

What is your opinion of Sean's approach to creating a WBS and estimating project costs? Please elaborate.

CASE 6.2 STARTREK ENTERPRISES: DEVA'S PROJECT PLAN

Deva Patel, project manager at Startrek Enterprises, Inc., is planning and coordinating the company's move to a new building currently under construction. Deva wants the move to commence as soon as the building is ready for the estimated June 1 occupancy—still 2 months away. The entire move, which will affect four departments and 600 people, is to be completed within 1 week. Because timing is critical, Deva starts her planning by preparing a Gantt chart. At the project level, she draws a bar 1 week (7 days) long, then subdivides it into three major categories: (1) pack office supplies, equipment, and furniture (3 days allotted); (2) move everything (2 days allotted); and (3) unpack and arrange it at new location (2 days). She then estimates the total number of boxes, equipment, and furniture that will have to be moved in 2 days, gives the estimate to a moving contractor, and receives a price quote. To assist in packing and unpacking boxes and equipment, Deva intends to hire temporary workers. She estimates the number of workers needed, gives it to a temp agency, and receives a price quote.

Deva shows the completed plan to her manager and asks him to review it. The plan consists of the Gantt chart and a budget that is largely based on the price quotes from the moving company and the temp agency.

QUESTIONS

1. What do you think about Deva's approach to scheduling work and estimating the costs?
2. If you were Deva's manager, would you consider her plan comprehensive?
3. How would *you* prepare a plan for the move, and what would your plan include?

CASE 6.3 WALTER'S PROJECT PLAN

Walter has just been assigned to manage a project—his first experience as a project manager. The project involves developing an end-item that must meet a long list of requirements, but after reviewing the project SOW and requirements list, the first thing Walter wonders is who is going to be on his project team. He asks his manager, who gives him the names of three people in the department who are available to work on the project.

Next, Walter starts thinking about what each of the three people on the team will do. He feels that for a project to be successful, team members should each be assigned to tasks they are the most qualified or experienced to do. Since he has worked with the people before, he knows a little about their individual expertise. He sits down to prepare a list of tasks for each person; as he considers each person, he thinks about things that need to be done in the project and selects those things he thinks are best suited to the person. When he is finished creating the lists, he sees that person A has 11 tasks, while persons B and C have 4 tasks and 5 tasks, respectively. To balance out the workload, he takes four of the tasks from person A and splits them between the other two. He is pleased because, he feels, with seven, six, and seven tasks, the team members will each have roughly the same amount of work.

On each list, he then arranges the tasks in the approximate sequence they must be done.

The next day, Walter meets with the team and gives them the lists of tasks. He asks that they estimate the time they will need to do each of the tasks and that they meet as a group to figure out how their tasks are interrelated and create a Gantt chart. He feels that by requiring team members to estimate task times and create their own schedule, the estimates and schedule will be realistic and accurately reflect the timing of the project.

Walter stops by his manager's office and eagerly reports that his "project plan" is soon forthcoming, to consist of a Gantt chart and lists of responsibilities for project team members.

QUESTIONS

1. Discuss Walter's approach to (a) defining work (creating task lists), (b) creating the schedule, and (c) assigning responsibility.
2. What do you think of Walter's approach to "balancing the workload" among the team members?
3. Do you think the Gantt chart will realistically reflect work that must be done in the project? Do you think the project will be able to satisfy the SOW and requirements?
4. How else might Walter have gone about defining work tasks, creating the schedule, and assigning responsibility?

CASE 6.4 PLANNING THE BOCA IMPLEMENTATION AT KULCZYŃSKI PRODUCTS

Tomasz Grabowski is newly hired as a project manager of IT at Kulczyński Products. His first project is to install the brand-new Boca Business System. This is his first management position, but with 4 years of IT experience, he feels confident he can do a good job. He will be leading a team of up to 12 IT professionals, 9 from Kulczyński and 3 from Boca Systems, the software contractor. So far, only 3 of the Kulczyński team have been assigned to the project.

To plan for the project, he prepares a detailed list of the tasks he believes need to be performed, shown subsequently. He is proud of the list and thinks it's quite comprehensive.

Task List

1. Identify resources to be monitored.
2. Define users and workflow.
3. Identify event sources by resource type.
4. Define the relationship between resources and business systems.
5. Identify members of the implementation team.
6. Order the server hardware for production as well as test/quality assurance.
7. Order console machines.
8. Order prerequisite software.
9. Install test and QA servers and prerequisite software.
10. Install consoles and prerequisite software.
11. Install Boca Business Systems Manager on console.
12. Install production servers and prerequisite software.
13. Install console machines and prerequisite software.
14. Configure Boca Console server and verify connectivity.
15. For each resource type, do the following:
    a. Extend the data model.
    b. Configure the vector placement in the model.
    c. Configure the Boca Enterprise Console rule to send events.
    d. Associate tasks and URLs with object types.
    e. Configure filtering, if appropriate.
    f. Verify the event flow.
16. For each business system interface, do the following tasks:
    a. Test Automated Business Systems file and XML definitions; verify resource inclusion.
    b. Create databases on the history server.
    c. Set up and test jobs on the database server to produce the database backup.
    d. Set up and test jobs to copy backup databases to the history server.
    e. Set up and test jobs to replicate events to the history server.
    f. Install your request processor on the Boca Business Systems Manager database server for use by the problem and change request processing function.
    g. **Optional**: Update the System Configuration table to reflect request processor names along with processing options for the request processors.
    h. **Optional**: Update the TLAP table to specify resource options for problem ticket creation.
17. Consider training a key group and have them train their peers.
    a. Evaluate the addition and deletion of user IDs.
    b. Establish a relationship between Boca Business Systems Manager and change management. Monitor system performance and adjust hardware as required.
    c. Boca Business Systems Manager SQL server jobs.

The project is to begin in March and finish by November 30. Tomasz is not accustomed to working according to schedules, but the department manager says he ought to prepare one to make sure the project can be done on time. For the schedule, Tomasz decides to create a "timeline" similar to one he saw in an earlier project. He takes that timeline and modifies it to show 11 "work categories" that he believes represent the Boca project. He then estimates how long each work category will take to the nearest half-month. Arranging the categories and times on the timeline, Tomasz finds that the project will finish in January, which is too late. He reviews the estimates and reduces several of them enough to shorten the timeline by 2 months. Figure 6.19 is the finished timeline.

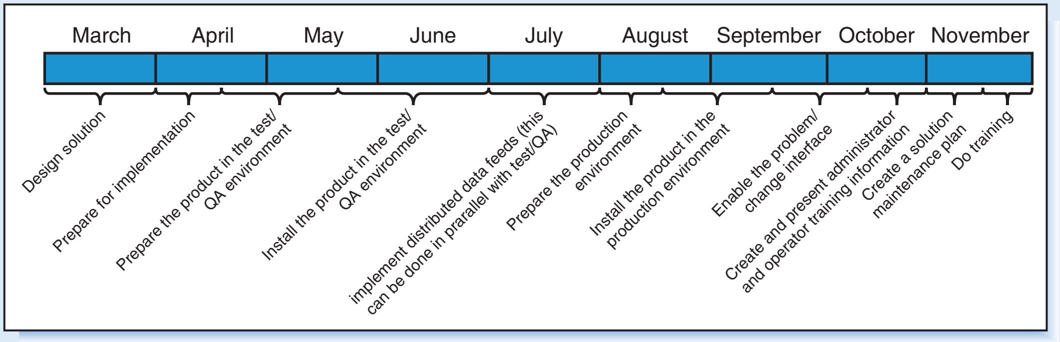


Figure 6.19
Boca Implementation project timeline.

Tomasz intends to assign responsibility as follows:

- The Boca Team is responsible for everything on the task list with the word "Boca."
- The Kulczyński Team is responsible for everything else on the list.

Just before the project begins, Tomasz gives the Boca Team and Kulczyński Team each a copy of the task list and the timeline. He then explains, "Here's the list of what we need to do. If you are able to do everything within the timeline, we should be able to meet the project deadline." Comment on Tomasz's "plan."

Notes

1. Some organizations use the term "project charter" to refer to an "execution plan." Our preference is for the more common usage, that is, the charter is a somewhat brief document to announce and authorize the decision to undertake a project, while the execution plan is a comprehensive document that will guide the project team though the project execution phase.
2. Contents of execution plans are listed in Cleland D.I. and King W.R. *Systems Analysis and Project Management*, 3rd edn. New York, NY: McGraw-Hill; 1983, pp. 461–469; Allen J. and Lientz B.P. *Systems in Action*. Santa Monica, CA: Goodyear; 1978, p. 95; Kerzner H. *Project Management*, 10th edn. New York, NY: Wiley; 2009, pp. 459–463.
3. See, for example, Cleland and King. *Systems Analysis and Project Management*, pp. 461–469.
4. Sarason S. *The Creation of Settings and The Future Societies*. San Francisco: Jossey-Bass; 1972 argues the importance of knowing the beginnings, origins, and history of any new "setting" before initiating work; especially important is to anticipate and prepare for possible difficulties, obstacles, and conflicts to be encountered (i.e. risks).
5. In technical projects, the subsystems and components—the "configuration items"—are identified during preliminary design studies in systems engineering, described in Chapter 2.
6. Cleland and King. *Systems Analysis and Project Management*, p. 258.
7. Archibald R.D. *Managing High-Technology Programs and Projects*. New York, NY: John Wiley & Sons; 1976, pp. 65, 156.

Chapter 7

Project schedule planning and networks

You can't always get what you want.

—Rolling Stones

Project scheduling is more than just displaying tasks on a Gantt chart. It is an integral part of project planning, a sometimes trial-and-error process of adjusting work tasks to satisfy resource constraints while trying to meet project deadlines. Although a Gantt chart is good for communicating the project schedule, it is limited as a planning tool because it does not explicitly show the impact of delaying activities or shifting resources on the overall project. The network methods described in this chapter do not have this limitation; they clearly show what happens to the project when resources are altered or activities delayed. This chapter and the next discuss the most widely used network-based approaches to project scheduling and planning.

7.1 Network diagrams

A network diagram shows project activities or tasks and their logical relationships—that is, the precedence relationships or dependencies among the tasks. Figure 7.1 is a network diagram for "getting up and getting dressed" (for a male). The boxes represent activities or tasks, and the arrows between them show how the tasks are related and the order in which they should occur, for example, put on shirt *before* tie, put on pants and socks *before* shoes, and so on. (The diagram in Figure 7.1 is of course for illustration purposes only; any real-life attempt to plan work in such detail would be micromanagement and a real time-waster!) Ordinarily, the boxes in the network would be the activities or work packages as defined in the work breakdown structure. Depending on the desired detail, however, they can represent any level of work, including projects in a program; subprojects belonging to a project; or work packages in a project, subproject, or specific facility.

Networks also show *events*. As described in Chapter 6, an event represents an instant in time, an "announcement" that something has happened or will happen. Typically, it signifies the start of an activity or the end of an activity. An activity with a very short duration may also be regarded as an event. An important event such as completion of a project phase is a *milestone*.

See Chapter 6

Two methods for constructing network diagrams are *activity-on-node* (AON)—also called the *precedence diagramming method* (PDM), and *activity-on-arrow* (AOA). Our discussion will center on the more commonly used AON method. The AOA method is addressed in Appendix A to this chapter.

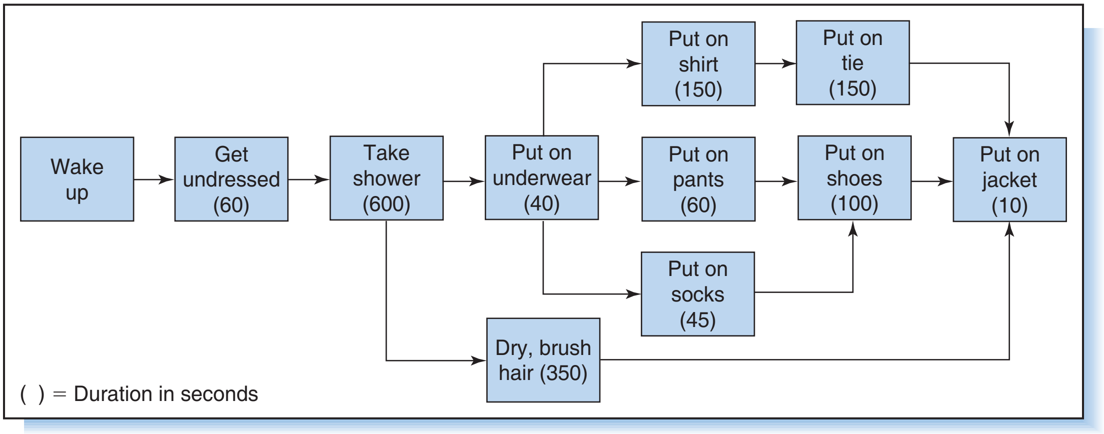


Figure 7.1
Network diagram for getting up and getting dressed.

Activity on node (or precedence diagramming method) diagrams

Figure 7.1 is a network diagram created using the AON method. Each box (or *node*) in the network is a work package, task, or activity, and shown inside each is information about the activity.

To construct an AON network, start by drawing the first activity in the project (e.g. "wake up"). From this activity, draw arrows to the activities that happen next. As shown in Figure 7.1, activities are added one after another, in sequence or parallel.

But before you can actually create a network, you first must know the *dependency* relationships among the activities. For example:

- What activities are its predecessors?
- What activities are its successors?
- What activities can be done at the same time as it?

In a network, every activity except the first one has *predecessors*, which are activities that must be completed ahead of it; in Figure 7.1, for example, "put on shirt" is a predecessor for "put on tie." Similarly, every activity except the last one has *successors*, which are activities that cannot begin until the current activity is completed; for example, "put on tie" is a successor of "put on shirt."

It is important to distinguish *mandatory* and *discretionary* dependency relationships:

- Mandatory: the sequence of two activities cannot be reversed, and the dependency cannot be eliminated. The relationship between "put on socks" and "put on shoes" in Figure 7.1 is an example.
- Discretionary: the sequence is a matter of choice. For example, "dry, brush hair" and "put on jacket" *can* be done in either order. Sometimes a discretionary dependency can be eliminated and activities overlapped to speed up the project. This is called *fast-tracking*.

In another kind of dependency, called *external* dependency, an activity depends on some event or activity that is not in the network. For instance, in Figure 7.1, the activity "take umbrella" might be included at the end of the network; it would depend on an external factor, the "forecast for rain."

Sometimes only the *immediate predecessors* are used to construct the network. An immediate predecessor is an activity that *immediately* precedes another activity. For example, "wake up" and "get undressed" are both predecessors for "take shower," but only "get undressed" is an immediate predecessor. (The logic is, to "get undressed," you have to "wake up" first.) Given information on immediate predecessors, it is easy to construct a network. For example, the network in Figure 7.1 can be constructed solely from the information in Table 7.1. Start with the first activity in the project, the one with no immediate predecessor in Table 7.1, which is "get undressed;" then connect to it the activity that has "get undressed" as its immediate predecessor, which is "take shower." Next come "put on underwear" and "dry, brush hair," since "take shower" is *their* immediate predecessor. Continuing in this fashion, the result is the diagram in Figure 7.1.

Once the network is constructed, it is easy to see which activities are sequential and which are parallel. Activities that have a predecessor–successor relationship (one follows the other) are called *sequential* activities; "take shower," "put on underwear," and "put on shirt" are examples. Two or more independent activities that can be performed at the same time are called *parallel* activities. "Put on shirt"; "put on pants"; "dry, brush hair"; and "put on socks" are parallel activities because they can be done all *at the same time* or *in any order*. Once the network has been completed, check the relationships among activities for completeness and logical consistency.

Another example is given in Table 7.2. The network diagram for this project, shown in Figure 7.2, begins at Activity A (no immediate predecessors). Since Activities B and C both have A as their common immediate predecessor, both are connected directly to A. Then, because D has two immediate

Table 7.1 Activities and immediate predecessors

Activity	Immediate Predecessors	Duration (Seconds)
Get undressed	—	60
Take shower	Get undressed	600
Put on underwear	Take shower	40
Dry, brush hair	Take shower	350
Put on shirt	Put on underwear	150
Put on pants	Put on underwear	60
Put on socks	Put on underwear	45
Put on tie	Put on shirt	150
Put on shoes	Put on pants Put on socks	100
Put on jacket	Put on tie Put on shoes Dry, brush hair	10

Table 7.2 Activities and immediate predecessors

Activity	Immediate Predecessor
A	—
B	A
C	A
D	B, C
E	B, C

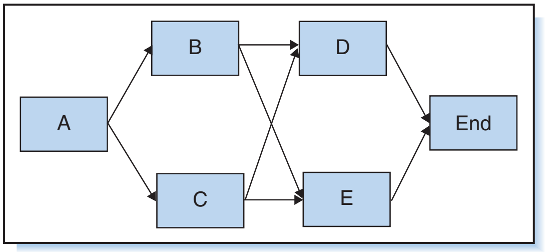


Figure 7.2
AON diagram corresponding to project in Table 7.2.

predecessors, B and C, it is connected to both of them; similarly, so is Activity E. Each node is labeled to identify the activity.

In general, good practice dictates that a network should always have only one "start" and one "end" node, each a single place on the network to represent the start and end of the project. Whenever a project has multiple nodes at the start or end of the network, then a single node should be inserted before or after them, respectively. In Figure 7.2, for example, a single end node (with implied zero duration) has been inserted after Activities D and E. Without this node, the mistaken understanding might be that the project ends upon completion of either Activity D or Activity E. The "end" node means that the project ends when *both* D and E are completed.

See Chapter 6

As a final example, Table 7.3 shows the immediate predecessors for the LOGON project using work packages from the WBS in Chapter 6. Figure 7.3 shows the corresponding network.

Table 7.3 Activities and immediate predecessors for LOGON project

Description	Immediate Predecessors	Duration (Weeks)
H Basic design	—	10
I Hardware design for A	H	8
J Hardware design for B	H	6
K Drawings for B	J	4
L Software specifications	J	2
M Parts purchase for B	J	4
N Parts purchase for A	I	4
O Drawings for A	I	5
P Installation drawings	I, J	5
Q Software purchases	L	5
R Delivery of parts for B	M	5
S Delivery of parts for A	N	3
T Software delivery	Q	3
U Assembly of A	O, S	1
V Assembly of B	K, R	5
W Test A	U	2
X Test B	V	3
Y Final installation	P, W, X	8
Z Final system test	Y, T	6

*Work packages from WBS, Figure 7.3.

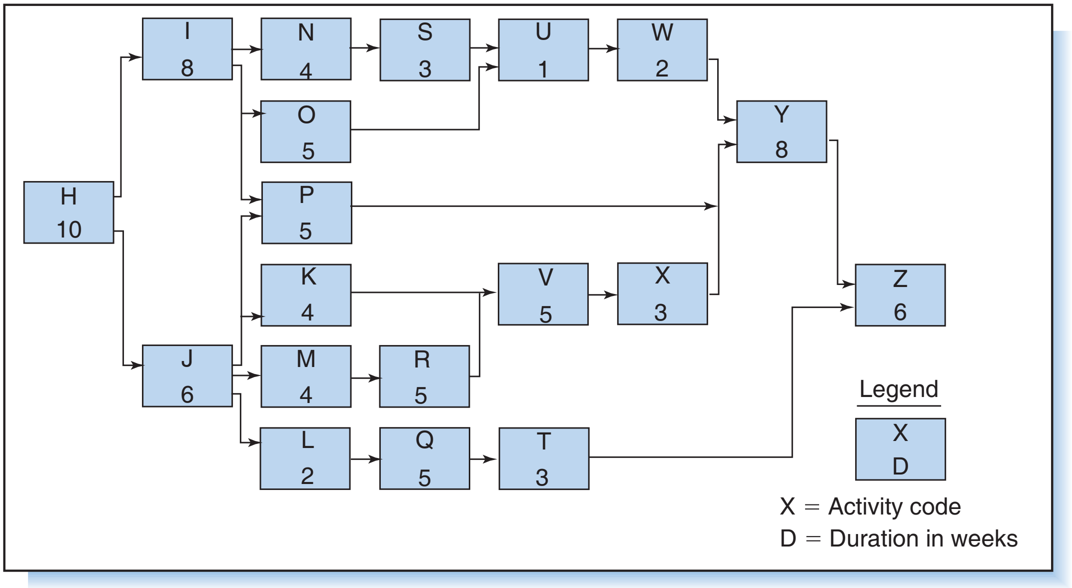


Figure 7.3
Network diagram for LOGON project.

Tables 7.1, 7.2, and 7.3 for the examples show only the immediate predecessors for each activity. While it would have been okay to show all the predecessors for each activity in these tables, it would have been unnecessary. For example, had Table 7.2 shown all the predecessors for Activity D (A, B, and C), it would have been correct but also unnecessary because A is the predecessor for B and C, and hence listing A would have been redundant. The point: once dependencies have been thoroughly checked, only the immediate predecessors for each activity need be known to construct a network.

Creating a project network

A project network is created using a list of activities from the WBS and their predecessors. If done by hand, the process is trial and error, and the network might have to be redrawn a few times before it is correct. Even if done by computer, good practice is to first sketch out the network by hand to create an initial ("coarse-grained") network and then enter the data into a computer. This affords the project manager an intuitive "feel" for the project. The activities can be clustered into higher-level subnetworks that represent, for example, subprojects or project phases. Project phases are normally conducted in series, although, as mentioned, discretionary dependencies can be eliminated so phases can be overlapped and *fast-tracked*. Even when phases overlap, however, it is still necessary to define their start and end points so that the phases can be authorized and milestone payments approved.

In lengthy projects, the network might show detailed activities only for the early phases and rough clusters of activities for later phases. As a phase moves toward completion, details for activities in the next phase are added. This phased approach (called *rolling wave planning or progressive elaboration*) reduces the complexity of the network for a large project.

Computer software for creating networks is a convenience in small projects but a necessity in large projects. The resulting network should be reviewed for accuracy, omissions, and mistakes. As a rule, the network should be created only after a suitable scope statement and WBS have been developed (i.e. the list of work tasks should be created before—not while—the network is created). Afterward a Gantt chart can be developed, as explained later.

7.2 The critical path

Project networks are important tools for project planning and control. They are useful for determining *how long* the project will take (the *expected project duration*), *when* each activity should be scheduled to start and finish, and the *likelihood* of completing a project on time.

In general, the expected project duration, T_e, is determined by finding the *longest path* through the network. A "path" is any route composed of one or more activities connected in sequence. The longest path in the network from the start node to the end node is called the *critical path*, and its length is the expected project duration. Should any activity that forms part of the critical path (called a critical activity) take longer than planned (due to delays, interruptions, lack of resources, etc.), the entire project will also take longer than planned.

This concept is illustrated in the following example. The firm of Kelly, Applebaum, Nuzzo, and Earl, Assoc. (KANE) is working on the Robotics Self-Budgeting (ROSEBUD) project. Figure 7.4 shows the network. [Parts (a) and (b) of Figure 7.4 are very similar; for now, look only at (a).] The first phase in the project is systems design (Activity J), followed by the simultaneous phases of (1) purchase, assembly, and installation (Activities M–V–Y) and (2) software specification and purchase (L–Q). These two phases are followed by the last phase of the project, system test and user test (W–X).

How long will this project take? The first activity, J, takes 6 weeks; after J has been completed, activities on the paths M–V–Y and L–Q can begin. The activities on path M–V–Y will take 4 + 6 + 8 = 18 weeks, and the activities on path L–Q will take 2 + 8 = 10 weeks. Because Activity J takes 6 weeks,

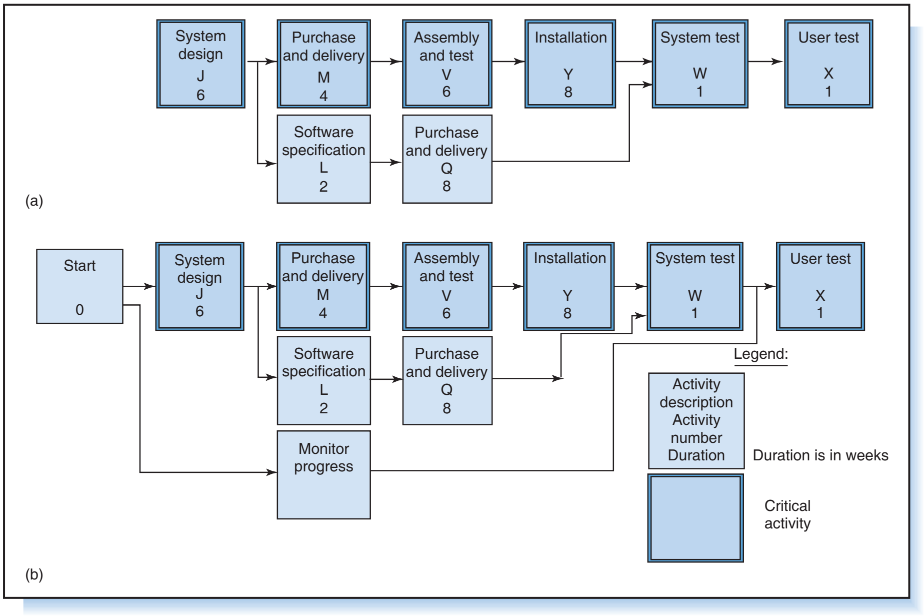


Figure 7.4
Network diagram for ROSEBUD project.

path M–V–Y will be completed in 6 + 18 = 24 weeks, and path L–Q will be completed in 6 + 10 = 16 weeks. The diagram implies that for Activity W to begin, *both* Activity Y and Activity Q must be finished. Thus, the earliest Activity W can begin is after 24 weeks. Activity W will be completed 1 week later, and Activity X will be completed 1 week after that. Thus, the ROSEBUD project duration (denoted as T_e) is $T_e = 24 + 1 + 1 = 26$ weeks.

Notice again from Figure 7.4(a) that there are two paths from the start node (J) to the end node (X). The shorter path, J–L–Q–W–X, is 18 weeks; the longer path, J–M–V–Y–W–X, is 26 weeks. In general, *the longest path*—the *critical path*—gives the project duration. The critical path is highlighted on the figure; activities with the darker "framed" boxes are critical.

If it becomes necessary to reduce the project duration, any reduction effort (e.g. reducing the time for an activity) must happen on the critical path. Shortening any critical activity by, say, 1 week would have the effect of shortening the project duration by 1 week. In contrast, shortening activities *not* on the critical path would have no effect on project duration. For example, had either L or Q been reduced by 1 week, then Activity Q would be completed in week 15 instead of week 16, but since Activity W must still wait on completion of Activity Y—which won't happen until after week 24—there would be no change in project duration.

As mentioned, the critical path is important for another reason: *any* delay among the activities on the critical path will result in a delay in the project completion. Should any critical activity be delayed by, say, 1 week, the project completion will be delayed by 1 week. Note, however, that noncritical activities can be delayed somewhat from their earliest possible dates without delaying the project. In fact, in the example, noncritical Activities L and Q can be delayed by up to 8 weeks. This is because normally they will be completed in 16 weeks, which is 8 weeks earlier than the activities on path M–V–Y will be completed, at 24 weeks. In other words, although activities on path L–Q can be completed as early as 16 weeks, it is okay if they are completed as late as 24 weeks. Thus, the critical path shows the project manager which activities are most critical to completing the project on time. To prevent delays, the project manager should focus on the critical activities.

Although the critical path is important, that doesn't mean the project manager can ignore noncritical activities. Whenever a noncritical activity is delayed, the path to which it belongs gets longer. When the length of a noncritical path grows to exceed the critical path, the former noncritical path becomes critical and the (former) critical path becomes noncritical! In other words, the critical path changes.[1] This change can happen without warning and leave the project manager focused on the wrong activities. One solution is to signal a warning when a noncritical activity is at risk of becoming critical; this happens in the *critical chain* method, discussed in the next chapter.

Figure 7.4(b) illustrates an activity that "spans" multiple other activities, called a *hammock*. The activity "Monitor progress" is a hammock because it covers every activity in the project except "User test," implying that the project manager is responsible for monitoring progress on every activity except "User test." The duration of a hammock is determined by the duration of the longest path of activities it spans; in Figure 7.4(b), this is 6 + 4 + 6 + 8 +1 = 25 weeks. Note, however, that although a hammock spans a portion of the longest path, it is not considered a critical activity. (The term hammock can also refer to a *summary activity*; e.g. a set of activities aggregated into one work package.)

A final example network is Figure 7.5; it has four paths leading from start node H to end node Z:

a.	H–J–P–Y–Z	35 weeks
b.	H–J–K–V–X–Y–Z	42 weeks
c.	H–J–M–R–V–X–Y–Z	47 weeks
d.	H–J–L–Q–T–Z	32 weeks

The longest of the four paths is Path c (indicated by the "shadowed" boxes); hence, c is the critical path and $T_e = 47$. (In Figure 7.5, notice the arrow between X and Z is unnecessary: if Z follows Y and Y follows X, then it goes without saying that Z must follow X!)

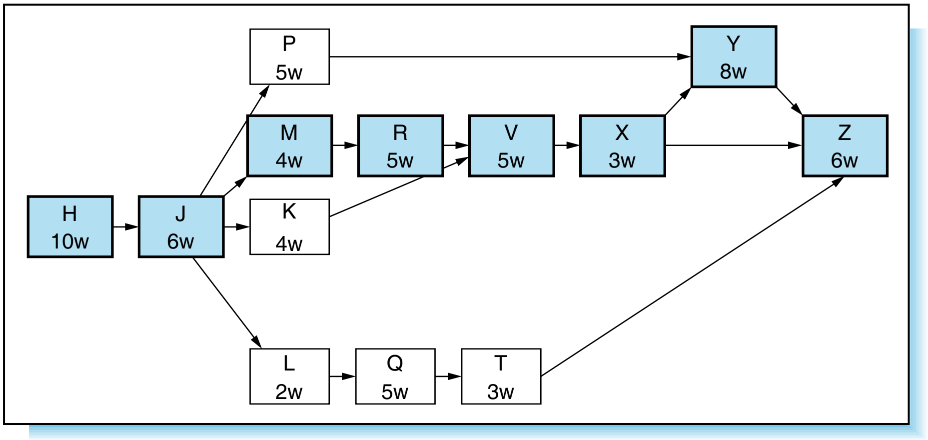


Figure 7.5
Example network showing the critical path.

Multiple critical paths

Can a project have more than one critical path? In a word: yes. Suppose the duration of Activity L in Figure 7.5 were 17 weeks instead of 2 weeks. In that case, the durations of path M–R–V–X–Y and path L–Q–T would both be 25 weeks. The project would have *two* critical paths, both with duration 47 weeks, and the project would be delayed if a delay were to occur on *either* critical path. If, however, the project duration had to be *shortened* to less than 47 weeks, it would then be necessary to shorten *both* critical paths.

Early times: early start and early finish

Scheduling each activity in a project involves, at the minimum, specifying when the activity must be started and finished. The scheduling procedure depends on whether the project is assumed to start "at Time 0" or "on day 1." It makes a difference. The procedure described subsequently is based on the more common "Time 0" assumption; Appendix B to this chapter describes scheduling under the "day 1" assumption.

The formula for computing finish time given the start time and activity duration is:

$$\text{Finish time} = \text{Start time} + \text{Duration}$$

These start and finish times for an activity are represented on the network as "early times": (1) the *early start* (ES) *time* and (2) the *early finish* (EF) *time*. They represent the earliest possible times that the activity can be started and completed.

But the ES of an activity depends on the EFs of its immediate predecessor, which is found by summing the durations of all the predecessor activities along the path leading to the activity in question. When an activity has more than one immediate predecessor, the ES for the activity will be determined by the immediate predecessor that has the *latest EF*.

All this is shown in Figure 7.6 Suppose the ES for the first activity, H, is 0 (meaning the project starts at time 0). Since Activity H's duration is 10 weeks, its early finish, EF, must be week 10. This was determined from the formula In Figure 7.6, ES is shown in the upper left of each node and EF on the upper right.

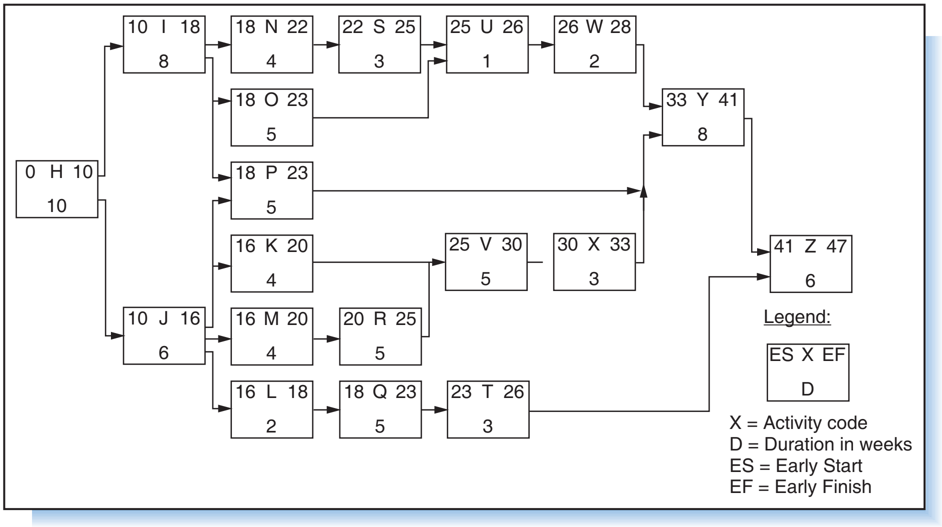


Figure 7.6
Example network showing ESs and EFs.

$$\text{EF} = \text{ES} + \text{Duration}$$

Given that Activity H's EF is week 10, Activity J's ES will be week 10 and its EF will be week 16. Activity I's ES is also 10, and its EF is 18. Activity J is the only immediate predecessor for activities K, M, and L, so the ES for activities K, M, and L will be week 16. Activity V has two immediate predecessor activities, K and R, meaning it cannot start until both have been completed. The EF for Activity K is the length of the path H–J–K, or 10 + 6 + 4 = 20; the EF for Activity R is the length of the path H–J–M–R, or 10 + 6 + 4 + 5 = 25. The ES for Activity V will depend on the later EF of its two immediate predecessor activities, which is R. Thus, ES for Activity V is week 25.

The same happens at Activity P: it has two immediate predecessor activities, I and J. Since Activity I's EF is 18 and Activity J's EF is 16, Activity P's ES must be week 18. Activity Y has three immediate predecessor activities, W, P, and X; Activity X has the latest EF, 33; thus, the ES for Activity Y is week 33. Finally, the ES for Activity Z is 41, the latest EF of its immediate predecessor activities and Y and T. Activity Z's EF is week 47, which gives the expected project duration, T_e, 47 weeks.

In summary, ESs and EFs are computed by taking a "forward pass" through the network. When an activity has only one immediate predecessor, its ES is simply the EF of the predecessor. When an activity has several immediate predecessors, its ES is based on the *latest* EF of all the immediate predecessors.

Late times: late start and late finish

As earlier discussed, a noncritical activity can be delayed without delaying the project; the question is: How much can it be delayed? To answer that easily, we must determine the "late times," that is, the latest allowable times an activity can be started and finished without delaying project completion. Just like the ES and the EF, every activity has a *late start* time, LS, and a *late finish* time, LF.

Refer to Figure 7.7. LS is shown on the lower left of each node, LF on the lower right.

To determine the late times, begin by assigning a *target completion date*, T_s, to the *last node* in the network. For projects that have to be completed *as soon as possible*, the date for T_s is the same as the *estimated completion date*, T_e, calculated in a forward pass—the EF of the last activity. For projects with a due date set by the customer or the sponsor, T_s is the due date, not the calculated T_e value.

To determine the late times, start at the *last activity* in the network and make a "backward pass" through the network using the formula:

$$\text{LS} = \text{LF} - \text{Duration}$$

In Figure 7.7, start with Activity Z. If T_s is 47 weeks, then LF for Activity Z is 47 and LS is 47 − 6 = 41; that is, Activity Z must start in week 41 for the project to end in week 47. Continuing backward, for Activity Y and Activity T, the LF is 41 weeks, and LS for Y is 41 − 8 = 33. Continue moving backward like this through each path, computing LF and LS for each activity.

Whenever we encounter an activity that has *multiple* paths leading backward to it (i.e. it has multiple *immediate successors*), it is the *earliest* (or *smallest*) EF of the immediate successors that determines the activity's LF. For example, Activity J has four paths leading backward to it (four immediate successor activities):

- LS for Activity P = 28
- LS for Activity K = 21 weeks
- LS for Activity M = 16 weeks
- LS for Activity L = 31 weeks.

Since the smallest (earliest) LS is 16 for Activity M, the LF for Activity J must be 16; this is the latest time Activity J can be finished to enable all of its successors to meet their late start times and thus complete the project by its target date of 47 weeks.

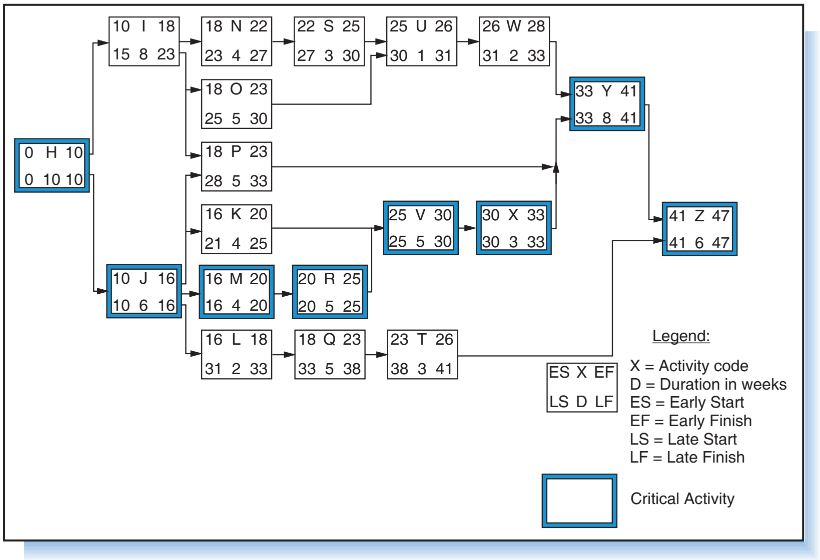


Figure 7.7
Example network showing LFs and LSs.

In summary, calculations for LFs and LSs start at the last node of the project network and work backward. When an activity has more than one path leading back to it, the smallest (earliest) value of LS among the immediate successors is the basis for determining the activity's LF. Having completed both forward and backward passes through the network, we now have the earliest possible and latest allowable scheduled times for every activity in the network. Once the forward and backward pass calculations have been completed, the durations of hammock activities become evident.

Total slack

Notice that for most activities in Figure 7.7, the early times and late times are not the same. The difference between LS and ES (or LF and EF) is referred to as *total slack* (also called "total float," or simply "slack" or "float") of an activity. Slack is the amount of allowable deviation between the latest an activity must take place and the earliest it can take place. It is the amount of time an activity can be delayed without delaying the project:

$$\begin{aligned}\text{Total Slack} &= \text{LS} - \text{ES}\\ &= \text{LF} - \text{EF}\end{aligned}$$

In Figure 7.7, the total slack for Activity H using start times is $0 - 0 = 0$ weeks; for Activity I, it is $15 - 10 = 5$ weeks, and so on. Notice that activities on the previously identified critical path H–J–M–R–V–X–Y–Z have zero slack; hence, these activities cannot be delayed by any amount without delaying the project. (The case where critical activities *do* have some slack is discussed later.) The activities that *do have* slack (which, as it turns out, are the *noncritical activities*) can be delayed from their earliest possible dates by their slack time without delaying project completion. Total slack is shown in Table 7.4.

When activities lie in sequence on a path, a delay in earlier activities will result in a delay to later ones; this is the equivalent of reducing slack for the remaining activities. In Figure 7.7, for example, activities L, Q, and T all lie on the same path and all have the same slack of 15 weeks. But if Activity L is delayed 5 weeks, then Activities Q and T will also be delayed 5 weeks and thus will have only 10 weeks of slack remaining, not 15. If, in addition, Activity Q is delayed 10 weeks, then Activity T will have no remaining slack and must be started immediately upon completion of Q. Having used up all their slack, Activities L, Q, and T would then all become critical activities. Once slack is used up, noncritical activities become critical activities, which means any further delays for these activities will delay project completion.

The practical implication of slack is that it gives the project manager flexibility regarding exactly when noncritical activities can be scheduled: they can be scheduled any time as long as it lies somewhere within the available slack—between the ES and LF times. Knowing the slack is important for managing resource workload. By starting some activities as early as possible and delaying others, the workload can be smoothed; this concept is discussed later. In general, when there are sufficient resources, noncritical activities are usually scheduled as early as possible (their ESs); this preserves slack and minimizes the risk of noncritical activities delaying the project. (Another method, called *critical chain* and discussed in the next chapter, schedules activities as late as possible.)

See Chapter 8

Notice that decisions about when exactly to schedule an activity require knowing *both* the late and early times for the activity. The implication is that a network analysis should be done *before* the Gantt chart is created. Most project management software develops networks and Gantt charts simultaneously, although they create Gantt charts using the early times. As discussed, however, activities should not necessarily be scheduled according to the early times.

Table 7.4 LOGON project time analysis (from Figure 7.7)

Activity	Duration (Weeks)	Start Node		Finish Node		Slack		Note
		ES (START OF WEEK)	LS (START OF WEEK)	EF (END OF WEEK)	LF (END OF WEEK)	Total*	Free**	
H	10	1	1	10	10	0	0	CP
I	8	11	16	18	23	5	0	
J	6	11	11	16	16	0	0	CP
K	4	17	22	20	25	5	5	
L	2	17	32	18	33	15	0	
M	4	17	17	20	20	0	0	CP
N	4	19	24	22	27	5	0	
O	5	19	26	23	30	7	2	
P	5	19	29	23	33	10	10	
Q	5	19	34	23	38	15	0	
R	5	21	21	25	25	0	0	CP
S	3	23	28	25	30	5	0	
T	3	24	39	26	41	15	15	
U	1	26	31	26	31	5	0	
V	5	26	26	30	30	0	0	CP
W	2	27	32	28	33	5	5	
X	3	31	31	33	33	0	0	CP
Y	8	34	34	41	41	0	0	CP
Z	6	42	42	47	47	0	0	CP
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	

Total Slack, (7) = (4) – (3) = (6) – (5)
Free Slack, (8) = [(3) of earliest successor] – (5)

**Total slack* is the spare time on an activity that, if used up and the activity delayed any further, delays successors and affects the end date of the project as a whole.

***Free slack* is the spare time on an activity that, if used up, does not affect the early start time of any succeeding activities (i.e., will not affect the total slack nor delay any successor).

Free slack

While *total slack* refers to the amount of time an activity can be delayed without delaying *the project*, the term *free slack* refers to the time an activity can be delayed without delaying *the start of any successor activity*. Free slack of an activity is determined by the formula:

$$\text{Free slack for activity} = \text{ES}\left(\text{earliest successor}\right) - \text{EF}\left(\text{activity}\right)$$

For example, in Figure 7.7, Activity I has a total slack of 5 weeks but free slack of 0 weeks because *any* delay in it will delay the start of activities N, O, and P. Activity O, on the other hand, has free slack of 2 weeks because its EF of 23 can be delayed to 25 without delaying the ES of its successor, Activity U, which is 25.

Knowing the free slack, managers can readily identify activities where slippages immediately impact other activities. When an activity has zero free slack, *any* slippage will cause at least one other activity to slip also. If, for example, Activity L slips, then so will Q and T, and teams working on Q and T (specified in the responsibility matrix) must be notified of the delay.

As with total slack, the amount of free slack available to an activity assumes the activity starts at its ES time. Thus, the free slack for Activity O is 2 weeks, as long as Activity I, its immediate predecessor, is completed at EF = 18. If Activity I is delayed by any amount, then Activity O's free slack will be reduced by that same amount.

Free slack is important because many activities are scheduled to start as soon as possible, and resources are booked to be available on these dates. If an activity is delayed, it can delay other activities and disrupt the schedules of everyone who planned to work on those activities. Moreover, such delays extend the period over which resources (e.g. equipment contracted at a daily or hourly rate) are needed and can lead to cost overruns.

Table 7.4 summarizes these concepts, showing ES, LS, EF, and LF and total and free slack for the LOGON project in Figure 7.7. Notice that for activities on the critical path, the total slack and free slack times are zero.

The effect of project due date

In discussing total slack, we assumed that the target completion date, T_s, was the same as the earliest expected completion date, T_e. But, in fact, the target completion date can be set to be either later or earlier than T_e to reflect a customer's or supporter's wishes.

Setting the target date to *later* than T_e has the effect of *increasing* total slack for every activity in the project by the amount $T_s - T_e$. Although no longer zero, the slack on the critical path will still be the smallest slack anywhere in the network. For example, if the target completion date for the project in Figure 7.7 were increased to $T_s = 50$ weeks, then the total slack in Table 7.4 would be $50 - 47 = 3$ weeks for all critical activities and 3 *additional* weeks for all noncritical activities.

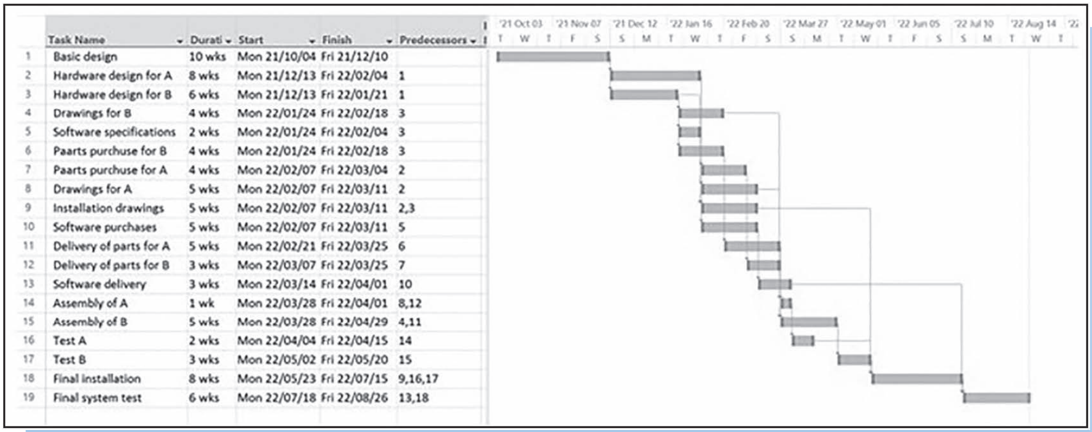
If T_s is set *earlier* than T_e, then total slack times everywhere in the project will be reduced by the amount $T_s - T_e$, and activities along the critical path will have *negative* slack times. The size of this negative slack is the amount of time by which the project duration must be reduced to meet the target completion date. (Note, altering T_s has no influence on free slack times: these depend on early start and early finish times, both of which are affected the same amount when changing T_s.)

In general, projects must be completed either as soon as possible or by a predetermined due date. For projects that have to be completed as soon as possible, the project manager does a forward-pass calculation through the network, then commits to the computed T_e. For projects that must meet a predetermined due date, the project manager substitutes T_s at the last event, then works backward through the network, noting the feasibility of speeding up activities in the project to eliminate negative slack times on the critical path.

7.3 Converting to Gantt calendar schedules

Using information from tables such as Tables 7.2 or 7.3 to create a network with activity start and finish times is a simple procedure that requires no management decisions and can readily be performed by computer software. To be usable, however, the times in the network must be converted into dates (day, month, and year) on either a Gantt chart or an actual calendar. But converting network times to a Gantt or calendar schedule is not a simple procedure and *does* require management decisions.

For starters, the Gantt or calendar schedule must account for *non-working time* such as weekends, holidays, and vacations. Figure 7.8 shows the LOGON project schedule as produced by Microsoft Project software and incorporating time off for weekends and holidays.



	Task Name	Durati	Start	Finish	Predecessors
1	Basic design	10 wks	Mon 21/10/04	Fri 21/12/10	
2	Hardware design for A	8 wks	Mon 21/12/13	Fri 22/02/04	1
3	Hardware design for B	6 wks	Mon 21/12/13	Fri 22/01/21	1
4	Drawings for B	4 wks	Mon 22/01/24	Fri 22/02/18	3
5	Software specifications	2 wks	Mon 22/01/24	Fri 22/02/04	3
6	Paarts purchuse for B	4 wks	Mon 22/01/24	Fri 22/02/18	3
7	Paarts purchuse for A	4 wks	Mon 22/02/07	Fri 22/03/04	2
8	Drawings for A	5 wks	Mon 22/02/07	Fri 22/03/11	2
9	Installation drawings	5 wks	Mon 22/02/07	Fri 22/03/11	2,3
10	Software purchases	5 wks	Mon 22/02/07	Fri 22/03/11	5
11	Delivery of parts for A	5 wks	Mon 22/02/21	Fri 22/03/25	6
12	Delivery of parts for B	3 wks	Mon 22/03/07	Fri 22/03/25	7
13	Software delivery	3 wks	Mon 22/03/14	Fri 22/04/01	10
14	Assembly of A	1 wk	Mon 22/03/28	Fri 22/04/01	8,12
15	Assembly of B	5 wks	Mon 22/03/28	Fri 22/04/29	4,11
16	Test A	2 wks	Mon 22/04/04	Fri 22/04/15	14
17	Test B	3 wks	Mon 22/05/02	Fri 22/05/20	15
18	Final installation	8 wks	Mon 22/05/23	Fri 22/07/15	9,16,17
19	Final system test	6 wks	Mon 22/07/18	Fri 22/08/26	13,18

Figure 7.8
LOGON project schedule adjusted for holidays and weekends.

In addition, a calendar schedule must account for issues that require analysis and management decisions; examples include:

- *Resource constraints*: a work package is delayed because the necessary resources are unavailable or must be shared with other parallel activities.
- *Cash flow*: procurement of an expensive piece of equipment must be delayed in order to defer cash outlay, improve cash flow, or await an exchange rate improvement.
- *Risk of changes*: a design activity is postponed due to changes in project scope or in technologies.
- *Logistics*: the acquisition of a bulky item for construction is delayed until space becomes available at the construction site.

Computer software can readily generate the project network, Gantt chart, and calendar schedule, but unless issues like those listed previously are accounted for, the schedule will be infeasible, unworkable, or too risky. The point is, project scheduling involves more than merely creating a computer-generated version of the project network; it requires analysis and management judgment. Thus, the Gantt chart should be created only *after* a network analysis has set the early and late dates and issues and constraints surrounding the project have been resolved.

7.4 Management schedule reserve

In common practice, the contractual or committed target completion time T_s is not simply the estimated completion time T_e plus allowance for non-working time but rather is some time *after* that and includes a *management schedule reserve*. This chapter has treated activity times and project durations as if they are fixed. Of course, each project is unique, and until it is actually completed, its duration is only an estimate (a best guess). All time estimates (of projects and of the activities that compose them) are subject to uncertainty; the more unique the project, the larger the uncertainty. To account for that uncertainty, a management schedule reserve is added to the estimated duration. This reserve constitutes a "safety buffer" or "time buffer" to accommodate any project delays. Time buffers are discussed in the next chapter.

See Chapter 8

7.5 Alternative relationships[2]

The network scheduling procedures discussed earlier assume a sequential relationship wherein the start of an activity is predicated upon the completion of its immediate predecessors. Such is the case illustrated in the diagram in Figure 7.9, where Activity B starts upon completion of Activity A. This strict start-only-when-predecessors-finish relationship is called *finish-to-start*, FS. The limitation of this assumption is that it precludes those kinds of tasks that can be started when their predecessors are only *partially* (but not fully) completed. For example, when a company relocates to a new facility, the activity "move in employees" would be able to start after *some* of the activity "move in furniture" has been done; that is, "move in employees" can begin *before* its immediate predecessor "move in furniture" has been completed. The *precedence diagramming method* allows for this and similar such situations. Besides the usual FS relationship, PDM also permits other relationships such as start-to-start (SS), finish-to-finish (FF), and start-to-finish (SF). It also allows for lags between the times activities must be started or finished. These relationships are described next.

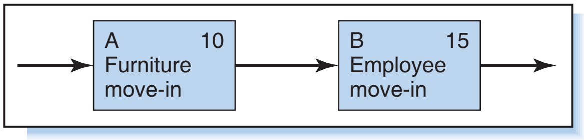


Figure 7.9
Example of FS relationship.

Start-to-start

In an SS relationship between two activities, A and B, the start of B can occur at the earliest *n* days after the start of its immediate predecessor, A. This is diagrammed in Figure 7.10.

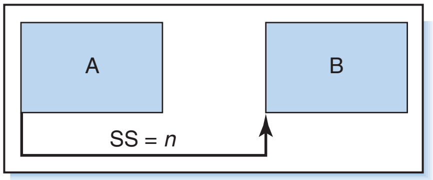


Figure 7.10
PDM representation of SS relationship with *n*-day lag.

Using the example from Figure 7.9, suppose that "move in employees" can begin 5 days after the start of "move in furniture"; the network diagram and associated Gantt chart for the two activities would appear as in Figure 7.11. The *n*-day delay is called *lag*—the start of B lags that of A by *n* days, that is, A and B overlap. (Confusingly, it is also called *lead*, as "the start of A leads that of B by *n* days.")

Finish-to-finish

In an FF relationship between two activities, A and B, B will finish *n* days at the latest after A finishes. An illustration is in Figure 7.12, where the finish of "paint parking lines" (B) must occur within 5 days of

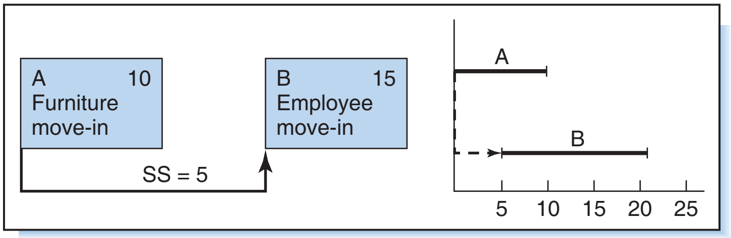


Figure 7.11
Example of SS relationship.

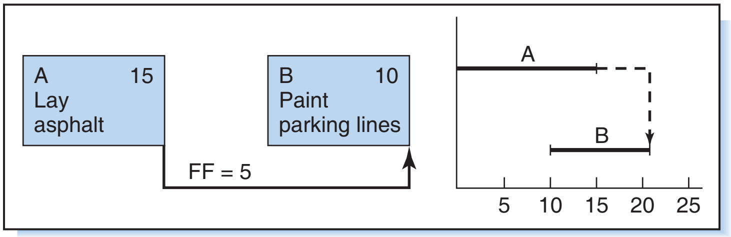


Figure 7.12
Example of FF relationship.

the finish of "lay asphalt" (A). An FF relationship with zero lag means the activities must finish at the same time.

Start-to-finish

In an SF relationship, the finish of Activity B must occur at the latest *n* days after the start of Activity A. For example, "phase out old system" (B) cannot finish until 25 days after "test new system" (A) begins. This is shown in Figure 7.13.

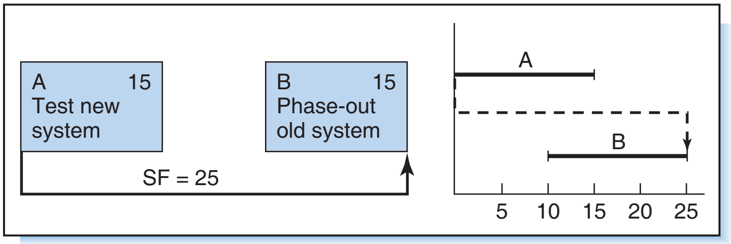


Figure 7.13
Example of SF relationship.

Finish-to-start

In an FS relationship, Activity B can start at the earliest *n* days after Activity A is finished. For example, "tear down scaffolding" (B) can start no sooner than 5 days after "plaster walls" (A) is finished. This is shown in Figure 7.14. Note that when $n = 0$, the FS relationship becomes the same as the traditional AON network method wherein the start of a successor coincides with the completion of its latest predecessor.

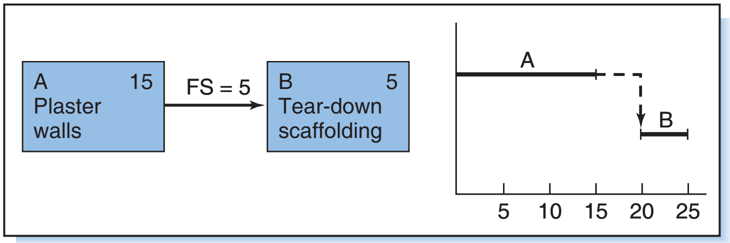


Figure 7.14
Example of FS relationship.

Multiple relationships

Two PDM relationships can be used in combination. Having both SS and FF is a rather common case. Notice in the example shown in Figure 7.15 that because B must finish no later than 10 days after A finishes, the start of B must occur at day 10. But suppose B is an *interruptible* activity (i.e. the work in B can be stopped and then resumed). In that case, B could instead be started 5 days after the start of A *and* finish 10 days after A finishes. This is represented in Figure 7.16. The assumption is that the 15 days of work for B will be performed sometime within the 20 days allotted between days 5 and 25. Notice that the 20 days allotted for Activity B give that activity two possible slack values, LS − ES = 5 or LF − EF = 0. PDM usually observes the smallest slack value, here 0.

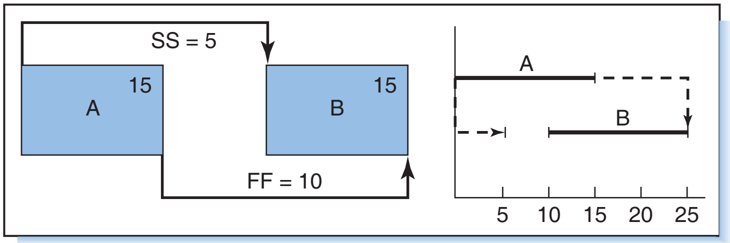


Figure 7.15
Schedule for non-interruptible Activity B.

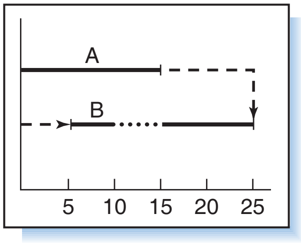


Figure 7.16
Schedule for interruptible Activity B.

Example 7.1: PDM in ROSEBUD Project

Figure 7.17 shows the AON diagram for the ROSEBUD project, and Figure 7.18 shows the corresponding "time-scaled network," which is a form of Gantt chart that explicitly shows dependencies among the activities.

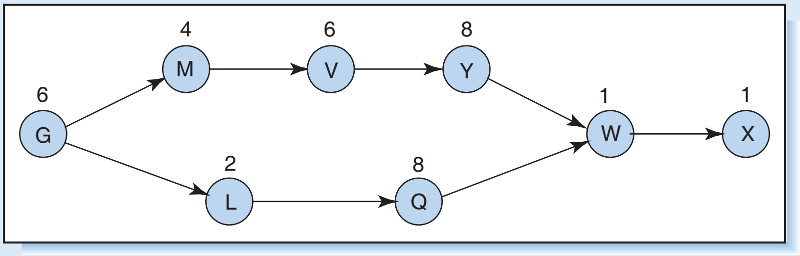


Figure 7.17
AON diagram for ROSEBUD project.

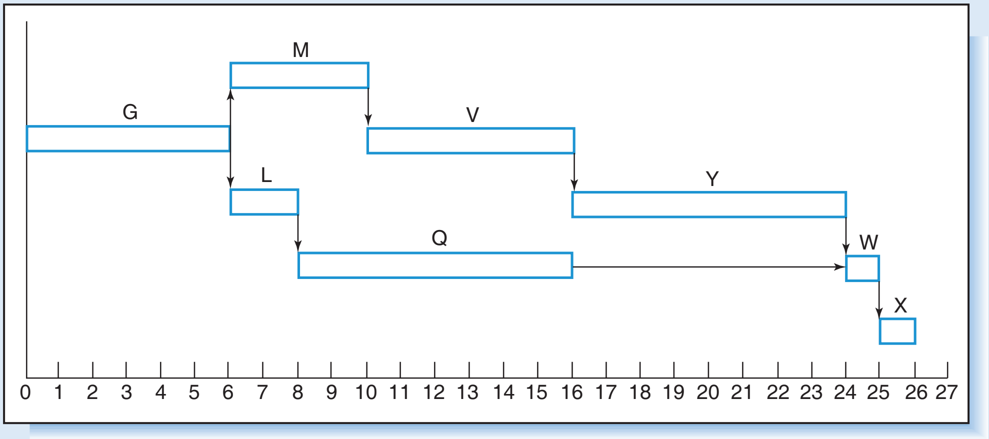


Figure 7.18
Time-scaled network for ROSEBUD project.

The network will now be altered to permit the following special relationships:

1. Activity L can begin 3 days after Activity G begins, but it cannot be finished until G is also finished.
2. Activity Y can begin 2 days after Activity V begins, but it cannot be finished until at least 6 days after V is finished.
3. Activity W can begin 5 days after Activity Y begins, but it cannot be finished until Y is also finished.
4. Activity X cannot be started until at least 1 day after Activity W is finished.

The PDM network in Figure 7.19 shows these relationships. Figure 7.20 shows the corresponding time-scaled network assuming earliest start dates and allowing for interruptible activities.

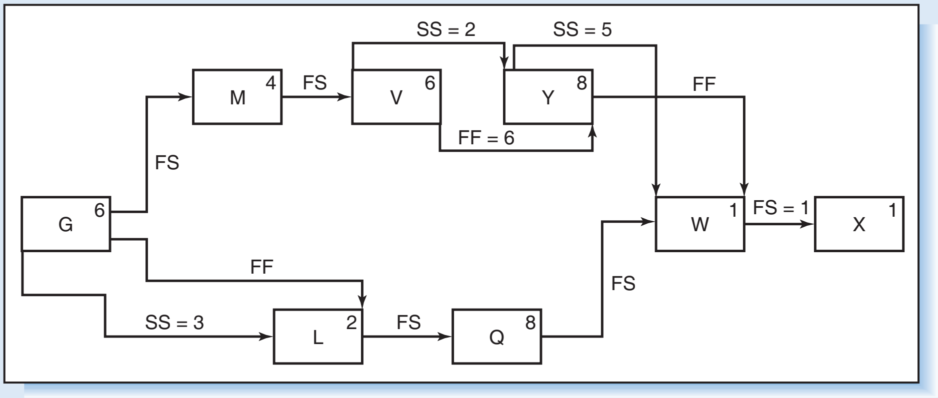


Figure 7.19
PDM network for ROSEBUD project.

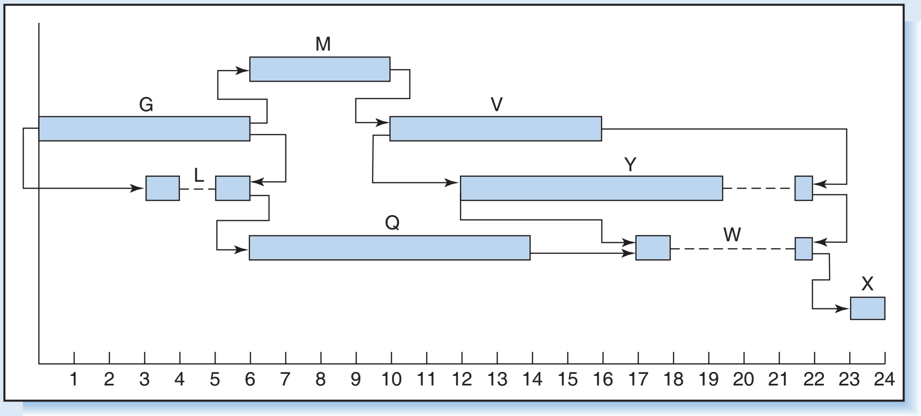


Figure 7.20
Time-scaled network for ROSEBUD project revised for PDM.

A traditional FS network can handle relationships where FS > 0 by creating artificial activities, but it has no way of incorporating SS, FF, or SF; thus, the obvious advantage of PDM is that it permits greater scheduling flexibility. The tradeoff is that PDM networks are more complex and require greater care both in their creation and interpretation. Because activities do not follow a neat FS sequence, finding the critical path and slack times is not so simple either. Complex precedence relationships also cause counter-intuitive results. For example, in a simple network, the way to reduce the project completion time is to reduce the duration of activities on the critical path; doing the same thing in a PDM network, however, does not necessarily shorten the project. In the previous example, the critical path is G–M–V–Y–W–X. Suppose we decide to reduce the time on Activity Y. Because of the precedence requirement that Y cannot finish sooner than 6 days before V finishes, the completion date of Y cannot be changed. Thus, any shortening of the duration of Y serves to *move back* the start date of Y. Because of the precedence requirement, moving back the start date of Y results in moving back the start date of W and, as a result, the start date of X. In other words, shortening critical Activity Y actually causes an *increase in the project duration*.

In general, interpreting a PDM network requires more care than ordinary AON networks. However, such care is relatively inconsequential when the PDM network is created with project management software.

7.6 Scheduling with resource constraints

While people think project scheduling means scheduling work tasks or activities, it is more urate to think of it as *scheduling resources*. Every activity requires resources—people, equipment, material, working capital, and so on—and whenever an activity is scheduled, that means resources *are scheduled, too*. So far, we have assumed that such resources would always be available when needed. But, of course, resources are not always available, and when they are not, *the schedule must be changed to whenever the resources will be available*. We now consider project scheduling when resources are constrained and the effect it has on workload and project duration.

Resource availability and project duration

Very often the availability of skilled workers, equipment, and working capital dictates whether activities can be scheduled at their early times or must be delayed. This is especially true when multiple activities requiring the same resource are scheduled for the same time; when resources are not sufficient to satisfy the needs of all of them, some activities must be delayed. Figure 7.21 illustrates this: (a) shows the network, and (b) shows the project schedule, not accounting for the resources. Suppose Activities B and C both require a resource that can be used by only one of them at a time. In that case, the schedule must be revised; (c) shows two alternatives.

In general, projects tend to be either *resource constrained* or *time constrained*. In a resource-constrained project, such as shown in Figure 7.21, the resources are limited, and the project completion date is determined by the availability of those resources. In a time-constrained project, the project completion date is fixed, and the resources must be found to meet that date.

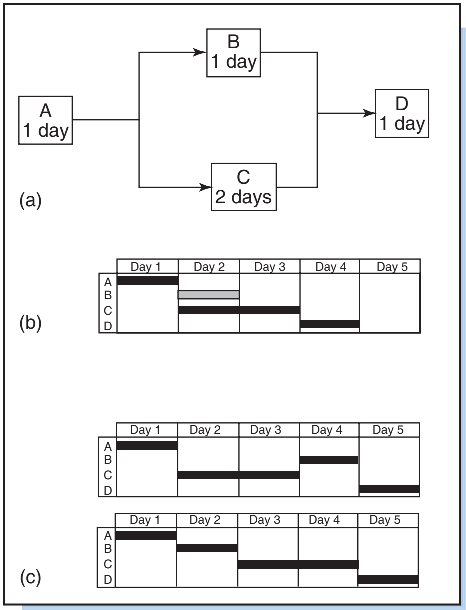


Figure 7.21
The effect of a constrained resource on schedule. (a) Network diagram; (b) Gantt chart, case where resource is unlimited; (c) Gantt charts, case where same resource is limited and must perform Activities B and C.

Resource allocation, workload, and resource loading

The terms resource allocation, workload, and resource loading convey related but different concepts. *Resource allocation* refers to assigning one or more resources to an activity or project. *Workload* refers to the amount of work imposed on a resource. *Resource loading* refers to the amount of a particular resource needed to conduct all the activities in a project to which the resource is allocated. For an *individual resource* (such as a person), the workload can be specified either as a percentage of the resource's full workload potential or, more commonly, in units such as labor hours. For a *facility* or *labor category* (such as a department of workers with specific skills), the workload is specified in terms of number of workers. Since all the people in a labor category (such as "computer programmer") seldom have exactly the same skills, ordinarily it is better to allocate a specific person (a specific programmer) rather than a labor category to an activity. The usual assumption when allocating people from a labor category is that everyone in the category is equally capable; often, though, after the work begins, it becomes evident that not everyone is.

The workload that an individual can handle in a year is computed as the number of working days (excluding holidays and all types of leave) times the number of productive (working) hours per day. Many companies have guidelines restricting the number of hours an individual should work on projects per week, month, or year. In a matrix organization, functional managers are responsible for ensuring that each worker's time is well utilized and her workload does not exceed a recommended maximum.

Workload is always from the perspective of the particular resource; in contrast, resource loading is from the perspective of the *project*. It is the number of hours, people, or other units of a particular resource needed at a given time in a project (or in multiple concurrent projects). Resource loading is important, since virtually all resources are finite, and many are scarce. Thus, the resource loading (total amount of the resource needed for a project or multiple projects at a given time) cannot exceed the amount available. When resources are scarce, their allocation is constrained, and sometimes activities in a project must be rescheduled to accommodate the scarcity. The example in Figure 7.21 was such a case: Activities B and C require the same resource, but the resource cannot be used in both at the same time. Resources that are available in sufficient quantity do not pose an issue and can be ignored for scheduling purposes (breathable air is an example—except when the project is conducted under water or in outer space where air is limited!).

The following sections consider two cases where the project schedule must be altered to accommodate resources. The first is called *resource leveling* in a *time-constrained project*. In this case, there is enough of the resource to complete the project on time; however, the quantity of the resource needed fluctuates throughout the project, making it difficult to manage the resource. The objective of resource leveling is to level the amount of the resource needed throughout the project. The second case is the situation mentioned before, the *resource-constrained project*—not having enough of a resource to do multiple activities at the same time.

Leveling a time-constrained project

Because the loading for a particular resource depends on the amount of the resource needed by project activities and the start and finish dates of those activities, the loading for a particular resource tends to vary throughout a project. A common resource-loading pattern in a project is a steady buildup in the amount of the resource needed, a peak, and then a gradual decline. Thus, relatively little of the resource is needed early and late in the project, but much is needed in the middle. This pattern is problematic for functional managers who oversee a fixed pool of workers and equipment, because it results in the pool being either underworked or overworked. Certainly better would be a relatively uniform workload on the resource pool. This is the purpose of resource leveling: to alter the schedules of project activities such that the resultant workload for a required resource is somewhat uniform throughout the project.

Figure 7.22 shows the schedule for the LOGON project and the resultant resource loading—here the resource being workers of a particular skill or trade (programmers, steel worker, etc.). The loading, bottom of Figure 7.22, is created from the schedule, top of Figure 7.22, and the weekly labor requirements in Table 7.5; it shows week by week the number of workers needed in the project. For example, for the first 10 weeks, only Activity H is scheduled, so the loading for those weeks is 5 workers (the weekly labor requirement for H). Over weeks 10–16, Activities I and J are scheduled, so the loading, based on their labor requirements, becomes 4 + 8 = 12, and so on.

From Figure 7.22, you can see that the loading for the LOGON project might pose a problem because it fluctuates so much, varying from a maximum of 23 workers in week 26 to zero workers in weeks 24 and 25 (perhaps Activities R, S, and T are outsourced and do not require any workers). The problem facing the manager allocating these workers to LOGON is what to do with excess workers in slow periods and where to get additional workers in peak periods.

A way to handle the problem is to adjust the worker loading so it is more "level." This is done by "juggling" activities—by taking advantage of slack times and delaying noncritical activities so as to reduce workload peaks and fill in workload valleys. For example, the somewhat smoothed workload in Figure 7.23 is achieved by delaying Activities P and Q (and hence T) by 2 weeks and U (and hence W) by 5 weeks.

Although resource leveling is often necessary to reduce workload fluctuations, it potentially increases the risk of project delays because it reduces slack time. Less slack time means greater risk that an activity will not be completed by its late finish date. In Figure 7.23 delaying Activities U and W makes them critical (no slack remaining), so any delay in either will delay the project.

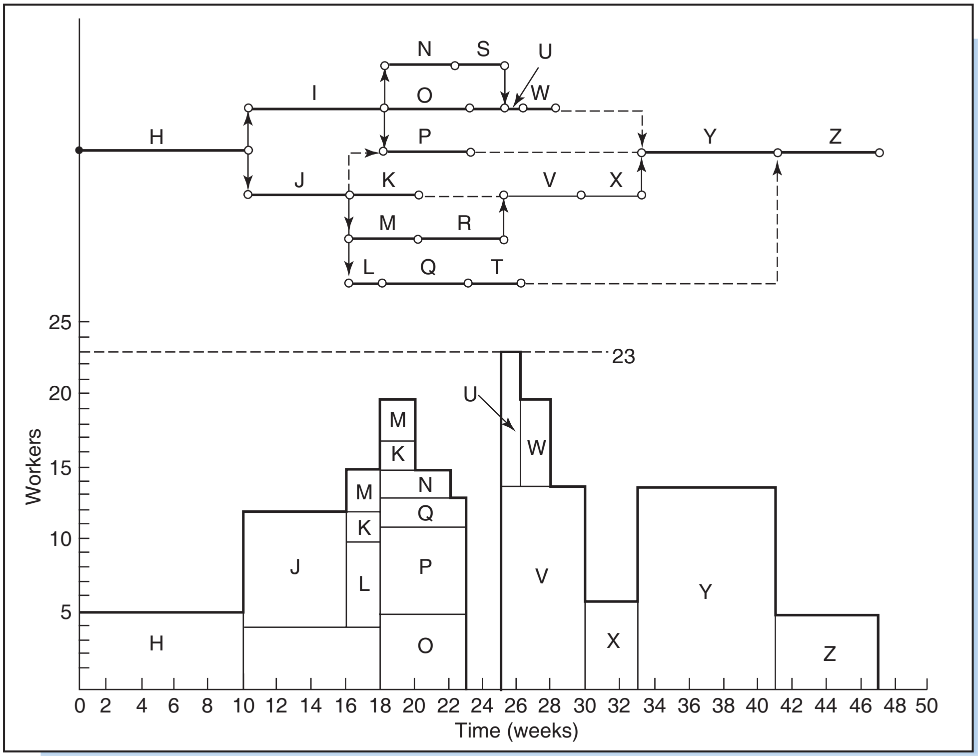


Figure 7.22
Schedule and corresponding worker loading for the LOGON project.

Table 7.5 LOGON project weekly labor and equipment requirements.

Activity	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z
Weekly Labor Requirements (workers)	5	4	8	2	6	3	2	5	6	2	0	0	0	9	14	6	6	14	5
Weekly Equipment Requirements (hours)	8	2	6	1	2	2	0	0	6	0	4	4	0	8	8	8	8	8	8

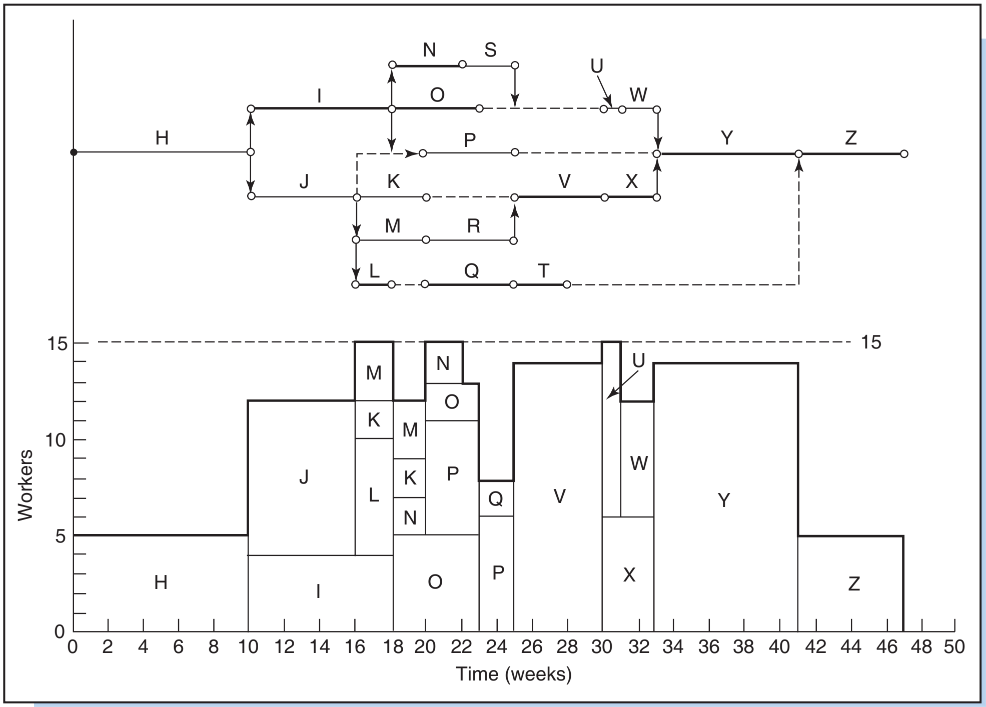


Figure 7.23
Smoothed worker loading for the LOGON project.

Splitting activities, multitasking, and handover points

In the previous example, an even more uniform loading could have been achieved if activities were split and the pieces scheduled at different times. Whether this is feasible depends on whether a job, once started, can be interrupted and then restarted later. As discussed earlier, project activities and work packages are defined during the WBS process, and these activities become the basis for establishing schedules, budgets, and so on. Once an "activity" has been defined in the WBS, it cannot be arbitrarily "split" later on.

Although activity splitting can lead to a more uniform loading, the downside is that it can lead to wasted time and longer activity durations. Figure 7.24 illustrates how this happens. Uninterrupted, the activity starts slowly but then builds momentum as it moves ahead. Split into pieces, each piece starts

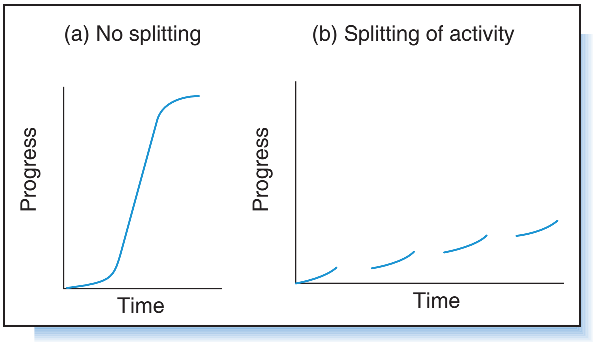


Figure 7.24
The effect of splitting of an activity on duration.

slowly and never gains momentum. The sum of the durations of the pieces in (b) exceeds the duration in (a). The effect, called *multitasking*, leads to slower-paced work on average and extends the activity duration. The moral is, once an activity has been started, it is usually better to finish it uninterrupted.

Multitasking, wherein the work is stopped and then resumed, should not be confused with work that continues uninterrupted but has multiple *handover points*. The handover concept is illustrated in Figure 7.25, where the design and build activities each progress uninterrupted, although multiple handover points (called "laddering") enable the build activity to start and continue well before the entire design activity (encompassing Design A + Design B + Design C) is completed. Although the activities appear to be split (Design A, Design B, Design C), in fact they are not, since there is no time lag between them. The method shortens the project duration and facilitates interaction between designers and builders.

Leveling multiple resources

Leveling is easy for a single resource but can be difficult for several simultaneous resources. Because work packages usually require resources from more than one functional unit or subcontractor, a schedule that

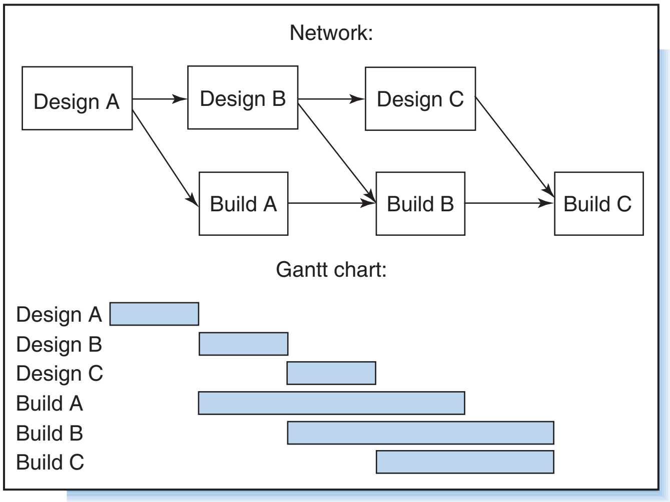


Figure 7.25
Multiple handover points of an uninterrupted activity.

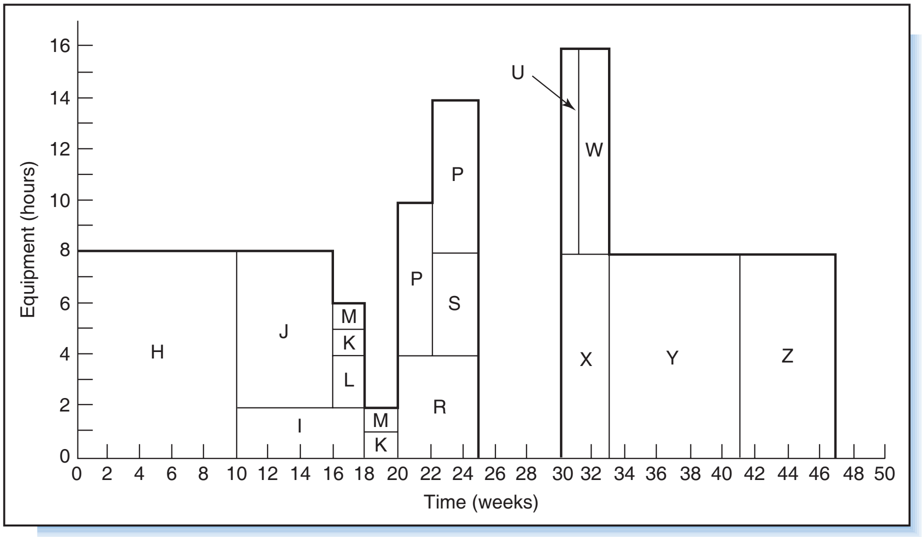


Figure 7.26
Equipment loading for the LOGON project.

provides a level loading for one unit may cause overloading or difficult-to-manage situations for others. For example, based on the weekly equipment requirements for LOGON shown in Table 7.5, the schedule that provides the somewhat level *worker* loading in Figure 7.23 yields the erratic *equipment* loading shown in Figure 7.26. An attempt to level the equipment loading by adjusting or delaying activities will disrupt the worker loading. As you can verify, the schedule in Figure 7.22 that produces the erratic loading for workers yields a relatively level loading for equipment.

It is impossible to completely level the load for all resources at once. The best results arise from applying the scheduling equivalent of the "Pareto optimum"; that is, schedule activities in the best interests of the project while trying to minimize the number of conflicts and problems in the departments and contractors that supply the resources. When considering multiple resources simultaneously, focus on leveling the "priority" resources—those where irregular loadings are the most costly to the organization or demoralizing to workers. The financial and social costs associated with hiring, overtime, and layoffs often dictate giving human resources—the workers—the highest priority. Many project software packages perform scheduling analysis that permit simultaneous leveling of multiple resources.

Delaying activities is one method to level resources; others are to:

- Eliminate some activities or work segments (reduce project scope).
- Substitute some resources for others.
- Substitute high-resource activities with lower-resource activities.

For example, when the most qualified workers are not available, either eliminate the work that requires their expertise or use less qualified workers. These options, however, might compromise the scope or quality of the work and increase the risk of the project not meeting requirements.

Leveling a resource-constrained project

What happens when the number of personnel, pieces of equipment, or available working capital are strictly limited? This is a resource-constrained project. Activities in the project must be scheduled so that the loading of a particular resource to the project does not exceed the available maximum. The focus differs from time-constrained resource leveling because the issue is the resource's *maximum* requirement, not its loading *variability*. As each activity is scheduled, the sum of its required resources plus the resources required for activities already scheduled at the same time must be checked against the maximum. The problem is more than just leveling of resources; it involves rescheduling jobs or delaying them until the resources become available.

In the LOGON project, for example, suppose only 14 workers are available in any given week. The "leveled" schedule in Figure 7.23 resulted in a maximum loading of 15 workers. To reduce the loading to the 14-worker maximum, some activities will have to be delayed beyond their late start dates, which will delay the project beyond 47 weeks. With a problem like this, something has to give, because it is not possible to satisfy both the 14-worker limitation *and* the project deadline of 47 weeks. Figure 7.27 shows a schedule that satisfies the 14-worker constraint. It was determined by trial and error, making certain not to violate either the precedence requirements or the 14-worker limit. Notice that the project now requires 50 weeks to complete because Activity X had to be delayed 3 weeks beyond its late start date.

As the example shows, a resource needed by multiple activities can dictate the project duration and override the critical path time. Consider another example from the LOGON project. Suppose one important resource is a technical inspector who has the skills to inspect a wide variety of activities. Her work, however, is exacting, which prevents her from working on more than one activity at a time. Suppose the activities in which she will be working are H, J, P, K, L, V, and X. These activities are highlighted in Figure 7.28. Because she can work on them only one at a time, the activities must be scheduled sequentially. Summing the durations of these activities gives the time required

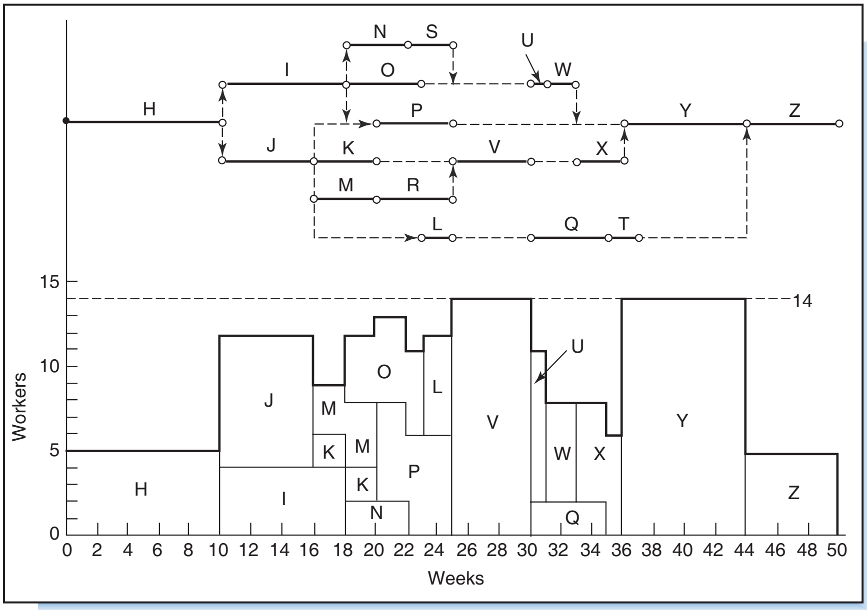


Figure 7.27
Schedule and corresponding worker loading for the LOGON project with 14-worker constraint.

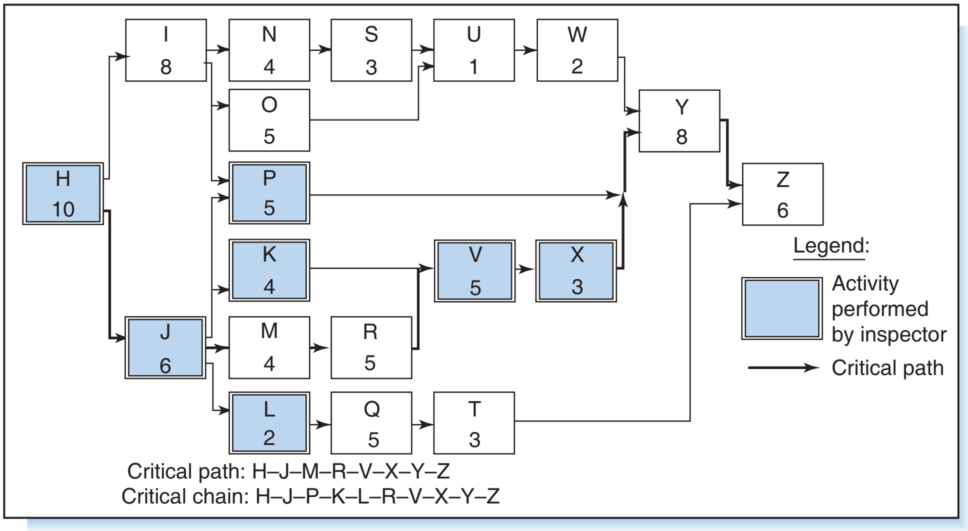


Figure 7.28
Activities in the LOGON project involving the resource of technical inspector.

for her to inspect all of them, 35 weeks. Add to this the times for the last two activities, Y and Z, and the total is 49 weeks. Thus, the project duration will be 49 weeks, not 47 weeks as determined by the critical path.

Goldratt calls the path connecting activities that require the same constrained resource the *critical chain* (here, H–J–P–K–L–V–X plus Y and Z) and distinguishes it from the critical path (H–J–M–R–V–X–Y–Z).[3] Back in Figure 7.21, the critical path is A–C–D, but the critical chain is A–C–B–D or A–B–C–D. The significance of this is that when activities must be performed sequentially due to a constrained resource and when the sum of the durations of those activities, the critical chain, exceeds the length of critical path, it is the critical chain—*not* the critical path—that sets the project duration. This is further discussed in Chapter 8.

See Chapter 8

Scheduling with constrained resources involves deciding which activities should receive resources and be scheduled immediately and which should be delayed until resources are available.

The constrained-resource problem also occurs in multiproject organizations that draw resources from a common pool. To schedule activities for any one project, managers must account for the resources required by other, concurrent projects. The result is that schedules for some projects are determined in part by when resources will be freed up from other, higher-priority projects. Complex resource-constrained scheduling situations like this call for software-generated solutions, which typically use *heuristics* (simple rules that yield good results) to create schedules. Some of these heuristics are discussed in the next chapter.

7.7 Criticisms of network methods

Network methods have been criticized because they incorporate assumptions and yield results that are sometimes unrealistic. For example, they assume that a project can be completely defined up front in terms of identifiable activities with known precedence relationships. In many projects, however, not all work tasks can be anticipated or clearly defined at the start. Rather, the project "evolves" as it progresses. But this is a problem with scope planning and activity definition, which plagues every scheduling method, not just networks.

A related problem is that activities and durations require periodic modification; a partial reason being that the network has many activities that are not well defined. This problem can be addressed by creating an initial "rough" schedule and then developing more detailed schedules in a phased approach (discussed in Chapter 4) and by avoiding "proliferation" of activities, that is, keeping the number of activities in the schedule to a minimum, as prescribed in the work definition guidelines in Chapter 6.

See Chapters 4 and 6

In short, the failings of networks are actually inadequacies in project definition. It can be argued (and many project managers will attest) that network methods, though not perfect, offer a good approach for analyzing and creating project schedules.

7.8 Summary

The advantage of networks is that they clearly display the interdependencies of project activities and show the scheduling impact that activities have on each other. This feature enables planners to determine critical activities and slack times, which is important for project planning and control. Knowledge of critical activities tells managers where to focus; knowledge of slack enables them to address the problems of non-uniform resource requirements and limited resources. The PDM method accounts for a variety of relationships between project activities to better reflect the realities of project work.

The next chapter describes other well-known and more advanced network scheduling methods: PERT, simulation, time-cost tradeoff analysis (CPM), and critical chain project management (CCPM).

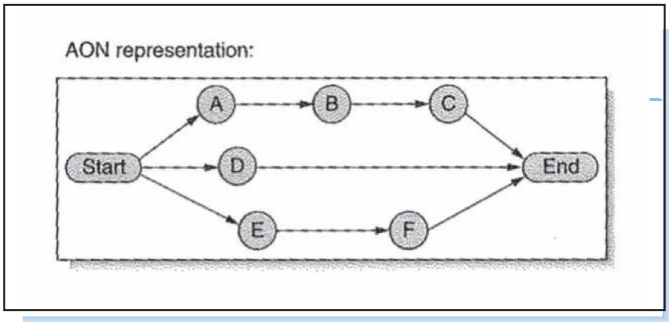
Summary List of Symbols

T_e	Expected Project Duration: the expected duration of the project based on the critical path.
T_s	Target Project Completion Date: the contracted or committed date for project completion.
ES	Early Start for an Activity: the earliest feasible time an activity can be started.
EF	Early Finish for an Activity: the earliest feasible time an activity can be completed.
LS	Late Start: the latest allowable time an activity can be started to complete the project on target.
LF	Late Finish: the latest allowable time an activity can be completed to complete the project on target.
t	Activity Duration: the most likely or best-guess time to complete an activity.
$FS = n$	Finish-to-Start: an activity can start no sooner than n days after its immediate predecessor has finished.
$SS = n$	Start-to-Start: an activity can start no sooner than n days after the start of its immediate predecessor.

SF = n Start-to-Finish: an activity can finish no later than *n* days after its immediate predecessor has started.

FF = n Finish-to-Finish: an activity can finish no later than *n* days after its immediate predecessor has finished.

Summary illustration problem



						Slack	
Activity	**Time**	**ES**	**EF**	**LS**	**LF**	**Total**	**Free**
A	2.0	0	2.0	0	3.0	1.0	0
B	5.0	2.0	7.0	3.0	8.0	1.0	0
C	2.0	7.0	9.0	8.0	10.0	1.0	1.0
D	5.0	0	5.0	5.0	10.0	5.0	5.0
E*	5.0	0	5.0	0	5.0	0	0
F*	5.0	5.0	10.0	5.0	10.0	0	0

*Activities on critical path

APPENDIX A: ACTIVITY-ON-ARROW DIAGRAMS

This chapter described the AON (*activity-on node*) method of network diagramming. Another diagramming method is the *activity-on-arrow* or *arrow diagramming* technique. The major feature that distinguishes AOA from AON is the way activities and events are denoted on the network. Figure 7.29 shows the AOA representation for one activity and its events: each activity is represented by an *arrow* between two nodes (the circles). As shown in Figure 7.29, the nodes represent the start and finish events for the activity, and the arrow in between represents the activity itself. The number inside each node merely identifies an event;

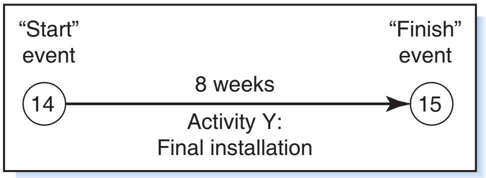


Figure 7.29
AOA representation for an activity and its start and finish events.

each event has its own unique identifier. In the example, the numbers 14 and 15 were chosen arbitrarily. Node 14 represents the event "start Activity Y," and node 15 represents the event "finish Activity Y."

The length of the arrowed line has no significance in AOA. As in AON networks, an AOA network should have only *one origin* event and *one terminal* event. All arrows generally point toward the right, toward the end of the network, and the arrows cannot double back.[4]

Now, as in the AON method, the activities follow a sequential order as defined by their immediate predecessors. When an activity has more than one immediate predecessor, the network must show that it can be started only after *all* of its immediate predecessors have been completed. This is the purpose of a special kind of activity called a "dummy."

Dummy activities

A *dummy activity* is used to illustrate precedence relationships in AOA networks. It serves only as a "connector"—it is not a "real" activity and represents neither work nor time.[5] As an example, an engineer needs to write a computer program, purchase a new computer, and install the program on the computer. The specific activities and their dependencies are:

1. Buy computer.
2. Write computer program.
   [Note: (1) or (2) can be done in either order.]
3. Pay for computer *after* buy computer (assume credit is okay!).
4. Install program on computer *after both* writing program *and* buying computer.

The activities and their dependencies are illustrated in the AON network in Figure 7.30.

The AOA network for the project is shown in Figure 7.31. Note that to show the dependencies "install program" after both "buy computer" and "write computer program" requires a dummy activity

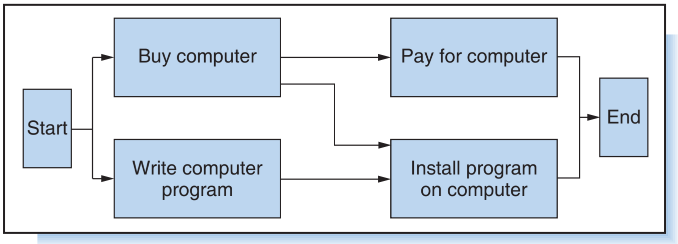


Figure 7.30
AON diagram.

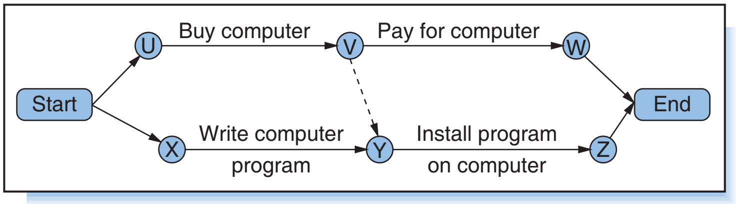


Figure 7.31
AOA diagram for AON diagram in **Figure 7.30**

(the dashed arrow) between node V and node Y. This dummy links the start of "install program" to its two immediate predecessors, finish "buy computer" and finish "write computer program." Notice that the network has only one "Start" node and one "End" node—standard good practice.

Activity-on-node versus activity-on-arrow

Since AON networks do not require the use of dummies, they are easier to construct and interpret than AOA networks; as a consequence, they are more popular. But because AOA diagrams use line segments (the arrows) to represent the flow of work and time, they can easily be converted into time-scaled networks that look like Gantt charts. Some project software packages create time-scaled networks (a good example of a time-scaled network is Figure 7.18), and some create both AOA and AON network diagrams. For a particular project, it's best to adopt just one kind of network method.

APPENDIX B: ALTERNATIVE SCHEDULING METHOD: PROJECT STARTS AT DAY 1

The scheduling technique illustrated in this chapter is the usual approach to introduce network scheduling. It assumes that the project *begins at time zero* and that a successor activity *begins immediately upon completing all its predecessors*. The method is simple and is mathematically correct.

For practical purposes, however, the method is incorrect. People speak of the "first day" of the project, not the "zeroth day." Thus, they say, the project start time should be indicated as day 1, not day 0. Further, whenever activities are in series, each activity *starts on the period following* the completion of its predecessors, not in the same period. Thus, the network would show the early start time of an activity as being a day (or week) *after* the finish of its latest predecessor. Realistically, this approach makes sense.

As an example, refer to Figure 7.32, which is Figure 7.7 revised for "day 1" assumptions. Activity H is the first activity in the project and lasts 10 days. Using the day 1 scheme for Activity H, ES = 1. In making the forward pass through the network, computationally

$$\text{EF} = \text{ES} + \text{Duration} - 1$$

Thus, EF = 1 + 10 −1 = 10. Now, the ES for Activity H's successors, Activity I and Activity J, will be the *next* day, that is, ES = 11.

Of course, using the day 1 assumptions affects the late times, too. Making the backward pass through the network,

$$\text{LS} = \text{LF} - \text{Duration} + 1$$

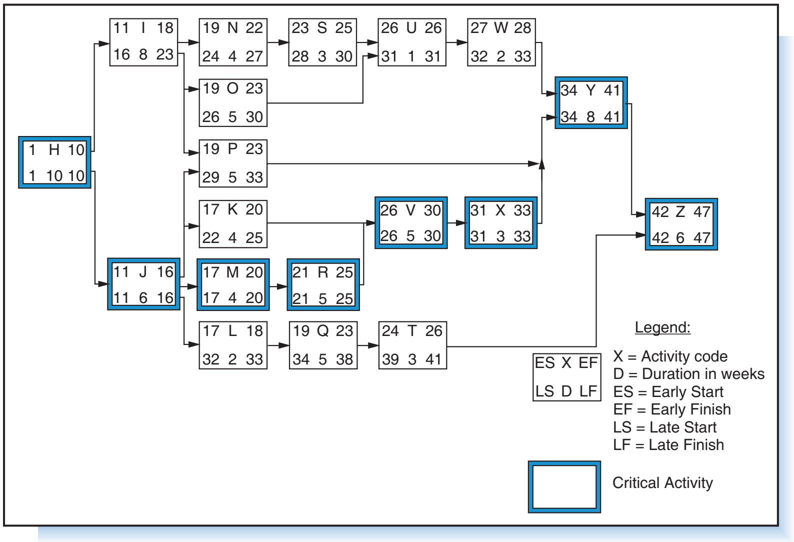


Figure 7.32
Figure 7.7 adjusted for "day 1" assumption.

For example, for Activity J and duration 6, if LF = 16, then LS = 16 − 6 + 1 = 11. The immediate predecessor of Activity J, Activity H, must finish the day before this, so LF = 10 for Activity H.

The day 1 scheme does not impact the computation of total slack, which remains the simple difference between early and late start times or early and late finish times. It does, however, change the computation of free slack:

$$\text{Free slack for an activity} = \text{ES (earliest successor)} - \text{EF (activity)} - 1$$

Project management scheduling software uses calendar dates, not elapsed times, and the project start event will be indicated by the date of the first day (or week) of the project. Throughout the network, the start dates of successor activities will all be shown as the period (day or week) *after* the finish dates of their successors. In other words, scheduling software incorporates the day 1 assumption.

Review Questions and Problems

1. What are the advantages of networks over Gantt charts?
2. Draw a network diagram of your college studies, starting with enrolment and finishing with graduation. Indicate the courses, projects, and exams as well as precedence relationships where applicable.
3. How is a WBS used to create a network, and what role does a scope statement play?
4. Can a Gantt chart be created from a network? Can a network be created from a Gantt chart? Which is the preferred way? Explain.
5. Why is it vital to know the critical path? Explain the different ways the critical path is used in network analysis and project planning.
6. Explain the difference between total and free slack.

7. Explain the difference between ES, EF, LS, and LF.
8. Considery of the following projects:
   - a. Composing and mailing a letter to an old friend.
   - b. Preparing a five-course meal (you specify the main course and dishes served).
   - c. Planning a wedding for 500 people.
   - d. Building a sundeck for your home.
   - e. Planning, promoting, and conducting a rock concert.
   - f. Moving to another house or apartment.
   - g. Developing, promoting, manufacturing, and distributing a new packaged food item.
   - h. Developing and installing a computerized information system, both hardware and software.
   - i. Remodeling a bathroom.
   - j. Adding a bedroom to a house.

   Now, answer the following questions for each project:
   1. Using your experience or imagination, create a WBS.
   2. List the activities or work packages.
   3. Show the immediate predecessors for each activity.
   4. Draw the network diagram (using the AON scheme).
9. Draw the AON network diagrams for the following four projects:

a. Activity	Immediate Predecessors
A	—
B	A
C	A
D	B
E	D
F	D
G	D
H	E, F, G

b. Activity	Immediate Predecessors
A	—
B	A
C	A
D	B
E	B
F	C
G	D
H	D
I	G
J	E, F, H, I

c. Activity	Immediate Predecessors
A	—
B	A
C	—
D	—
E	D
F	B, C, E

d. Activity	Immediate Predecessors
A	—
B	—
C	—
D	C
E	A
F	B
G	E
H	F, G, J
I	A
J	D, I

10. Refer to Figure 7.1 in the text.
    a. If the person wants to get more sleep by waking up later, which of the following steps would be useful?
        i. Put socks on faster.
        ii. Put tie in pocket to put on later.
        iii. Put shoes on faster.
        iv. Buy a hair dryer that works faster.
    b. Calculate the total float and free float of the activity "Put on socks."
11. Eliminate redundant predecessors from the following lists so only *immediate predecessors* remain. [Example: In (a) subsequently, the specified predecessors for G are B, D, C, E, but B and C are also predecessors for D and E, respectively; hence, it is redundant to specify them. They can be removed, leaving only D and E, which are the immediate predecessors.]

a. Activity	Predecessors
A	—
B	—
C	—
D	B
E	C
F	A
G	B, D, C, E
H	A, B, C, D, E, F, G

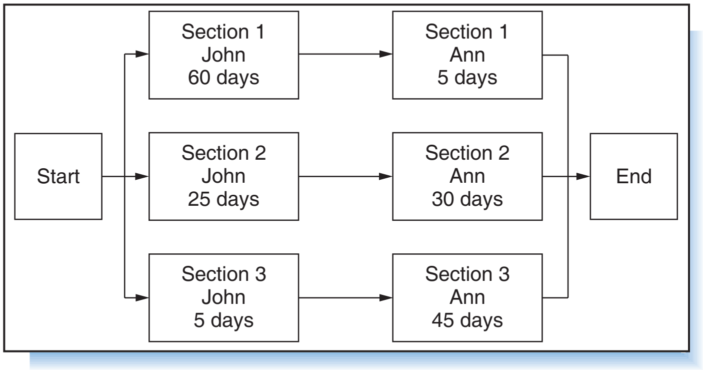
b. Activity	Predecessors
A	—
B	A
C	A
D	A, B
E	A, B
F	A, C
G	A, B, C, D, E, F
H	A, B, C, D, E, G

c. Activity	Predecessors
A	—
B	—
C	A
D	A
E	B
F	B
G	A, C
H	A, B, D, E
I	B, F
J	C, D, E, F, G, H, I

12. Use Figure 7.4(a) and (b) to draw Gantt charts for the ROSEBUD project.
13. Some projects have a fixed due date, while others have to be finished as early as possible, and the project manager only makes commitments on the completion date once she and her project management team have scheduled the project. Explain how the backward pass differs for these two project types.
14. Explain how it is possible for the critical path to have non-zero slack. What is the implication of negative slack on the critical path?
15. In the development of a new (first of its kind) complex system, the design of a certain subsystem has large slack. Sufficient resources are available for either an early start or a late start.

Discuss the pros and cons of early and late starts. Consider the risk of delaying the project and the risks of changes in the design, management focus, cash flow, and any other factor that you can think of.[6]

16. What limitations of simple AON networks does PDM overcome? What limitations does it not overcome?
17. Give examples of applications of PDM. Take a project you are familiar with (or invent one) and create a PDM network.
18. For the PDM network in Figure 7.19, calculate ES, EF, LS, and LF for all activities.
19. To produce a three-section manual, John must write the text, after which Ann must prepare drawings and key in the document. John can start with any section of the book (i.e. he doesn't have to start with Section 1). The manual has to be completed within 95 days. The following network diagram shows the precedence relationships and duration of each activity.



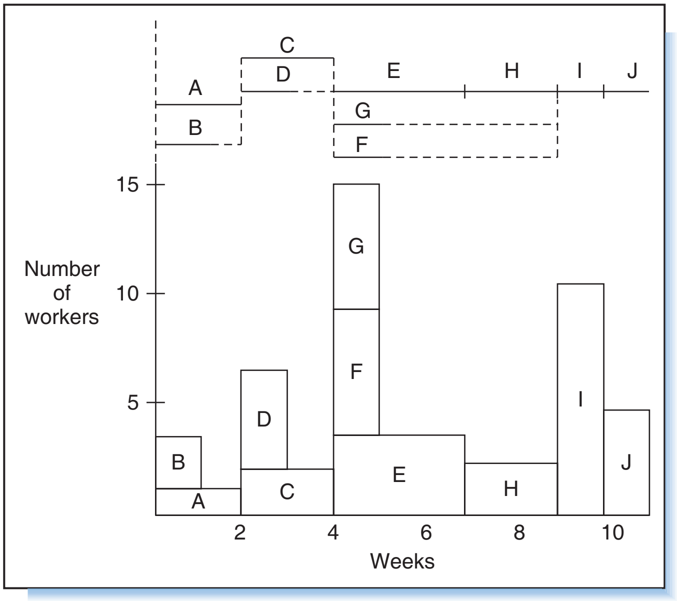
Draw a Gantt chart to show how the work can be done within 95 days. Take into account that both John and Ann are able to attend to only one task at a time.[7]

20. Why is leveling of resources preferred to large fluctuation of workload? What negative result could resource leveling cause?
21. Describe how resource leveling of a resource-constrained project differs from resource leveling in a time-constrained project.
22. The requirements for systems analysts and programmers for the GUMBY project are as follows:

Activity	J	M	V	Y	L	Q	Z
Predecessors	—	J	M	V	J	L	Y, Q
Duration (weeks)	6	4	6	8	2	8	2
Systems Analysts (weekly)	8	5	3	2	5	3	5
Programmers (weekly)	3	4	2	3	3	2	3

a. Draw the network. Compute ESs, LSs, and total slack times.
b. Then show the separate resource loadings for systems analysts and programmers, assuming early start times.
c. Suppose the maximum weekly availability is eight systems analysts and five programmers. Can activities be scheduled to satisfy these constraints without delaying the project?

23. Level the resources for a project with the workload diagram subsequently. In the time-phased diagram at the top of the figure, dotted lines indicate slack.[8] Discuss pros and cons of the alternatives available.



24. Discuss the implications of resource allocation for organizations involved in multiple projects.
25. Show that the schedule in Figure 7.22 (that produced an erratic loading for workers) yields a more balanced loading for equipment than the one shown in Figure 7.26.
26. Suppose in Figure 7.19 everything is the same, except Activity Y can start 4 days after Activity V starts but cannot be finished until 6 days after Activity V is finished. Show how this changes the values for ES, EF, LS, and LF.
27. Redraw Figure 7.5 as an AOA diagram.
28. For each of the following predecessor tables:
    - Draw a corresponding AON network.
    - Compute ES and EF for each activity.
    - Compute LS and LF for each activity. Find the critical path.
    - Determine the total slack and free slack.

a. Activity	Predecessor	Duration
A		6
B		3
C	A	9
D	B	5
E	B	4
F	D	2
G	E	8

b. Activity	Predecessor	Duration
A		3
B	A	8
C	B	9
D	C	3
E	B	2
F	E, H	4
G	A	6
H	G	5
J	D, F	1

c. Activity	Predecessor	Duration
A		9
B	A	2
C		8
D	C	8
E	B, D	7
F	E	4
G	C	4
H	B, D, G	3
J		6
K	J	10
M	G, K	3
N	H, M	6

d. Activity	Predecessor	Duration
A		10
B	A, E	9
C	B, N	15
D	C	7
E		5
F	A, E	6
G	K, F	7
H	G	12
J		12
K	E, J	4
L	K, F	11
M	L	8
N	E, J	7

Questions About the Study Project

1. Were networks used for scheduling? If so, describe the networks. Show examples. What kind of computer software system was used to create and maintain them? Who was responsible for system inputs and system operations? Describe the capabilities of the software system.
2. At what point in the project were networks created? When were they updated?
3. Was scheduling software used?
4. What was used first to develop the schedule: (a) a table such as Table 6.3, (b) a network diagram, or was (c) the Gantt chart drawn first? Comment on the method used.
5. Was all detail planning done up front, or was a phased approach followed?
6. How was the schedule reserve determined and included in the schedule?
7. Was the workload on resources made visible?
8. If the project was done within a matrix structure, how did communication between the functional and project managers take place?
9. Did the functional manager(s) take responsibility for workload on resources?
10. Was resource leveling done?
11. Were there any complaints about unrealistic workloads?

CASE 7.1[9] NETWORK DIAGRAM FOR A LARGE CONSTRUCTION PROJECT

The following table lists activities for constructing a bridge over an operational railway line. This project is similar to the bridge described in Case 11.3.

1. Construct a network diagram for the project.
2. Do forward and backward pass calculations to indicate early and late start and finish times.

Activity No.	Activity Description	Duration (Months)	Predecessors
A	Detailed site investigation and survey	2	–
B	Detailed planning	6	A
C	Detailed design	6	B
D	Preparation of site	4	C
E	Relocate services	3	C
F	Re-align overhead track electrification	4	C, E
G	Access road and ramp construction	1	D
H	Piling	2	G
J	Construct foundations and abutments	3	H
K	Construct temporary supports to support bridge deck during construction	2	F, G
L	Fabrication planning of structural steel components	2	C
M	Manufacture structural steel components (off-site)	2	L
N	Transport structural steel components and erect on-site	1	M
P	Erect pylons and fill with concrete	2	J
Q	Construct main span deck on pre-cast concrete beams	3	H, K, N, P
R	Install stay-cables and lift the bridge deck off temporary supports	3	Q
S	Remove temporary supports	1	R
T	Electrical system installation	1	S
U	Roadway surfacing (paving)	2	S
V	Finishing and ancillaries	2	T, U
W	Commissioning—cut-over	1	V
X	Formal handover and ceremony	1	W
Y	Project sign-off	1	X
Z	Administrative closure	1	W
AA	Project end	0 (milestone)	Y, Z

3. Identify the critical path and the project duration.
4. Compute the total and free slack of each activity.
5. The following resources are required to perform the activities. Allocate the resources to the activities and indicate the workload on the resources. If needed, adjust the schedule.

Activity No.	Activity Description	Resources
A	Detailed site investigation and survey	Surveyors, Engineering, Project Manager
B	Detailed planning	Project Manager, Engineering, Construction, Contractors
C	Detailed design	Engineering
D	Preparation of site	Construction
E	Relocate services	Engineering
F	Re-align overhead track electrification	Engineering, Contractors
G	Access road and ramp construction	Construction
H	Piling	Construction, Contractors
J	Construct foundations and abutments	Engineering, Construction
K	Construct temporary supports to support bridge deck during construction	Engineering, Construction
L	Fabrication planning of structural steel components	Engineering, Manufacturer
M	Manufacture structural steel components (off-site)	Engineering, Manufacturer
N	Transport structural steel components and erect on-site	Transporter, Engineering
P	Erect pylons and fill with concrete	Construction, Engineering
Q	Construct main span deck on pre-cast concrete beams	Construction, Engineering
R	Install stay-cables and lift the bridge deck off temporary supports	Construction, Engineering
S	Remove temporary supports	Construction, Engineering
T	Electrical system installation	Construction, Engineering
U	Roadway surfacing (paving)	Contractor, Engineering
V	Finishing and ancillaries	Contractors, Engineering
W	Commissioning – cut-over	Project Manager, Engineering, Construction, Contractors
X	Formal handover and ceremony	Project Manager, Engineering, Construction, Contractors
Y	Project sign-off	Project Manager, Engineering
Z	Administrative closure	Engineering
AA	Project End	Project Manager

CASE 7.2 MELBOURNE CONSTRUCTION COMPANY, A

Bill Asher, scheduler for Melbourne Construction Company, has created a network of activities for a hotel project the company is planning. Figure 7.33 shows part of the network and the estimated number of days for each activity. What are the early and late start and finish times for all the activities? What is the earliest this portion of the project will be completed?

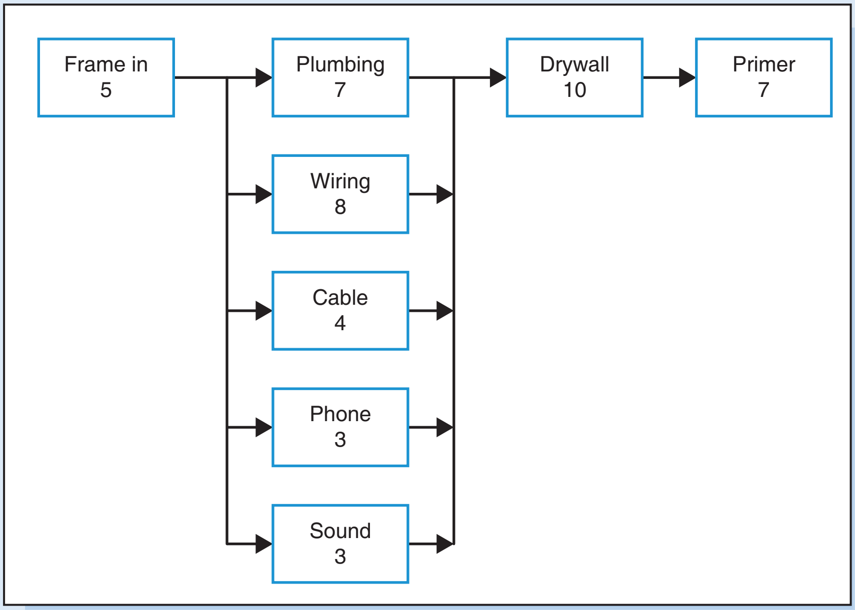


Figure 7.33
Partial network for hotel construction project.

In general, project schedulers often face constraints that originate outside the project. For example, materials might not arrive or a contractor might not be ready until a particular date, which imposes a constraint on when the work can start—a start no earlier than (SNET) date. At other times a customer, inspector, or someone else will require the work to be completed by a particular date—a finish no later than (FNLT) date. Bill faces such a situation. He has been informed that drywall boards will not arrive at the site until day 15; that is, Drywall has a SNET date of 15. What effect will this delay have on the project?

Additionally, the owner of Melbourne Construction, Naomi Watts, wants to give the hotel owner a tour of the building but not before all the walls have been primed. She has scheduled the tour on day 29, which imposes a FNLT of day 28 on Primer. Bill is now faced with this requirement—plus the drywall delivery constraint. Is it possible to finish this portion of the project on day 28? If not, what adjustments must be made to the work so they can be? Bill is meeting with Naomi to discuss the situation.

CASE 7.3 MELBOURNE CONSTRUCTION COMPANY, B

One way to speed up a project is to speed up activities on the critical path (to be discussed in the next chapter); another is to *overlap* activities. Refer to Case 7.2 previously: the network diagram in Figure 7.33, which shows the activities for *one floor* of the hotel and assumes finish-to-start relationships, meaning successors can start only upon completion of predecessors. Now suppose each floor is large enough so that the crew for any activity can begin work when the crews for its predecessor activities are only *partially* completed (called a start-to-start relationship), meaning the start of an activity *lags* the start of its predecessors by some specified amount; this allows activities normally in sequence to be overlapped. Ordinarily, an SS lag is used when successor activities are *slower* than immediate predecessor activities (so successors won't "catch up" with predecessors and have to wait on them). This is the case for the Plumbing and Wiring activities that succeed Frame-in, so Bill assigns an SS lag of 3 days between Frame-in and Plumbing and Wiring (meaning Plumbing and Wiring can start 3 days *after* Frame in starts); he does the same for Cable, Phone, and Sound. This is shown in Figure 7.34. The same case applies to Drywall installation, which is slower than its immediate predecessors, so Bill assigns an SS lag of 4 days between Drywall installation and its predecessors.

When activities are to be overlapped but successors are *faster* than predecessor activities, a finish-to-finish lag can be used. Primer is faster than Drywall, so Bill inserts an FF lag of 3 days between them. This means Primer should finish no earlier than 3 days before Drywall finishes—also shown in Figure 7.34.

1. Prepare two Gantt charts, one using the original FS relationship and one using the SS and FF lags. Compare the charts. By how much do the lags speed up the project? Since Cable, Phone, and Sound take less time than Frame-in, what potential problem might occur in overlapping them with Frame in?

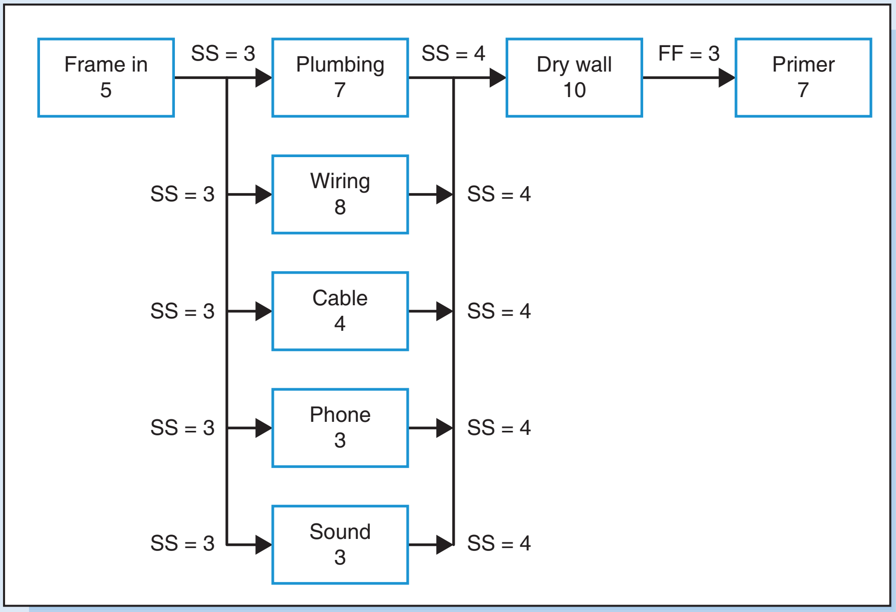


Figure 7.34
Network with lags inserted.

2. Again refer to Case 7.2. Given that drywall board delivery will not happen until day 15 and Naomi has scheduled a tour for day 29, what is the effect of the SS and FF lags? Can Naomi conduct her tour as planned?

CASE 7.4 MELBOURNE CONSTRUCTION COMPANY, C

Bill Asher, scheduler for Melbourne Construction Company, has created a network of the activities for a three-story boutique hotel the company is planning to build on the Mornington Peninsula. Bill identified seven major activities for each floor. Figure 7.35 shows the network of activities for the three floors and the number of days he estimated for each activity. Each activity will be done by a different subcontractor; as shown in the network, upon completing work on one floor, the subcontractor moves to the next floor.

1. What is the critical path? Based on Bill's estimates, how long will it take to complete the three floors?
2. The activity times shown in Figure 7.35 are based on Bill's estimates of total labor hours per activity and an 8-hour work day. For example, Bill estimated that Frame-in will require 40 labor hours; given an 8-hour day, he came up with 5 days. Thus, all the times in Figure 7.35 assume that subcontractors assign a "crew" of one worker to each activity. According to these time estimates, it should take 54 days to complete each floor. His boss, Naomi Watts, says that 54 days per floor is too long and that to complete the project on time, each floor should take no more than 35 days.

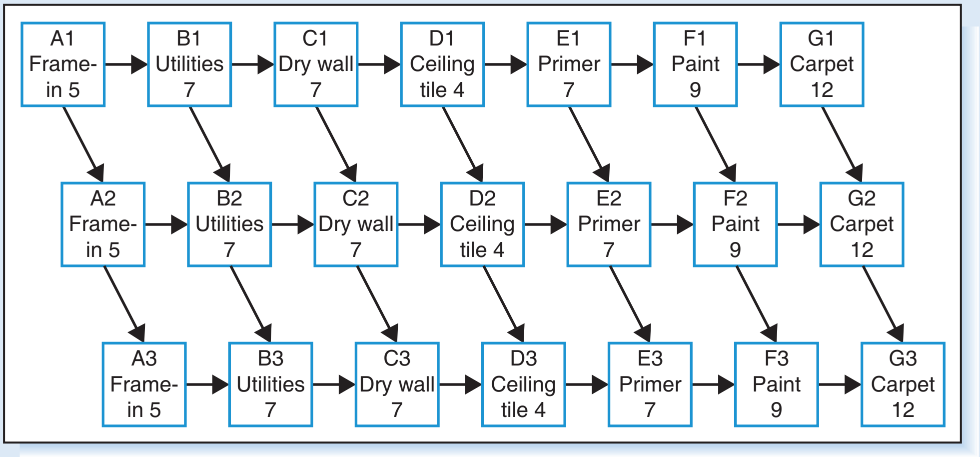


Figure 7.35
Network for three floors.

Looking at the seven activities per floor, Bill sees that 35 days per floor could be achieved if *each activity took no more than 5 days*. He intends to point this out to his subcontractors.

a. Bill's estimates assume one worker per activity. How many workers (what crew size) should the contractors assign to each activity such that it will take at most 5 days?
b. Given the increased crew sizes, how long will it take to complete the project? Assume that a computed fractional day's duration is always rounded up.

Notes

1. Duncan W.R. (ed.). *A Guide to the Project Management Body of Knowledge*. Newton Square, PA: Project Management Institute Standards Committee; 1996. The definition of the critical path in later editions of this document does not say that the critical path can change; that does not alter the fact that it does.
2. For more about PDM scheduling, see Dreger J.B. *Project Management: Effective Scheduling*. New York, NY: Van Nostrand Reinhold; 1992.
3. Goldratt E.M. *Critical Chain*. Great Barrington, MA: North River Press; 1997.
4. Loops are permitted in a special form of network analysis called GERT.
5. Adapted from Gordon G.D. and Villoria R.L. *Network-based Management Systems (PERT/CPM)*. New York, NY: John Wiley & Sons; 1967.
6. Steyn H. (ed.). *Project Management: A Multi-disciplinary Approach*. Pretoria: FPM Publishing; 2003. Reproduced with permission.
7. Ibid.
8. Ibid.
9. Ibid.

Chapter 8

Advanced project network analysis and scheduling

Look beneath the surface; never let a thing's intrinsic qualities or worth escape you.

—Marcus Aurelius, *Meditations*

The scheduling methods discussed in Chapter 7 assume that activity times are known and fixed, even though in reality, they are estimated and variable. This chapter discusses the implications of variable activity times on project schedules and ways for shortening project the duration, starting with the CPM method.

Example 8.1: The House Built in Less Than 4 Hours[1]

With virtually unlimited resources and meticulous planning and control, a project can be done *very* fast. On March 13, 1999, the Manukau, New Zealand, chapter of Habitat for Humanity (a nonprofit organization dedicated to eliminating poverty housing) set a record for building a house: 3 hours and 45 minutes.

The project specifications included construction of a four-bedroom house on an established foundation (Figure 8.1). It incorporated prefabricated wall panels, wooden floor, roofing iron, ceilings, decks, and steps. Doors, windows, bath, toilet, plumbing, and the electrical system had to be installed and ready for use; walls, ceilings and window frames had to be painted; and carpets and curtains had to be installed. The specifications also included a path to the front door, letter box, installed clothesline, wooden fence around the yard, three trees planted, and a leveled lawn with grass. The new owners, Mr. and Mrs. Suafoa, watched the construction with their four children while CNN filmed the event. The house was inspected and passed all local building codes, and the keys were handed over to the family.

What made the speedy completion possible? *First* were abundant resources: 150 people, mostly volunteers. *Second* was comprehensive and meticulous preparation: 14 months of planning, including many iterations of network analysis. The detailed plan was recorded on special task sheets so team leaders could hand over tasks from one to another without deliberation. With so many people and construction items at the site, workspace was at a premium. A crane was provided to lift the wooden

Figure 8.1
The house built in less than 4 hours.
Source: Photo courtesy of Habitat for Humanity.

roof frame onto the wall structure. *Third* was a systematic computerized method for planning, monitoring, and controlling the project that included the critical chain method and time buffers (explained later). The bathroom-fitting task was estimated to take 30 minutes but took 1 hour; the 30-minute overrun was absorbed in the project buffer. *Finally*, the project made use of suitable technology, including prefabricated walls and components.

8.1 Reducing project duration with critical path method

With enough resources and meticulous planning, most every project can be shortened. But to avoid wasting resources, certain principles must be applied, and these are incorporated in the *critical path method* (CPM).[2] CPM is a mathematical procedure for estimating the tradeoff between project duration and project cost in determining the least expensive way to reduce the project duration.

Time–cost relationship

CPM assumes that the time to perform a project activity can be varied, depending on the amount of resources applied; as more resources (labor, equipment, etc.) are applied to particular activities, the project duration is shortened. Adding resources speeds up the project, but it also increases the project cost. A major element of project cost is labor: a project can be sped up by working or adding more workers, but either way, the cost goes up.

Ordinarily, work on any given activity in a project is performed at a so-called *normal* (usual and customary) work pace—the "normal" point shown in Figure 8.2. Associated with this pace is the *normal time*, T_n, which is the time do the activity under normal work conditions, and the *normal cost*, C_n, which is the cost to do the activity in the normal time. (The normal pace is assumed to be the most efficient and thus *least* costly pace. Taking longer than normal will not reduce the cost.)

To reduce the time to complete the activity, more resources are applied in the form of additional personnel or overtime. As more resources are applied, the duration shortens, but the cost increases. When the maximum effort is applied so the activity can be completed in the shortest possible time, the activity is said to be *crashed*. The crash condition (see Figure 8.2) represents not only the shortest duration but the most costly as well. (Some activities, called *process limited*, cannot be sped up; they require a specific amount of time, regardless of resources. Fermenting wine or curing concrete are examples.)

As illustrated in Figure 8.2, the normal conditions and crash conditions define two theoretical extremes. The line connecting the points, called the *cost slope*, represents the time–cost relationship or marginal time–cost tradeoff for the activity. The time–cost relationship for every activity is unique and can be linear, curvilinear (concave or convex), or a step function. The nature of the actual time–cost relationship is usually unknown; thus, it is often assumed to be linear,[3] in which case the formula for the cost slope is

$$\text{cost slope} = \frac{C_c - C_n}{T_c - T_n}$$

where C_c and C_n are the crash and normal costs, respectively, and T_c and T_n are the crash and normal times for the activity. The cost slope is how much it would cost to speed up or slow down the activity.

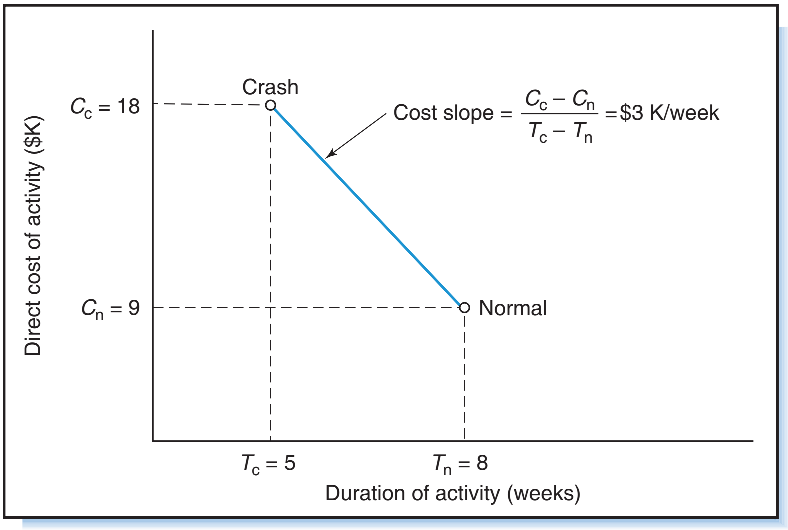


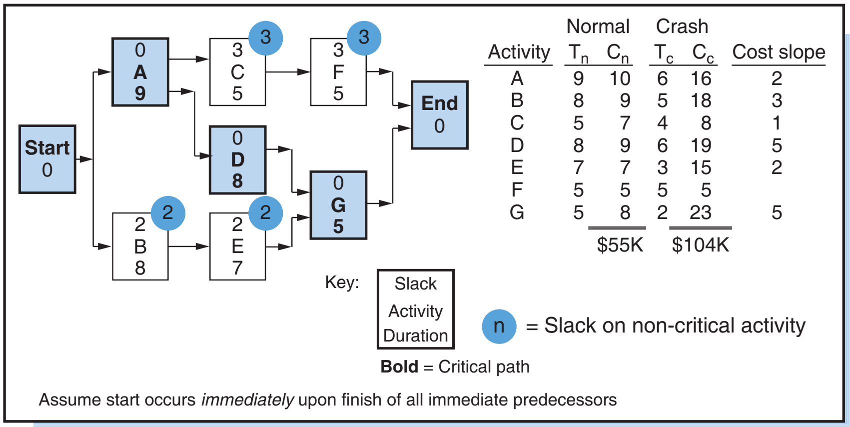
Figure 8.2
Time–cost relationship for an activity

In Figure 8.2, which represents the time–cost tradeoff for a particular activity, the cost slope is \$3K per week. That means that for *each week* the activity duration is reduced from the normal time of 8 weeks, the cost will increase by \$3K. Completing the activity 1 week earlier (from 8 weeks to 7 weeks) would increase the cost from the normal cost of \$9K to the “sped up” cost of \$9K + \$3K = \$12K, completing it another week sooner (in 6 weeks) would increase the cost to \$12K + \$3K = \$15K, and completing it yet another week sooner (in 5 weeks) would increase the cost to \$18K. According to Figure 8.2, this last step puts the activity at the crash point, 5 weeks, the shortest duration for the activity.

Shorten the critical path

The cost–slope concept can be used to determine the least costly way to shorten a project. Figure 8.3 illustrates this with an example. Start with the preliminary project schedule by assuming a normal pace for all activities; therefore, the project in the figure can be completed in 22 weeks at an expense of \$55K. Recall from Chapter 7 that the *project duration is the length of the critical path*. In general, what that implies is that if you want to shorten the project, you must shorten the critical path. Because the critical path A–D–G is the longest path (22 weeks), to shorten the project, it is necessary to *shorten a critical activity*—either A, D, or G. Reducing an activity increases its cost, but because the reduction can be made *anywhere* on the critical path, the increase can be minimized by selecting the activity with the smallest cost slope; this is Activity A. Reducing A by 1 week shortens the project duration to 21 weeks and adds \$2K (cost slope of A) to the project cost, bringing it to \$55K + \$2K = \$57K. This step does not change the critical path, so, if need be, an additional week can be cut from A, resulting in project duration of 20 weeks and cost of \$57K + \$2K = \$59K.

In general, each time an activity is shortened, it is necessary to check for changes in the critical path. For example, look at the network in Figures 8.3 and 8.4. As Figure 8.4(a) shows, shortening A by 2 weeks uses up the slack on Path B–E, and the project now has two critical paths: A–D–G and B–E–G. Any further reduction in project duration must be made by shortening *both* paths (since shortening just one would leave the other at 20 weeks). The least costly way to reduce the project to 19 weeks is to reduce both A and E by 1 week, shown in Figure 8.4(b). The additional cost is \$2K for A and \$2K for E, so the resulting project cost would increase to \$59K + \$2K + \$2K = \$63K. This last step reduces A to 6 weeks, its crash time, so no further reductions can be made to A.



	Normal		Crash		
Activity	T_n	C_n	T_c	C_c	Cost slope
A	9	10	6	16	2
B	8	9	5	18	3
C	5	7	4	8	1
D	8	9	6	19	5
E	7	7	3	15	2
F	5	5	5	5	
G	5	8	2	23	5
		\$55K		\$104K	

Assume start occurs *immediately* upon finish of all immediate predecessors

Figure 8.3
Time–cost tradeoff for example network.

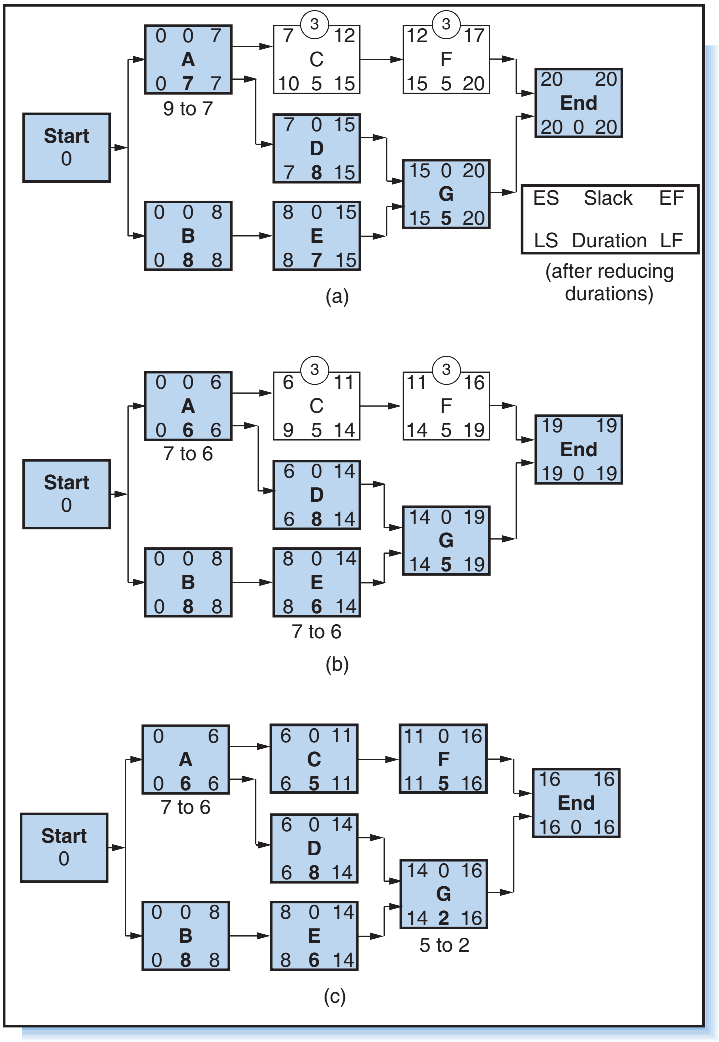


Figure 8.4
Reducing project duration.

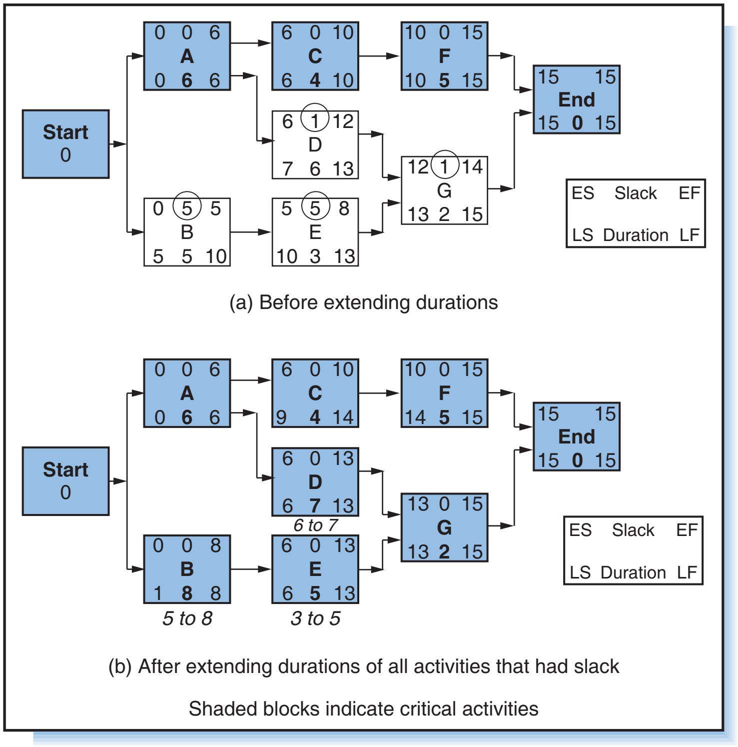
If a further reduction in project duration is desired, the least costly way to shorten both paths is to reduce G. In fact, because the slack on the noncritical path C–F is 3 weeks, and because the crash duration for G is 2 weeks (which means, if desired, 3 weeks *can* be taken out of G), the project can be reduced to 16 weeks by shortening G by 3 weeks, indicated in Figure 8.4(c). This adds $5K per week, or 3 × $5K = $15K, to the project cost. With this last step, all slack is used up on Path C–F, and all the paths in the network (A–C–F, A–D–G, and B–E–G) become critical.

Any further reductions desired in the project must shorten *all three critical paths* (A–C–F, A–D–G, and B–E–G). As you may wish to verify, the most economical way to reduce the project to 15 weeks is to cut 1 week each from E, D, and C, bringing the project cost up to $86K. This step reduces the time of C to its crash time, the shortest possible project duration. The sequence of steps is summarized in Table 8.1.

Table 8.1 Duration Reduction and Associated Cost Increase

Step	Duration (T_e, weeks)	Activities on CP With Least Cost Slope	Cost of Project (K$)
1*	22		$55
2	21	A ($2)	$55 + $2 = $57
3	20	A ($2)	$57 + $2 = $59
4	19	A ($2), E ($2)	$59 + $2 + $2 = $63
5, 6, 7	18, 17, 16	G ($5)	$63 + $5 + $5 + $5 = $78
8	15	E ($2), D ($5), C ($1)	$78 + $2 + $5 + $1 = $86

*Duration and cost using normal conditions



(a) Before extending durations

(b) After extending durations of all activities that had slack

Shaded blocks indicate critical activities

Figure 8.5
Example network using crash times.

Crashing the project: shortest project duration

The time–cost procedure described determines which activities to speed up, step by step, so as to reduce the project duration. This stepwise procedure will eventually lead to the shortest project duration and its associated cost. However, if we want to directly find the *shortest project duration* and avoid the intermediate steps, a simpler way is to simultaneously crash *all* activities at once. This, as Figure 8.5(a) shows, yields a project duration of 15 weeks. However, the expense of crashing all activities, \$104K (table in Figure 8.3) is unnecessarily high, because, as will be shown, not *all* activities must be crashed to finish the project in the shortest time.

The project duration of 15 weeks is the length of the critical path. Because the critical path is the longest path, other (noncritical) paths are of shorter duration and consequently have no influence on project duration. Thus, it is possible to "stretch" or lengthen any noncritical activity by a certain amount without lengthening the project. In fact, noncritical activities can be stretched until all the slack in the network is used up.

Just as reducing an activity's time from the normal time increases its cost, so *extending* its time from the crash time *reduces* its cost. As a result, by extending noncritical activities, the \$104K project crash cost can be reduced. To do so, start with those noncritical activities that will yield the greatest savings—those with the greatest cost slope. Notice in Figure 8.5(a) that because Path B–E–G has a slack of 5 weeks, activities along this path can be stretched by up to a total of 5 weeks without extending the project. Three weeks could be added to Activity B (bringing it to the normal duration of 8 weeks) without lengthening the project. Also, 2 weeks could be added to E and 1 week to D, both without changing the project duration. (Reminder: in extending an activity's duration, never can the duration exceed the activity's normal time.) The final activity times are shown in Figure 8.5(b). Notice, all paths are now critical.

The final project cost is computed by subtracting from the initial crash cost the savings obtained in extending B by 3 weeks, E by 2 weeks, and D by 1 week.

$$\$104K - 3(\$3K) - 2(\$2K) - 1(\$5K) = \$86K$$

In summary, to obtain the shortest project duration (called "crashing the project"), first crash all activities, then stretch the noncritical activities, starting with the greatest cost slopes first, to use up available slack and obtain the greatest cost savings. An activity can be stretched, at most, to its normal duration, which is assumed to be its least costly time (Figure 8.2).

Lowest total project cost

See Chapter 9

The previous analysis dealt only with *direct* costs—costs immediately associated with individual activities and that increase directly as resources are added to them. But beyond direct costs, the cost of conducting a project also includes *indirect* costs such as administrative and overhead charges. (The distinction between direct and indirect cost is elaborated upon in the next chapter.) Usually indirect costs are a function of, and are proportionate to, the project duration, which is to say that indirect costs, in contrast to direct costs, *decrease* as *project duration decreases*.

The mathematical function for indirect cost can be derived by estimation. As an illustration, suppose indirect costs in the previous example are approximated by the formula

$$\text{Indirect cost} = \$\ 10K + \$3K(T_e)$$

where T_e is the expected project duration in weeks. Figure 8.6 shows this indirect cost as a function of project duration; it also shows the direct cost, obtained from Table 8.1. *Total project cost* is the sum of direct and indirect costs. Notice from the figure that by combining direct costs and indirect costs, it is possible to determine the project duration that gives the lowest total project cost. In Figure 8.6, from a cost standpoint, the "optimum" project duration is 20 weeks.

See Chapter 12

In addition to direct and indirect costs, some other costs that influence total project cost (and hence the optimum T_e) are *contractual incentives* such as *penalty charges* or *bonus payments*. As described in Chapter 12, he

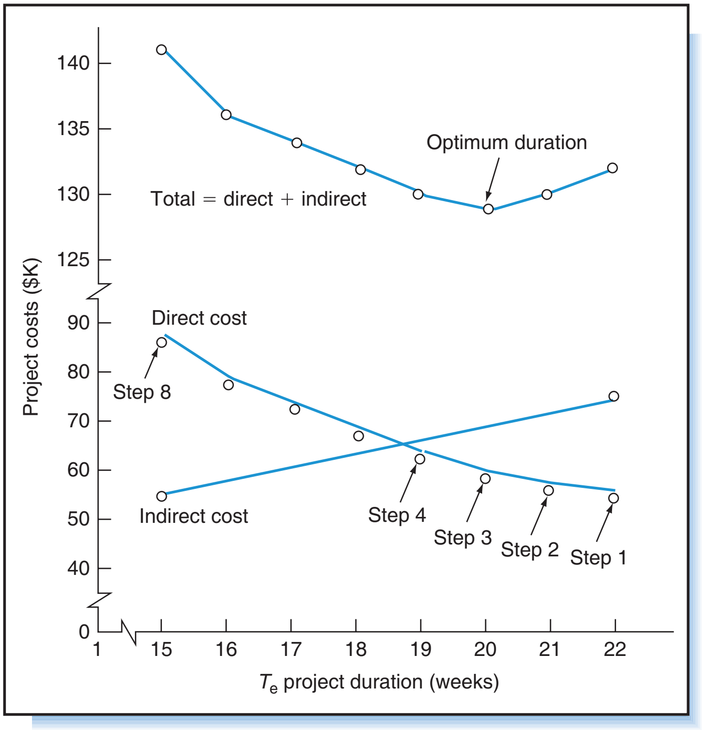


Figure 8.6
Total time–cost tradeoff for the project.

contract might specify a penalty fee on the contractor for not meeting schedule or performance requirements, and a bonus reward for exceeding requirements.

Suppose in the previous example the contract specified a target completion date of week 18, with a bonus of $2K per week for finishing before 18 weeks and a penalty of $1K per week for finishing after 18 weeks. Figure 8.7 shows the influence of these incentives on total project cost. Notice that even with incentives, the optimum duration (for the contractor) is at 19 or 20 weeks, not the contractual 18 weeks. This example reveals that a formal incentive agreement alone is not necessarily enough to influence performance. For the incentive to motivate the contractor it must have "teeth"; that is, it must be of sufficient magnitude with respect to other project costs to affect contractor performance. Had the penalty been raised to $3K (instead of $1K) per week for finishing after 18 weeks, the contractor's optimum duration would have shifted to 16 weeks.

8.2 Variability of activity duration

Suppose you are driving somewhere, and Figure 8.8 shows the estimated time it will take you to get there. If everything goes well (no traffic or mechanical problems), you will arrive in the shortest time—the "optimistic duration." However, "most likely," it will take you about 30 minutes. Of course, it could take longer than this—say, when traffic is congested or, worst case, you get in an accident. In the figure, note that the area below the curve to the left of the duration is much less than to the right of it. This indicates that the chances of arriving later are much greater than the chances of arriving earlier.

Like your travel time, the activity durations in a project are variable. The question is, since you cannot say for sure how long each activity in a project will take, how can you possibly say when the project will be completed?

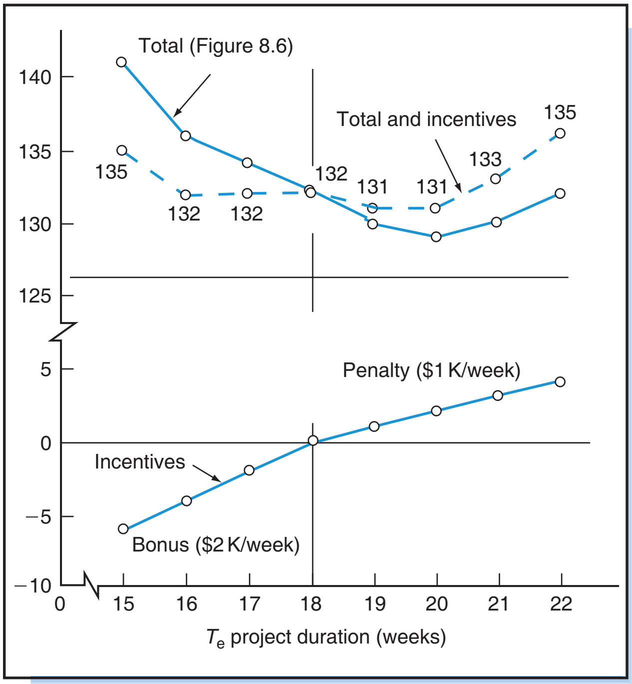


Figure 8.7
Time–cost tradeoff for the project with incentives.

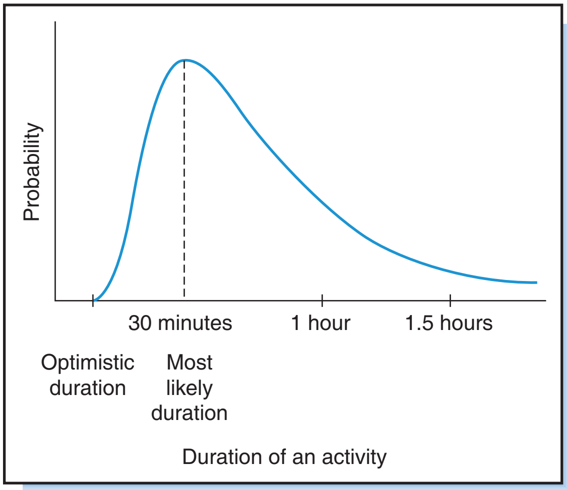


Figure 8.8
Variability of activity duration.

The scheduling approaches discussed in Chapter 7 and the preceding section on time–cost tradeoff ignore variability and assume that activity durations are known and constant; this is called the *deterministic* approach. In the following sections, we consider what happens when the activity durations are assumed variable; this is called the *stochastic* approach.

Variability effects on a project network

In a project, some activities will be completed earlier than expected, others later. When combined in a network, however, the earlier-than-expected activities and later-than-expected activities do not average out: in general, *it is the later-than-expected activities that impact the project completion*. This is one reason projects tend to take longer than estimated.

For example, consider the project schedule Figure 8.9. If Activity A takes longer than planned, it would delay Activity B, which in turn would delay Activities C and D and thus the completion of the project. Suppose, however, that Activity A is finished *earlier* than planned. In that case, will Activity B start earlier? Not necessarily. Resources needed for Activity B (people and equipment) will likely have other commitments, which would preclude Activity B starting early. So, Activity A finishing later delays the project, but Activity A finishing earlier does not necessarily speed it up. Consider a second example. Most project networks consist of several paths that merge into a critical path. Figure 8.10(a) illustrates a project with two critical paths, each with a 50 percent chance of finishing on time. The probability that the project will finish on time is the probability that both paths will finish on time, or $0.5 \times 0.5 = 0.25$ or 25 percent. Figure 8.10(b) shows five paths merging (which is typical of what happens near the end of project networks), each with a 50 percent probability of finishing on time. The probability of finishing the project on time is now $(0.5)^5$ or about 3 percent. This effect is called *merge bias* or *merge-point bias*.

See Chapter 7

Chapter 7 addressed the fact that the critical path is not necessarily stable but can change if noncritical activities take longer than planned and noncritical paths become critical. Thus, while delays on critical activities delay the project, long enough delays on noncritical activities also delay the project.

Several methods have been developed to help grapple with the uncertainty about activity durations and when a project will be completed. These are addressed in the following sections, starting with PERT.

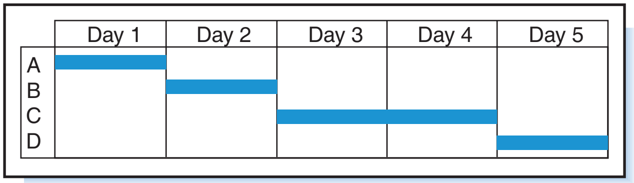


Figure 8.9
Activities delayed if Activity A is delayed.

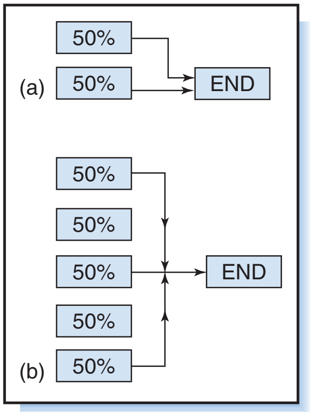


Figure 8.10
Activities delayed where paths merge. (a) Two paths merging, each with 50 percent chance of being on time; (b) five paths merging, each with 50 percent chance of being on time.

8.3 PERT: Program evaluation and review technique

The *program evaluation and review technique* or PERT originated during the US Navy's Polaris Missile System program, an example of a complex research and development program with much uncertainty about the kind of research and stages of development to be done and how fast they can be completed. In projects like this, project definition is occurring at the same time as technological developments are unfolding and before many of the problems with technology, materials, and processes have been identified. The project activity durations are uncertain, and there is great risk that the project will overrun the target completion date.

To provide greater certainty in estimating the duration of the Polaris Missile program, an operations research team was formed with representatives from the Navy's Special Projects Office; the consulting firm of Booz, Allen, and Hamilton; and the prime contractor, Lockheed Missile Systems. They devised a method, PERT, that would provide insight into the likelihood of finishing a project by a certain time.[4] PERT is a not scheduling tool, per se, but is a method for *analyzing the project duration*.

Three time estimates

The network methods discussed in Chapter 7 determine the critical path and slack times using *best estimates* for activity durations. PERT, however, addresses uncertainty in the activity durations by using three time estimates—*optimistic*, *most likely*, and *pessimistic*. Presumably the estimates are obtained from the people most knowledgeable about difficulties likely to be encountered and the potential variability in time; usually they are expert estimators or people who have performed similar activities or will perform or manage the activity.

The three estimates are used to calculate the *expected time* for an activity. The range between the optimistic and pessimistic estimates is a measure of variability that permits making statistical inferences about the likelihood that a project event will happen by a particular time.

Shown in Figure 8.11, the *optimistic time*, a, is the minimum time for an activity—the situation where everything goes well and there is little possibility of finishing earlier. A normal level of effort is assumed with no extra personnel. The *most likely* time, m, is the time that would occur most often if the activity were repeated. Finally, the *pessimistic* time, b, is the longest time for the activity—the situation where bad luck is encountered at every step; it includes likely problems in the work and not highly unlikely occurrences such as natural disasters.

The three estimates are related in the form of a *beta* probability distribution with parameters a and b as the end points and m the most frequent (and most likely) value. The beta distribution is used because it is unimodal (has a single peak value) and is not necessarily symmetrical—properties that seem desirable for a distribution of activity durations. Note that whereas the distribution in Figure 8.8 had no end point on the right-hand side, the curve in Figure 8.11 precludes very unlikely events and has end point b.

Given the three time estimates and assuming a beta distribution, the *mean* or *expected* time, t_e, and the *variance*, V, of each activity are computed with the following formulas:

$$t_e = \frac{a + 4m + b}{6}$$

$$V = \left(\frac{b - a}{6}\right)^2$$

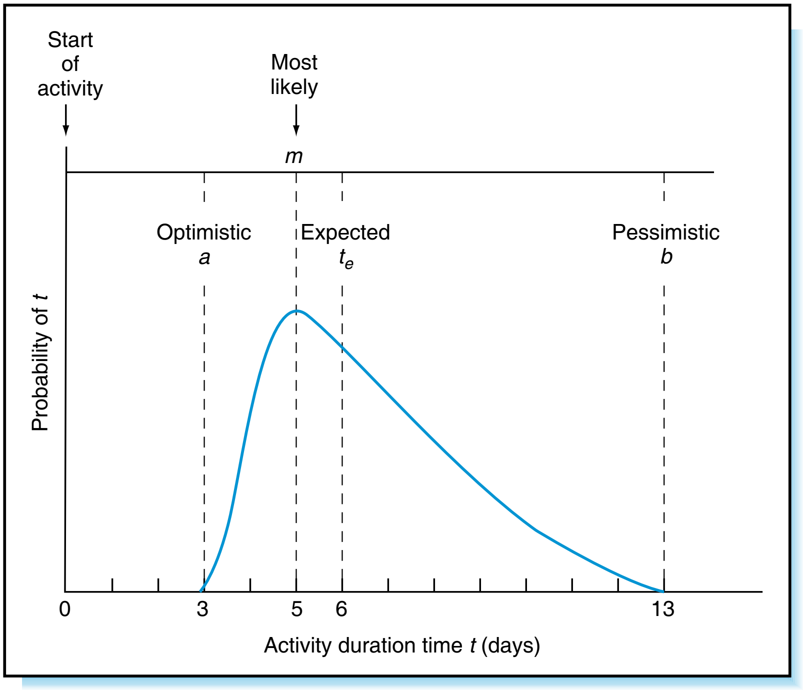


Figure 8.11 Parameters in estimating activity duration.

Since $V = \sigma^2$, where σ = standard deviation,

$$\sigma = (b - a)/6$$

The expected time, t_e, represents the duration in Figure 8.11 with a 50–50 chance that the activity will be completed earlier or later than t_e. In the figure

$$t_e = \frac{3 + 4(5) + 13}{6} = 6 \text{ days}$$

The variance, V, is a measure of variability in the activity duration:

$$V = \left(\frac{13 - 3}{6}\right)^2 = (1.67)^2 = 2.78$$

The larger V, the less reliable t_e and the higher the likelihood the activity will be completed much earlier or much later than t_e. This simply reflects that the farther apart a and b, the more dispersed the distribution and the greater the chance that the actual time will significantly differ from the expected time. In routine (repetitive) jobs, estimates of a and b are close to each other, V is small, and t_e is more likely.

Probability of finishing by a target completion date

The expected time, t_e, is used in the same way as the estimated activity duration was used in the deterministic networks in Chapter 7. Because statistically the expected time of a sequence of independent activities is the sum of their individual expected times, the expected duration of the *project*, T_e, is the sum of the expected activity durations along the critical path; that is

$$T_e = \sum_{CP} t_e$$

where each t_e is the expected time of an activity on the critical path.

PERT is a stochastic approach; hence, the project duration is not considered a fixed point but rather an estimate subject to uncertainty owing to the uncertainties of the activity durations along the critical path. Because the project duration T_e is computed as the sum of expected but uncertain activity durations, it follows that T_e is also an expected but uncertain time. The project duration can be thought of as a probability distribution with an *average* of T_e; the probability of completing the project before T_e is 50 percent, and so is the probability of completing it after T_e.

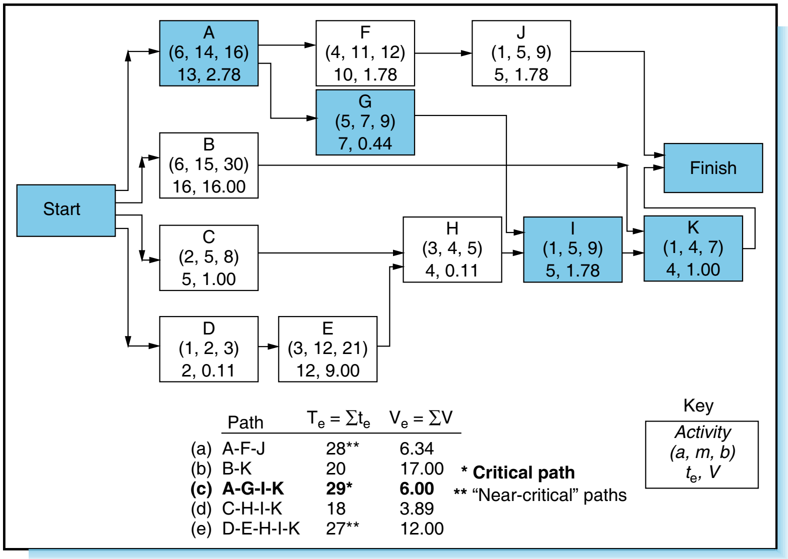
The variation in the project duration distribution, V, is computed as the sum of the variances of the activity durations along the critical path:

$$V_P = \sum_{CP} V$$

These concepts are illustrated in the network in Figure 8.12.

Unlike the distribution of activity durations, which is beta, the distribution of *project durations* is assumed to be normal—the familiar bell-shaped curve. Given this assumption, it is easy to determine the probability of meeting any specified project target completion date T_s.

As examples, consider two questions about the project in Figure 8.12: (1) What is the probability of completing the project in 27 days? (2) If we want to be 95 percent sure about meeting a project deadline, what deadline should we quote? To answer these questions, we invoke the assumption that the



	Path	$T_e = \Sigma t_e$	$V_e = \Sigma V$
(a)	A-F-J	28**	6.34
(b)	B-K	20	17.00
(c)	**A-G-I-K**	**29***	**6.00**
(d)	C-H-I-K	18	3.89
(e)	D-E-H-I-K	27**	12.00

* **Critical path**
** “Near-critical” paths

Figure 8.12
PERT network with expected activity durations and activity variances.

distribution of project duration is a standard *normal* distribution, and we begin by determining the number of standard deviations, z, that separate the target duration T_s from the expected project duration, T_e. The formula for the calculation is:

$$z = \frac{T_s - T_e}{\sqrt{V_p}}$$

To answer the first question, use $T_s = 27$ days. From the network critical path, the expected project duration, T_e, is 29 days. Therefore

$$z = \frac{27 - 29}{\sqrt{6}} = -0.82$$

Therefore, the probability of completing the project within 27 days is equal to the area under the normal curve to the left of $z = -0.82$, which, referring to Table 8.2(a), is about 21 percent.

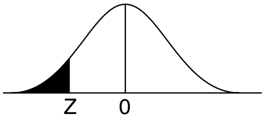
To answer the second question (95 percent certainty of meeting deadline): from Table 8.2(b), for a probability of 0.95, the z value is 1.6. Using the z formula, then solving for T_s:

$$1.6 = \frac{T_s - 29}{\sqrt{6}}, \text{so } T_s = 33 \text{ days}$$

In other words, it is 95 percent probable ("highly likely") that the project will be completed within 33 days. Note that since we are working with values that are merely estimates, it does not make sense to compute figures of great precision.

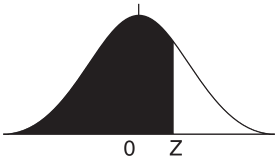
Table 8.2 Normal distribution function for completing a project by time T_s

(a) Probability that project will be completed on or before T_s, when $T_s < T_e$.



z Value	Probability	z Value	Probability
0	.50	−1.2	.12
−0.1	.46	−1.3	.10
−0.2	.42	−1.4	.08
−0.3	.38	−1.5	.07
−0.4	.34	−1.6	.05
−0.5	.31	−1.7	.04
−0.6	.27	−1.8	.04
−0.7	.24	−1.9	.03
−0.8	.21	−2.0	.02
−0.9	.18	−2.1	.02
−1.0	.16	−2.2	.01
−1.1	.14	−2.3	.01

(b) Probability that project will be completed on or before T_s when $T_s > T_e$.



z Value	Probability
0.0	.50
0.1	.54
0.2	.58
0.3	.61
0.4	.66
0.5	.69
0.6	.72
0.7	.76
0.8	.79
0.9	.82
1.0	.83
1.1	.86

z Value	Probability
1.2	.88
1.3	.90
1.4	.92
1.5	.93
1.6	.95
1.7	.96
1.8	.96
1.9	.97
2.0	.98
2.1	.98
2.2	.99
2.3	.99

Near-critical paths

The PERT procedure has been criticized for providing overly optimistic results, a justifiable criticism, since it does not account for the effect of *merge-point bias*. For example, Figure 8.12 has two paths that are "near critical" in length. The variance of these paths is large enough that either could easily become critical by exceeding the 29 days of the current critical path. In fact, as you may wish to verify using the statistical procedure described previously, the probabilities of *not* completing Path (a) (A–F–J) and Path (e) (D–E–H–I–K) within 29 days are 34 percent and 29 percent, respectively. So there is more than a slight chance that these paths could become critical. The warning is: don't ignore the near-critical paths—paths that could themselves become critical and jeopardize the project completion date.

Furthermore, the 50 percent probability of completing the project within 29 days, as presumed with the normal distribution, is overly optimistic. Because *all* activities in the network must be completed before the project is completed, the probability of completing the project within 29 days is the same as the probability of completing *all* five paths within 29 days. Although the probability of completing Paths (b) and (d) within 29 days is close to 100 percent, the probabilities of completing Paths (a) and (e) within that time are 100 – 34 = 66 percent and 100 – 29 = 71 percent, respectively, and the probability of completing (c), the critical path, is 50 percent. So the chance of completing all five paths within 29 days is the product of the probabilities 1.0 × 1.0 × 0.66 × 0.71 × 0.5, or less than 25 percent.

Meeting the target date

Clearly, one way to increase confidence in meeting a target date is to delay it, but when the target date cannot be delayed, the alternative is to revise the project network and shorten the critical and near-critical paths so T_e is somewhat less than T_s. Ways to do this include:[5]

1. Look for opportunities to fast-track (overlap) activities on the critical path, which implies scheduling an activity to start before its predecessors are completed. An alternative is to split the predecessors into subactivities and start successors when only some of the predecessor subactivities have been completed.
2. Add resources to critical and near-critical activities by transferring resources from noncritical activities with large slack times.
3. Substitute time-consuming activities with ones that are less so, or delete activities that are not absolutely necessary.

Each of these has drawbacks. Fast-tracking increases the risks of having to repeat activities in case of changes or mistakes. Adding resources to speed up activities increases the cost, and transferring them between activities involves changes to plans and schedules, increases administrative costs, and aggravates the managers who supply the resources. The final alternative, substitution or elimination of activities, jeopardizes project performance, especially when it equates to making "cuts" or using poorer-quality materials or lower-skilled labor.

Criticisms of PERT[6]

The PERT method assumes that activity durations are independent, though often they are not. Whenever resources are transferred from one activity to another, then the durations of both activities are changed.

PERT also assumes that three activity estimates are better than one. Unless based upon good historical data, however, the three estimates are still *guesses*, which might not improve over a single "best" guess. An advantage of the pessimistic estimate, however, is that it allows for the possibility of setbacks, which a single estimate cannot.

The accuracy of estimates often depends on experience. Whenever a database is formed, based upon experience from similar activities in previous projects, a "history" can be developed for each kind of activity that can be used to estimate the durations of future activities. In fact, reliance on good *historical data* for estimating times makes PERT more appropriate for somewhat "repeatable" projects and less so for first-of-a-kind projects. Thus, the PERT method tends to be used in construction and standardized technical projects but seldom elsewhere.

Some of PERT's shortcomings are addressed by Monte Carlo simulation.

Monte Carlo simulation of a project network

Monte Carlo computer simulation is a procedure that takes into account the effects of near-critical paths and merge-point bias. The critical path is computed from activity durations that are randomly selected from probability distributions. The procedure is repeated thousands of times to generate a distribution of project durations. It gives an "expected time" and standard deviation for the project duration that is more reliable and accurate than simple PERT computations, and it also gives the probabilities of other paths becoming critical.[7]

Simulation allows the use of a variety of probability distributions besides beta, including distributions based upon empirical data. As a result, the generated project durations more accurately represent the range of expected durations than the single-network PERT method.

Simulation can also avoid some limitations of PERT assumptions, such as independence of activity durations and normal distribution of the project duration. The following example from Evans and Olson illustrates simulation to assess the likelihood of project completion time.[8]

Example 8.2: Simulation to Determine Project Duration

Refer to the project activities and time estimates in Table 8.3 and the network in Figure 8.13.

The critical path is B–F–G–H–I–K–M–O–P–Q; summing t_e and V on this path gives a project duration of 147.5 days with a variance of 56.63.

Suppose the customer wants the project to be completed within 140 days. Using the PERT method, the probability of completing the project within 140 days is found from

$$z = \frac{140 - 147.5}{\sqrt{56.65}} = -0.996$$

Referring to Table 8.2(a), the probability is about 16 percent.

Table 8.3 Activities and time estimates.

	Activity	Predecessors	Minimum	Most Likely	Maximum	t_e	V
A	Select steering committee	—	15	15	15	15	0
B	Develop requirements list	—	40	45	60	46.67	11.11
C	Develop system size estimates	—	10	14	30	16	11.11
D	Determine prospective vendors	—	2	2	5	2.5	0.25
E	Form evaluation team	A	5	7	9	7	0.44
F	Issue request for proposal	B, C, D, E	4	5	8	5.33	0.44
G	Bidders’ conference	F	1	1	1	1	0
H	Review submissions	G	25	30	50	32.5	17.36
I	Select vendor short list	H	3	5	10	5.5	1.36
J	Check vendor references	I	3	3	10	4.17	1.36
K	Vendor demonstrations	I	20	30	45	30.83	17.36
L	User site visit	I	3	3	5	3.33	0.11
M	Select vendor	J, K, L	3	3	3	3	0
N	Volume sensitive test	M	10	13	20	13.67	2.78
O	Negotiate contracts	M	10	14	28	15.67	9
P	Cost-benefit analysis	N, O	2	2	2	2	0
Q	Obtain board of directors’ approval	P	5	5	5	5	0

Source: Evans J. and Olson D. *Introduction to Simulation and Risk Management*. Upper Saddle River, NY: Prentice Hall; 1998, p. 116, with permission.

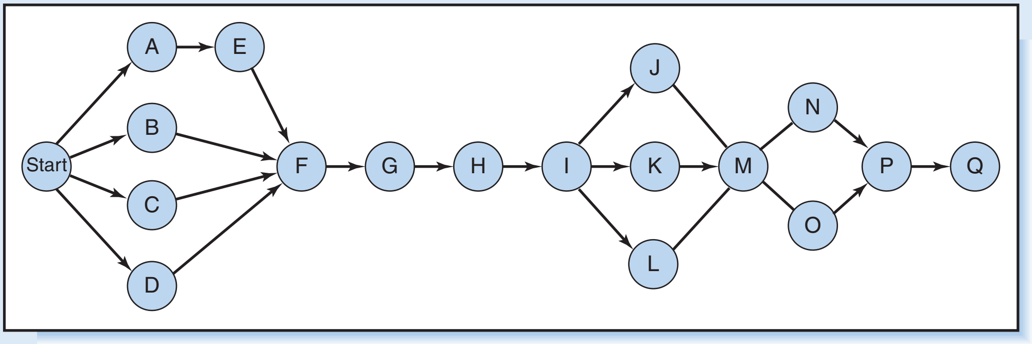


Figure 8.13
Project network.

Now, using the simulation program Crystal Ball™ to generate the completion times for 1,000 replications of the project yields the distribution in Figure 8.14. (Various other programs such as Risksim™, @Risk™, Arena™, and Simul-8™ could also be used.)[9]

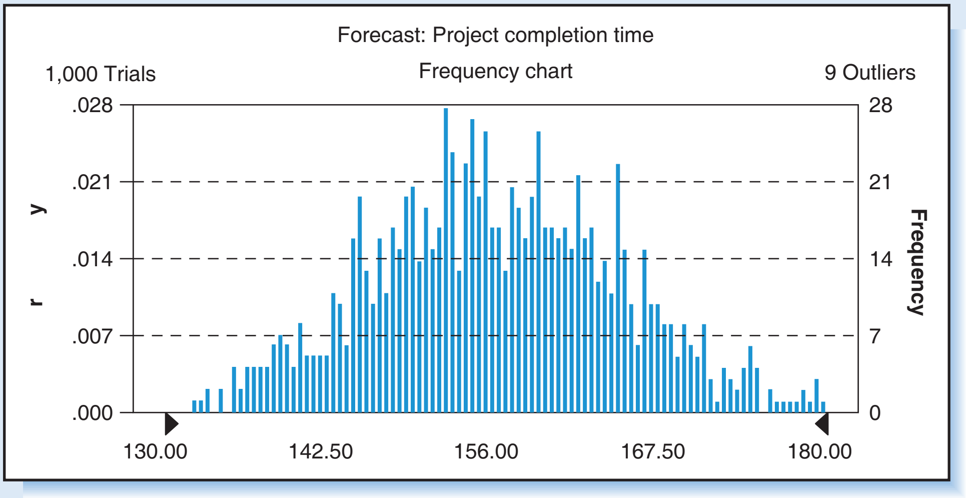


Figure 8.14
Crystal Ball simulation results for project completion times.

The simulated distribution has a mean of 155 days and gives a probability of completing the project in 140 days of about 6.9 percent (the sum of the probabilities to the left of 140 on Figure 8.14). It is thus unlikely that the project will be finished in less than 140 days, and only 50 percent likely that it will be completed within 155 days, which is 7.5 days longer than the PERT estimate of 147.5 days.

See Chapter 11

Simulation provides more realistic results than PERT because it compensates for noncritical paths that could become critical. But, like PERT, it is merely a method for analyzing schedules, not for creating them. It is a "better" analysis tool than PERT but, like PERT, does not eliminate the uncertainty associated with scheduling or specify what to do to reduce project risk; other tools are needed for that, as discussed in Chapter 11.

Why projects are often late

The project manager might face considerable risk when committing to a target due date based solely on the duration of the critical path. For example, according to the table in Figure 8.15, adding the critical-path activity durations gives a most likely project duration of 130 days. However, according to a Monte Carlo simulation to calculate the probability of finishing the project for the same critical-path activities, the chance of finishing the project in that time is only 15 percent. Further, the simulation accounted for the critical path only and not for noncritical paths that might become critical—which would reduce the probability even more. While individual *m* (most likely) values might be considered "realistic," the sum of the *m* values is not realistic at all! The project manager faces a similar risk when committing to a project cost that is derived from the sum of the most likely activity cost estimates. Many project managers estimate project duration and cost by simply adding up most likely estimates of activity durations and costs—one reason projects overrun due dates and budgets.

Activities on critical path	**Optimistic Duration *a***	**Most Likely Duration *m***	**Pessimistic Duration *b***
A	10	12	15
B	14	15	17.5
C	18	20	22
D	12	13	14.5
E	22	24	27
F	14	15	17
G	13	14	15.5
H	16	17	19
Sum of most likely durations		**130**	

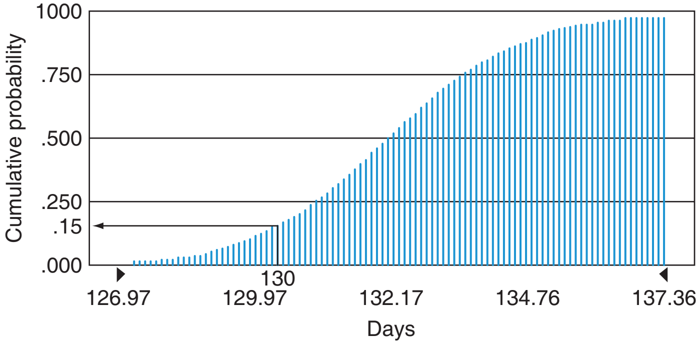


Figure 8.15
Simulation results show low probability of finishing within critical-path time. Generated by means of Crystal Ball software, assuming triangular distributions.

Another reason for overruns is human behavior. During the feasibility or proposal (tendering) stage of the project, champions and supporters work hard to "sell" the project. Everyone is optimistic, which is necessary to gain buy in from stakeholders but also leads to underestimating project duration and cost. The Channel Tunnel ("Chunnel") is an example. Originally, it was stated that 30 million people and 100 million tons of freight would be transported through the Chunnel *per year*, a claim that proved slightly exaggerated, since in the first 5 *years* the actual numbers were 28 million people and 12 million tons of freight. The cost, initially estimated at £7.5 billion, ultimately reached £15 billion, and the project took nearly 18 months longer to complete than originally estimated.

8.4 Allocating resources and multiple project scheduling

This section addresses the matter of scheduling multiple projects that share the same constrained resources. For example, organizations in construction, consulting, systems development, and maintenance commonly use a pool of shared skilled workers and equipment from which all projects draw. The same happens in matrix organizations (Chapter 15), where projects share resources from the functional departments.

See Chapter 15

Multiple projects that share resources must be planned and scheduled such that in combination they do not exceed the resources available in the shared pools. Although these projects might in all other ways be considered independent, with regard to their shared resources, they are *inter*dependent.

As might be expected, the problem of scheduling multiple concurrent projects is analogous to scheduling multiple concurrent activities within a single project but with modification to account for the economic, technical, and organizational issues that arise when dealing with multiple projects (see Chapter 19). First, each project has its own target completion date, and every project must be scheduled to finish as close to that date as possible to avoid deferred payments, penalty costs, or lost sales and revenues. Further, when projects are interdependent, delays in one project can ripple to others (the delay of a satellite development project will cause subsequent delay of a telecommunication-network project). In any case, scheduling of multiple projects requires first determining the relative priority among the projects to determine which project should get first dibs on scarce resources.

See Chapter 19

Because most organizations prefer to maintain a uniform level of personnel and other resources, the combined schedules for multiple projects ideally result in a uniform loading of those resources. In other words, the resource loading for the combined projects is ideally flat. In theory, projects are scheduled so that as resources are released from one project, they are assigned to others. This minimizes costs associated with hiring, layoffs, and idle workers and facilities and helps maintain worker morale and efficient use of resources.

When many activities or projects are ready to start and all require the same resource, the question is, to which activities or projects should the resource be allocated? When 10 activities are ready to start, the number of possible sequences in performing them is 10!, or more than 3.6 million. If n activities are ready to start and all of them require m resources, the number of possible schedules would be $(n!)^m$. Schedule optimization using normal polynomials is usually not feasible (the problem is "NP hard"), so heuristic methods must be used.

Heuristic methods for allocating resources

A heuristic method is a procedure based upon a simple rule. Heuristic methods for allocating resources to projects often employ *priority rules* or *dispatching rules*. While these methods do not produce optimal schedules, they do produce "good-enough" schedules for most situations.

Heuristic methods start with early and late times as determined by traditional network methods, and then analyze the schedule for the required resources (i.e. the resource loading). Whenever a resource requirement exceeds the constraint, the heuristic determines which activity gets high priority and should receive the resource. The most common heuristic rules for determining scheduling priority are:

1. *As soon as possible*: activities that *can* be started sooner take priority over (or an be scheduled ahead of) those that can be started later.
2. *As late as possible*: activities that must be finished earlier take priority over those that can be finished later.
3. *Most resources*: activities requiring more resources take priority over those requiring fewer resources.
4. *Shortest task time*: activities of shorter duration take priority over those of longer duration (sometimes referred to as *shortest activity duration*, *shortest processing time*, or *shortest operating time*).
5. *Least slack*: activities with less slack take priority over those with more slack; critical path activities thus have highest priority. (This rule is also referred to *as slack time remaining*.)
6. *First come first served*: activities that originate earlier or require the work or resource earlier take priority.
7. *Earliest due date*: activities or projects with the earliest target completion dates take priority. Alternatively, activities with the *earliest next operations* take priority.

All of the priority rules are subordinate to precedence requirements; that is, no matter the rule, the resulting schedule must not violate predecessor–successor relationships. Most project management software employs some combination of these rules (e.g. using "shortest task time," then using "as soon as possible" as a tie breaker).

Figure 8.16 shows examples of applying the previous rules 1 through 5 in assigning workers to activities and their impacts on the project schedule given a constraint of ten workers per week maximum. As the figure shows, the rules yield different results, some better than others. With the *as late as possible* rule, some activities are delayed from their early dates; the drawback of this is that it increases the risk of delaying the project. In contrast, the *least slack rule* is good since it reduces the risk of noncritical activities delaying critical ones.

The *shortest task time* rule is good when multiple projects must be executed at once, since it allows people responsible for succeeding activities to perform them sooner. Figure 8.17 shows what happens when activities are scheduled (a) *longest task time* versus (b) *shortest task time*. As represented by the area under the bars, the total waiting time in (b) is much less than in (a). The rule says: when you have several things to do, do the shortest ones first.

The typical scheduling goal is to complete the project by the target completion date; sometimes that is not possible, regardless of the priority rule. For example, suppose the target completion date for the project in Figure 8.16 is 9 weeks, the critical path length. Given the constrained-resource level of ten workers, none of the heuristics in the example meet this target, although one of them ("as late as possible") results in 10-week completion.

8.5 Theory of constraints and critical chain method[10]

The theory of constraints (TOC) is a systems approach to improving the performance of business systems.[11] A premise of TOC is that every system has a goal and that, often, only one element of the system, called the *system constraint*, precludes achieving that goal.

The application of TOC to project scheduling and control is called *critical chain project management* or the *critical chain method*. The role of CCPM is to reduce the duration of the project and provide a more predictable completion date.[12] CCPM accounts for both the stochastic nature of activity durations and the human behavioral impact on project scheduling and execution. It can be applied to single projects or to multiple concurrent projects.[13]

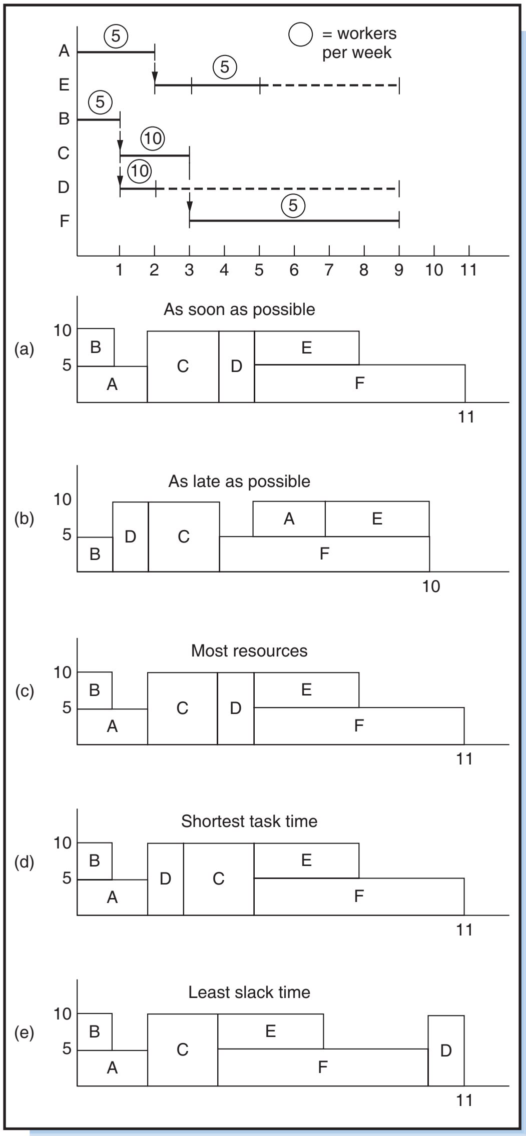


Figure 8.16
Results of several priority rules on project schedule and completion times.

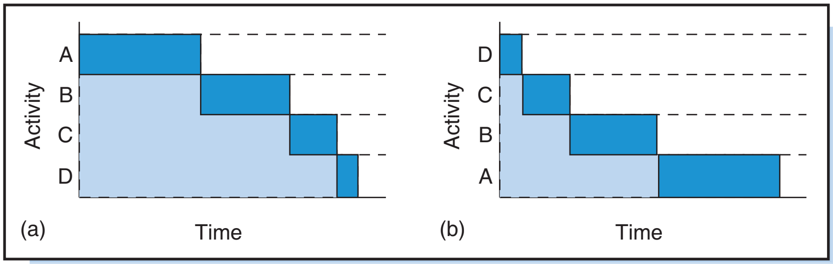


Figure 8.17
The shortest task time rule reduces waiting time.

Commitment to due dates

With traditional scheduling methods, people working in each project activity must *commit* to completing the activity by a target date (e.g. the scheduled early or late finish date), even though the activity duration is uncertain. There might be penalties for finishing late or rewards for finishing early, but out of fear of finishing late, people responsible for an activity often provide a time estimate that is pessimistic or "padded." Although this behavior is customary, it results in inflated estimated activity durations. Since not every activity necessarily requires pessimistic durations, padding all activities results in longer-duration projects.

The CCPM approach to avoiding time padding is twofold: (1) While the project manager obviously needs to commit to a due date for the project, people responsible for individual project *activities* are not required to commit to due dates. They are encouraged to work in earnest but are not held to target dates. In requesting time estimates, everyone is asked to provide a somewhat "pessimistic" time, meaning the time with an excellent chance of it being achieved. (2) The time estimate is then cut in half to obtain an "aggressive" estimate, which eliminates any possible padding. (It should be noted, however, that whenever project members already provide "aggressive" [not padded] estimates, the time is not then cut in half.) Of course, removing padding leaves the project prone to delays and increases the risk of it not meeting the project due date—unless the project due date is protected with a time buffer.

Project buffer and feeding buffers

To protect against unforeseen delays, a *project time buffer* (or time contingency) is placed at the *end* of the project. The date at the end of the buffer is the date to which the project manager commits to completing the project. But, you might ask, won't adding a time buffer lengthen the project duration? The answer is no, because the aggressive time estimates used to schedule project activities are typically only 50 percent of the "realistic" estimates originally provided. Dividing the realistic estimate by two results in two estimates: one an aggressive estimate for the duration, the other an estimate of the padding. Summing estimates of the padding for all the activities forms the so-called *project time buffer*. Placing this buffer at the end of the project will account for delays in any of the activities.

To illustrate, consider the project shown in Table 8.4 and Figure 8.18. The critical path, P–Q–R–Z, is 32 weeks long. Now look at Figure 8.19, where the activity durations have been cut in half. The 16 weeks (4 + 6 + 4 + 2) cut from the critical path P–Q–R–Z become the project buffer. Note also in Figure 8.19 the presence of a *feeding buffer*, which is the number of weeks cut from noncritical path S–T, 12 weeks (2 + 10). In general, CCPM calls for a single project buffer at the end of the critical path as well

Table 8.4 Activities for small system development project.

Activity Description (from WBS)	Activity Code	Duration (Days)	Resources
Design Subsystem A	P	8	Design Team A
Manufacture Subsystem A	Q	12	Technician
Test Subsystem A	R	8	Test team
Design Subsystem B	S	4	Design Team B
Build Subsystem B	T	20	Technician
Assemble Subsystems A and B	Z	4	Technician

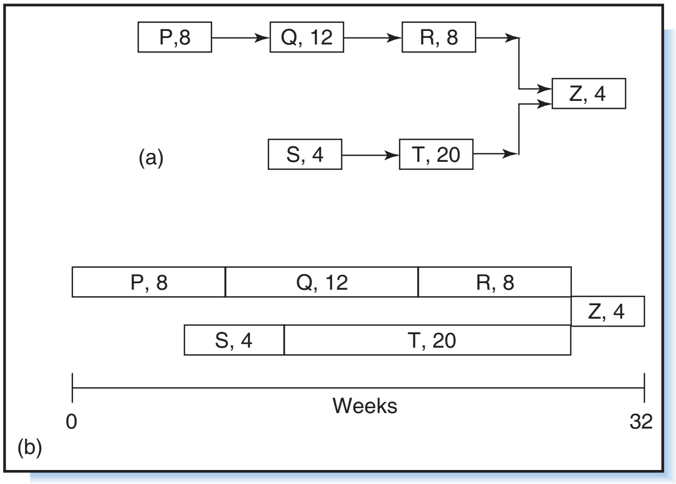


Figure 8.18
(a) Network for activities in Table 8.4. (b) Time-scaled network for the activities indicated in Table 8.4.

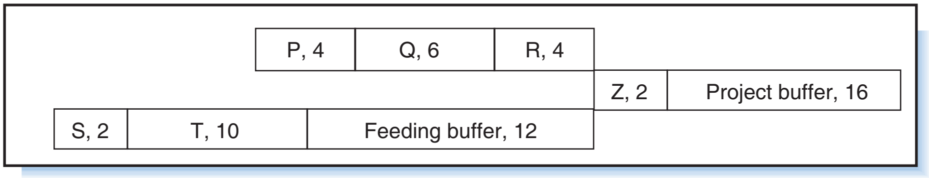


Figure 8.19
Schedule with contingency reserves (buffers).

as a feeding buffer located wherever a noncritical path feeds into the critical path. The feeding buffer protects the critical path from delays in noncritical activities.

While project buffers and feeding buffers bear a resemblance to slack, they are *not* slack. Whereas with traditional methods, activities are scheduled as early as possible and slack may be used to absorb any delays, in CCPM, all activities are planned to *start as late as possible* but with buffers. (As discussed later, however, once the project is underway, critical activities are encouraged to take advantage of predecessor activities finishing early and also to start early.) The buffers all "belong" to the project manager, and only she can allocate time from them, which she does whenever an activity exceeds its planned duration.

The size of the buffers in Figure 8.19 is the same as the length of the paths they follow, but in practice, they can be substantially less than that. There are two reasons:

1. The mathematical principle of *aggregation*, which, in this application, says that the uncertainty of finishing a project is much less than the sum of the uncertainties of finishing the individual activities in the project. In other words, the paddings removed from individual activities can be replaced by a project buffer that is much smaller than the sum of those paddings.[14]
2. Parkinson's Law states that "work expands to fill the time available." The obverse of this is that, given less time to do the work, people tend to work faster. In other words, removing padding from an activity creates a sense of urgency:

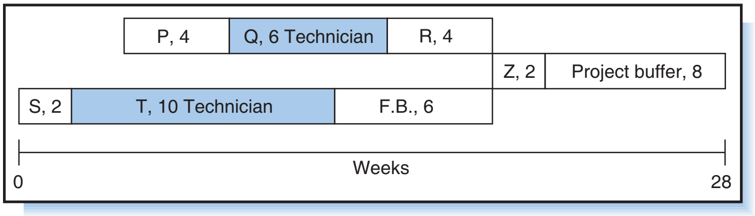


Figure 8.20
Schedule with buffer sizes reduced.

For these reasons, the project buffer size can be substantially reduced—typically by 50 percent. As shown in Figure 8.20, where the buffers have been cut in half, the estimated project completion time is 28 weeks. (A buffer of only a third the length of the path it follows is often found to be sufficient for setting a project commitment date.)

Thus, week 28 is the date the project manager commits to completing the project, while week 20—at the start of the project buffer—is the date the project team strives to meet. Consequently, while there is a chance (perhaps small) that the project will finish in 20 weeks, there is a very high likelihood of it being completed within 28 weeks. *This compares to the critical path method, which would yield an estimated project duration of* 32 weeks *plus a high likelihood of it taking longer* than that.

Critical chain

Now let's also consider resources. Figure 8.20 shows that Activities Q and T both use the same "technician" resource. Assume the technician can work on only one activity at a time, in which case the schedule is adjusted. This is shown in Figure 8.21, putting Activity T before Activity Q (putting Q before T is another possibility). In the revised schedule, path S–T–Q–R–Z is called the *critical chain*, defined as the *longest path that takes into account both precedence and resource dependencies*. (Path P–Q–R–Z does not consider resource dependencies between T and Q, so it is not the critical chain.) Whenever the length of the critical chain plus the project buffer exceeds the length of the critical path, it is the critical chain, *not* the critical path, that determines the project duration.

Traditional network scheduling also addresses resource-conflict problems by means of resource leveling, but the resulting schedule will not necessarily be the same as with CCPM. Whereas the former method starts with an initial schedule and uses available slack, CCPM addresses resource requirements during the initial scheduling process by giving priority to resolving resource conflicts.

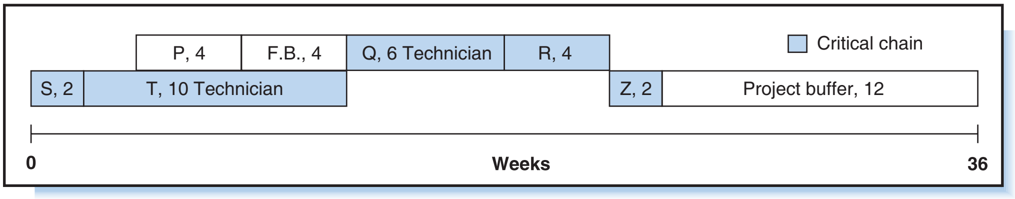


Figure 8.21
Schedule adjusted so every resource performs only one task at a time.

Note that the feeding buffer in Figure 8.21, F.B., is 4 weeks, not 2. This is because it follows only one activity, P, and hence the aggregation effect mentioned previously does not apply. Ultimately, however, the actual size of the buffer is at the manager's discretion.

Resource buffers: capitalizing on finishing work earlier than planned

Mentioned earlier was the fact that whenever activities finish late, their successors start late, but whenever they finish early, their successors *don't necessarily start early*. Resources that have been prescheduled often are not available to start earlier because they are busy doing something else. As a consequence, activities finishing late tend to delay the project, but activities finishing early do not speed up the project (they have no effect!).

In CCPM, however, the project *is* able to capitalize on activities finishing early through the use of *resource buffers*. Unlike project and feeding buffers, resource buffers do not add time to the schedule. Rather they present a *countdown signal* or warning to alert resources that an activity on the critical chain will possibly finish earlier than planned and to *be prepared to start early*. In a relay race, each runner is prepared to accept the baton whenever the previous runner arrives; likewise, resources on the critical chain are prepared to start work as soon as predecessors finish their work, regardless of the schedule. In practice, a resource buffer can take the form of a series of emails or other messages to a resource, counting down the time remaining before it must be ready to start an activity. The locations of resource buffers are illustrated in Figure 8.22. When priority is given to starting work early, the resource must drop whatever else it might be doing.

Note in Figure 8.22 that resource buffers are inserted only on the critical chain (S–T–Q–R–Z), since feeding buffers shield the critical chain from uncertainty on noncritical paths. Note also there is no resource buffer between Activity T and Activity Q, since the same resource (technician) does both and, obviously, needs no notification about when Activity Q will finish and Activity T will start.

Milestone buffers

Sometimes milestone dates are set at intermediate times in the project, such as at scheduled completion dates for project phases. In such cases, a *milestone buffer* is inserted before each milestone. When milestone buffers are used, the size of the project buffer is reduced; in effect, the project buffer is divided up among the milestone buffers. The different types of buffers used in CCPM are summarized in Table 8.5.

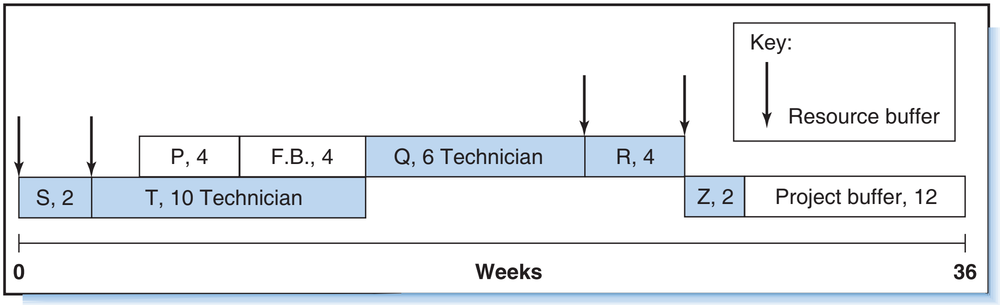


Figure 8.22
Resource buffers providing countdown on when to start critical activities.

Table 8.5 Summary of buffer types for a single project.

Buffer Type	Function of the Buffer
Project buffer	Composed of aggregated paddings (contingency reserves) taken from activities on the critical chain; provides a schedule reserve between the earliest possible completion date and the committed, target date.
Milestone buffer	Similar to a project buffer but used when a project phase or milestone has a fixed due date.
Feeding buffer	Composed of aggregated contingencies taken from activities on noncritical paths; prevents noncritical activities from delaying critical-chain activities.
Resource buffer	An early warning or "countdown" to prepare resources on critical activities to be ready to start work as soon as all predecessor activities have been completed.

Sizing of buffers

CCPM relies heavily on project and feeding buffers, so making them the right size is important. As illustrated in the examples in Figures 8.19 and 8.20, commonly, activity durations are cut in half, and then the resulting longest path through the network is cut in half to yield the size of the project buffer.[15] This method, which reduces project duration by 25 percent, is referred to as the "50 percent of chain" and "cut and paste" method.

When a path consists of many activities, even a buffer of 50 percent of the path length is too large.[16] Newbold proposes the *square root of sum of squares* (SSQ) method, where the buffer size is set to the square root of the sum of squares of the differences between the low-risk duration and the mean duration for each task along the longest path leading to the buffer.[17] Others have suggested additional methods.[18]

Padding, multitasking, and procrastination

Projects take longer than necessary for many reasons. First, as already stated, people *pad* their time estimates, and the effect of this gets worse as managers at all levels in the WBS add to the padding. If the person responsible for an activity pads the time by 10 percent and each person higher in the WBS also pads it by 10 percent, the padding at the project level for an n-level WBS would be $(1.1)^n$. For a five-level WBS, this yields a total contingency of 60 percent; if each pads 15 percent, the total contingency would be 101 percent.

Second, people *multitask*. For example, a contractor has three independent projects, X, Y, and Z, each of expected duration 10 weeks. The contractor is anxious to finish *all* of them as soon as possible, so he divides each into small pieces so that, in a sense, he can work on all of them at once. But in doing so, he actually delays the completion of two of the projects. If he had scheduled the projects sequentially X first, Y second, and Z last, without interruption, then, as shown in Figure 8.23(a), he would finish X at week 10, Y at week 20, and Z at week 30. But when he breaks up the projects into segments of, say, 5-week periods, and alternates working among them, he increases the *elapsed time* for each project from 10 weeks to 20 weeks. As shown in Figure 8.23(b), the result is that two of the projects are delayed: X finishes in week 20, and Y finishes in week 25. In general, the more the activities or projects are broken up and intermixed with other projects, the greater the elapsed time to finish any of them.

Compounding the effect is that multitasking precludes gaining the momentum that would have occurred by focusing uninterruptedly on only one task, as was illustrated in Chapter 7, Figure 7.25.

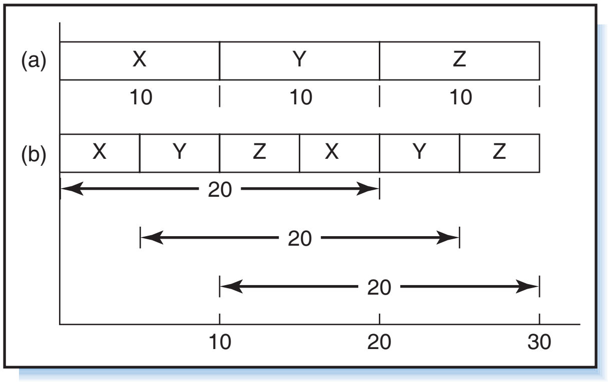


Figure 8.23
Effect of multitasking on elapsed and completion times.

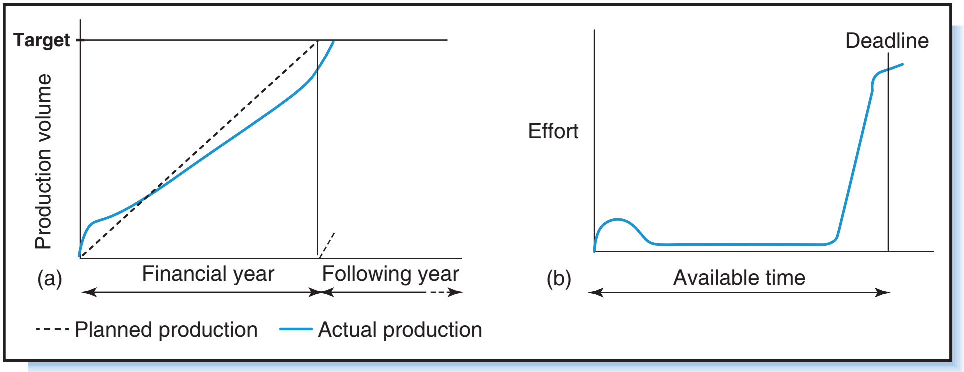


Figure 8.24
Students' syndrome (a) in a production and (b) in a project.

Multitasking should be avoided. By focusing on just one activity (or project) at a time, each is completed sooner, successors start sooner, and everything finishes sooner.

A third reason projects take longer than necessary is *procrastination* and wasting available slack.[19] Given a choice between two scheduled times, one early and one late, many people choose the late one; this automatically eliminates slack, puts activities on the critical path, and increases the likelihood of project delay. Also, whenever they perceive slack, people are less motivated to complete an activity early. The effect is called the "students' syndrome," hinting at students' initial enthusiasm for a new course that soon wanes, not to resume until just before the final exam. The same effect occurs in production and project environments (Figure 8.24). Shortening activity durations and scheduling activities as late as possible (with buffers) reduces the tendency to procrastinate.

Buffer management for project control

Every activity in the project is linked to a buffer: activities on the critical chain are linked to the project buffer and all others to feeding buffers. During project execution, those buffers are monitored to predict the project completion date and assess the risk of missing the due date. Every time an activity is delayed, buffer is "consumed." A delay occurs when the actual time to complete a task exceeds the estimated aggressive time. The amount of buffer consumed is determined each day by simply asking people working on activities the amount of work remaining and if they exceeded the estimate. As long as all the delays consume less time than the buffer holds, the project will be on time; if they consume more time than the buffer holds, the project will be late. Buffer consumption also provides a clear, objective way to determine priorities. Buffers are monitored, and whenever someone is required to work on more than one activity, the most consumed buffer indicates which activity gets highest priority. Buffer management is further discussed in Chapter 13.

See Chapter 13

Challenge of critical chain project management: changing behavior

A belief in most project organizations is that because the project manager commits to the target completion date, everyone in the project must also commit to target dates. The premise in CCPM is that only the project manager commits to a completion date; everyone else *works toward* "aggressive" estimated times but doesn't commit. While getting everyone to accept this in small projects might be relatively easy, in major projects, it isn't. Since most people are accustomed to working toward deadlines, this requires no less than cultural and behavioral changes at all levels of the organization, including top management. Not understanding the principles of CCPM, senior managers and customers will try to enforce deadlines on everyone.

Software support for critical chain project management[20]

Many project management software packages include provisions for CCPM, although others require add-ons to make them compatible with CCPM. For example, Sciforma™ and Concerto™ software fully support CCPM, but MSProject supports it only with an add-on such as Prochain™.

8.6 Theory of constraints method for allocating resources to multiple projects[21]

As much as 90 percent (by value) of all projects are done in multiproject environments.[22] The theory of constraints provides a five-step procedure for scheduling the start of new projects so as to maximize the number of projects an organization can do concurrently.

Step 1: identify the constraint

What prevents a company from doing more projects? If the company has few projects on the order books, the constraint might be limited market share or the size of the market. But if it has more demand for projects than the capacity to do them, the constraint will be anything that reduces the rate at which projects are completed below the maximum. The most common constraint is a highly loaded resource or multitasking.

Production environments such as manufacturing "job shops" use priority rules (discussed earlier) to select the next job to which a resource (usually a machine) should be assigned. In job shops, it is easy to identify the constraint—it is the machine at which queues of work pile up. Such a resource, the system constraint, is called the "drum resource" because it sets the pace of everything flowing through

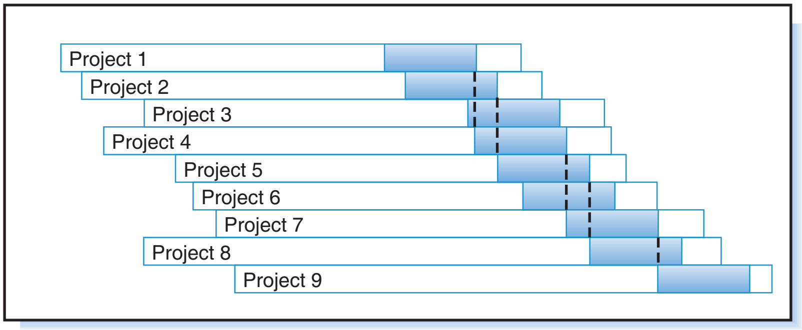


Figure 8.25
Only three projects in final integration at any point in time.

the process. The TOC philosophy emphasizes keeping the drum resource busy, preventing starvation and blockage, to keep work flowing. (To ensure this, *drum buffers* are used; their application to project management is described elsewhere.)

Experience with implementing TOC, however, suggests that while a specific resource might be identified as the constraint in a multiproject environment, often the real constraint is something *other* than that resource. In practice, the identified constraints might be different for *planning* a set of projects than for *executing* them. Typical such constraints are discussed next.

In a sequence of activities, regardless of the actual constraint, an activity near the end of a project may be chosen as a substitute for the constraint.[23] For *planning* a set of projects, *a rule* regarding the scheduling of this activity may be used as proxy for the constraint and for planning a set of projects. For example, in one electronics company that conducts multiple, concurrent projects, all projects must pass through "final integration" just before closeout, and a specialist engineer with high workload was identified as the resource constraint. Rather than using that resource to stagger projects, however, it was decided instead to use the rule of *only three projects in final integration at a time*. In Figure 8.25, the shaded activities represent final integration in nine projects. To ensure there will always be just three projects in final integration: Project 4 starts final integration as soon as Project 1 completes final integration, Project 5 starts final integration as soon as Project 2 completes final integration, and so on. This staggers the work for all resources through subordination of individual project schedules to the three-project rule, as discussed in step 3, discussed below. In the same company, the constraint for executing projects was identified as management time available to provide project support.

Step 2: decide how to exploit (utilize) the constraint

The rule "only three projects in final integration" enables the company to exploit the constrained final integration capacity for planning purposes. Starting with a project's scheduled start date for final integration and working backward through the project's duration determines the date the project should be initiated (release date). Whenever an integration task cannot start according to the rule or work must wait for an integration task, then the duration of integration tasks is adjusted to enable the appropriate staggering of project release.

In the event that a project's final integration is completed early, resource buffers (discussed earlier) will ensure that subsequent projects can be started early.

Because fewer projects are being worked on, staggering them in this way reduces the workload on most resources, reduces multitasking across projects, improves the flow of projects (i.e. rate at which projects are completed), and ensures that commitments to customers are met.

Step 3: subordinate everything else to decisions regarding the constraint

During scheduling, the release date of projects is based on the load on the constraint. When the company decided that it should have at most only three projects in the final integration phase, the proxy constraint was the rule "three projects in final integration." Each new project will be slotted to start final integration at whatever time is necessary to maintain that three-project maximum. The schedules of individual projects are therefore *subordinated* to the multiproject constraint—that is, the rule regarding the number of projects in the integration phase. The project with the highest risk of missing its due date would be scheduled to start first, as indicated by its project buffer status. The utilization of all resources for the set of projects is also subordinated to the schedule, and people do not multitask.

If the constraint for project execution is time available for management support, then all other work to be performed by managers must be subordinated to this support role.

Step 4: elevate the constraint

The constraint is "elevated" by providing additional capacity. Elevating the constraint involves, for example, increasing the final integration capacity so as to increase the number of projects in that phase from three to four, perhaps by adding another specialist engineer. It sometimes requires costly measures such as building new facilities and hiring additional people. Steps 2 and 3 therefore ensure that existing capacity is utilized effectively before spending money acquiring additional resources.

If the constraint is management time available for project support, then the management system might be simplified to improve its effectiveness in performing support functions.

In multiproject environments, resource buffers have less utility. Upon completion of work in one project, resources simply begin work on the next project, even if they have to wait a while before starting. Actually, it is okay that they are idle between projects: for the sake of maximizing project flow, the resources should have to wait for the project; the work should not wait for the resources.

In this way, it is possible that all activities (including those on noncritical paths) can start as soon as predecessor activities are completed. All that is necessary to keep projects on track is to monitor the project buffers (illustrated in Chapter 13, Example 13.2). Tracking project buffers simplifies the tracking and control process during project execution and relieves managers' workloads. In turn, this elevates the constraint for project execution—the time managers have available to provide project support.

See Chapter 13

Step 5: return to step 1

Adding resources might remove the constraint, in which case a new constraint would be identified and the process repeated. Sometimes, however, the new constraint would be too disruptive, in which case the extant constraint is allowed to remain and *not* be elevated.

Discussion

One company has applied the TOC method for managing multiple projects by using only three rules:

Rule 1: During planning, stagger the release of projects.

Rule 2: Plan aggressive project durations using project buffers only one-third the length of the critical chain.

Rule 3: During execution (a) ensure that activities are executed according to priorities by monitoring and controlling project buffer status (Example 13.2), and (b) minimize buffer consumption by doing all tasks as soon as possible.[24]

How good is TOC for planning compared to traditional priority rules? The answer is somewhat equivocal. For some simple projects, the results are the same. One exploratory experiment where TOC was compared with the oft-used least slack rule showed TOC gave better results,[25] but another yielded poorer results.[26] Although TOC is based on logic and seems to make sense, verification in practice would require empirical research from a variety of different industrial settings, which has yet to be done.

8.7 Discussion and summary

This chapter has covered project scheduling methods that address time constraints, resource constraints, uncertainty about activity and project durations, and multiple projects that share resources. The methods offer ways to accelerate projects and reduce uncertainty about completion dates, although, unlike simpler techniques such as Gantt charts and critical path networks, they have gained lower acceptance and are applied mainly in relatively sophisticated industries. All the methods have limitations, yet all have merits.

- CPM enables managers to determine the least costly way of reducing project duration to complete the project by a due date or in the shortest time.
- PERT enables managers to estimate the probability of finishing a project by a predetermined date. But the method considers only the current critical path and ignores noncritical paths that could become critical. Monte Carlo simulation overcomes this limitation by accounting for the possibility of any path becoming critical.
- The critical chain method, CCPM, based on the theory of constraints, aims at reducing project duration. Using time buffers, it transforms a stochastic problem into a simpler deterministic one. Unlike CPM, wherein noncritical activities are scheduled as early as possible, CCPM schedules them as late as possible but with buffers. With other methods, variability in activity durations can lead to changes in the critical path, but buffers in CCPM provide relative stability to the critical chain—the path connecting activities that require the same constrained resource. CCPM offers a practical and relatively simple way to schedule projects, but it requires a shift in human behavior, since only the project manager and nobody else is required to commit to due dates. Many managers find that concept hard to swallow.
- Multiproject scheduling presents the challenges of allocating scarce resources to concurrent projects. The traditional way to allocate resources among projects (and among activities within projects) is to use priority rules. The TOC way aims to allow as many concurrent projects as possible by improving the flow of projects through the system.
- All the previous methods are supported by commercial software, which simplify their application and eliminate computational difficulties. But, as with all management methods, appropriate application of the techniques assumes a sound understanding of the principles that underlie them and management acceptance.

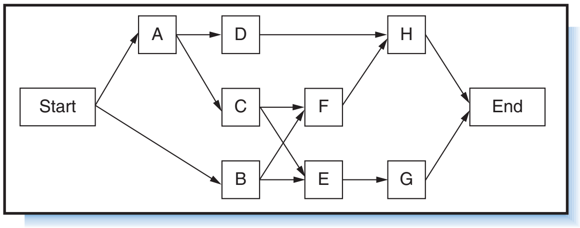
SUMMARY LIST OF SYMBOLS

n	Number of activities on the critical path.
C_n	*Normal Activity Cost*: The direct cost of completing an activity under normal work effort; usually, the lowest cost for completing an activity.
C_c	*Crash Activity Cost*: The direct cost of completing an activity under a crash work effort; usually, the highest cost for completing an activity.
T_n	*Normal Activity Duration*: The expected time to complete an activity under normal work effort; usually, assumed to be the longest time the work will take.

T_c	*Crash Activity Duration*: The expected time to complete an activity under a crash work effort; the shortest possible time in which an activity can be completed.
t_e	*Expected Activity Duration*: In PERT, the mean time to complete an activity, based on optimistic (a), most likely (m), and pessimistic (b) estimates of the activity duration.
T_e	*Expected Project Duration*: The probability of the project finishing earlier than this time is 50 percent and the probability of it taking longer is 50 percent.
T_s	*Target Completion Time for Project*: A time specified for project completion.
V	*Variance of an Activity*: The variability in expected activity duration.
Vp	*Variance of the Project Duration*: The variability in the expected project duration.

Review Questions and Problems

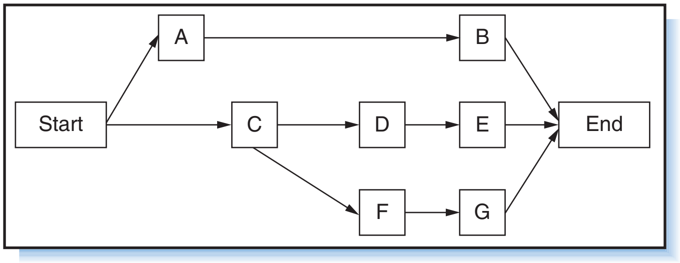
1. Define crash effort and normal effort in terms of the cost and time they represent. When would a project be crashed?
2. How do CPM and PERT differ? How are they the same?
3. What does the cost slope represent?
4. The cost slope always has a negative value. What does this indicate?
5. Time–cost tradeoff analysis deals only with direct costs. What distinguishes these costs from indirect costs? Give examples of both direct and indirect costs.
6. What are the criticisms of CPM? How and where is CPM limited in its application?
7. A project has the following network and costs (T in days, C in \$1,000s).



Activity	Normal		Crash		Cost Slope
	T_n	C_n	T_c	C_c	
A	4	210	3	280	70
B	9	400	6	640	80
C	6	500	4	600	50
D	9	540	7	600	30
E	4	500	1	1100	200
F	5	150	4	240	90
G	3	150	3	150	—
H	7	600	6	750	150

a. Verify that the normal duration is 22 days and that the direct cost is \$3,050.
b. What is the least costly way to reduce the project duration to 21 days? What is the project cost?
c. What is the least costly way to reduce the duration to 20 days? What is the project cost?
d. Now, what is the *earliest* the project can be completed, and what is the least costly way of doing this? What is the project cost?

8. A project has the following network and costs (T in days, C in \$1,000s).



Activity	Normal T_n	Normal C_n	Crash T_c	Crash C_c	Cost Slope
A	6	6	3	9	
B	9	9	5	12	
C	3	4.5	2	7	
D	5	10	2	16	
E	2	2	2	2	
F	4	6	1	10	
G	8	8	5	10	

a. What is the earliest the project can be completed under normal conditions? What is the direct cost?

b. What is the least costly way to reduce the project duration by 2 days? What is the project cost?

c. What is the *earliest* the project can be completed, and what is the least costly way of doing this? What is the project cost?

9. The following table gives information on a project (T in days, C in \$1,000s):

Activity	Immediate Predecessors	Normal T_n	Normal C_n	Crash T_c	Crash C_c
A	—	6	10	2	38
B	—	4	12	4	12
C	—	4	18	2	36
D	A	6	20	2	40
E	B, D	3	30	2	33
F	C	10	10	6	50
G	F, E	6	20	2	100

a. Draw the network diagram. Under normal conditions, what is the earliest the project can be completed? What is the direct cost? What is the critical path?

b. What is the cost of the project if it is completed 1 day earlier? Two days earlier?

c. What is the earliest the project can be completed? What is the lowest cost for completing it in this time?

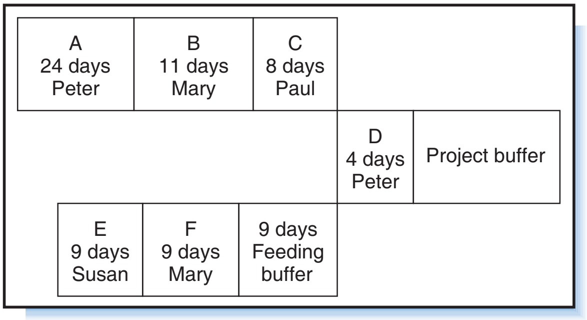
d. If overhead (indirect) costs are \$20,000 per day, for what project duration are total project costs (direct + indirect) lowest?

10. Has variability in a time estimate ever caused you to be late for an appointment? Describe.
11. A procurement officer discovers that the delivery time for a specific item is never less than 5 days. Ten days is the most frequent, but in the worst case scenario, it takes 30 days.
    a. Calculate the expected delivery time.
    b. Calculate the variance.
    c. What factors would you take into account when deciding the amount of time to allow for delivery of the item in the project plan?
12. The following tables show the immediate predecessors and *a*, *m*, *b* for each activity in the two projects. For each project, compute:
    a. t_e and V for each activity
    b. ES, EF, LS, and LF for each activity.
    c. T_e and V_p for the project.

Activity	Predecessors	*a*	*m*	*b*
A	—	7	9	11
B	A	1	2	3
C	A	7	8	9
D	B	2	5	11
E	C	2	3	4
F	C	1	4	8
G	D, E	6	7	8
H	F, E	2	6	9

Activity	Predecessors	*a*	*m*	*b*
A	—	2	4	6
B	—	2	2	3
C	—	4	8	10
D	A	4	6	7
E	A, B	7	9	12
F	D, E	1	2	3
G	C	2	3	4
H	F, E	2	6	9

13. Refer to the first network in the previous problem.
    a. What is P ($T_e < 23$)?
    b. What is P ($T_e < 32$)?
    c. For what T_s is the probability that the project will be completed 95 percent?
14. For the network in Figure 8.12, what is the probability of completing each of the five paths within 30 days? What is the probability of completing *all* of them within 30 days?
15. How would you use buffers to ensure that you are on time for appointments? What factors would you take into account when you make a decision on the size of the buffer?
16. Explain in your own words how the principle of aggregation plays a role in reducing project duration.
17. The following diagram was created before it was known that Mary would have to perform both Activity B and Activity F.



   a. With the realization that Mary has to do both tasks, indicate two possible critical chains.
   b. Reschedule the work and show the position and the size of the feeding buffer.

18. Refer to the network in Question 19 in the Review Questions and Problems for Chapter 7.
    a. Indicate the critical chain on the network diagram.
    b. Assume the schedule uses durations from which any contingency (padding) has been removed. Insert a project buffer and feeding buffers as required.
19. Refer to Figure 8.22. Scheduling Activity T before Activity Q would also have resolved the resource contingency. Explain why this alternative was not selected.
20. Consider the data about project activities given in the table subsequently.
    a. Create the Gantt chart. Schedule the work in such a way that each person always has only one task to perform (do not reduce the durations of activities or insert buffers as yet).
    b. Indicate the critical chain.
    c. Indicate where the feeding buffers should be inserted.
    d. What is the difference in the lengths of the critical path and the critical chain?

Activity	Predecessor(s)	Duration (Days)	Resources
A	—	2	John
B	A	3	Sue
C	—	3	Sue & John
D	C	2	Al
E	D, J	3	Sue & Al
F	E, B	2	John
G	F	2	Ann
H	—	4	Sue
J	H	2	Al

21. Discuss the difference between fast-tracking, concurrent engineering, and crashing.
22. Write an essay on the reasons projects are often late.
23. Discuss the implications that subcontracted work would have on implementing CCPM.
24. Discuss the implications of resource allocation for organizations involved in multiple projects.
25. Revisit Question 18:
    a. Use the shortest task time rule to solve the problem and draw a Gantt chart.
    b. Apply the least slack rule to solve the problem and draw a Gantt chart.
    c. Apply the first three of the five TOC steps (Section 8.6) and draw a Gantt chart.
    d. Who would be the "drum resource"?
    e. How do the days that Ann has no work to do on this project relate to TOC step 3?
    f. Assume the two people in this problem also work on several other projects as well, and the policy is to use the shortest task time rule and the relative priorities of projects

to decide on which activity a resource should work. Which rule (shortest task time or highest project priority) should have preference? Discuss.

26. In a multiple-project environment, the drum resource carries a certain "status," since work performed by other resources (and the needs of other resources) are subordinated to it. In one company, management placed a flag at a work center to indicate that it was the drum resource. An improvement (TOC step 4) removed this work center as the constraint, and the flag was moved elsewhere to the new constraint. People working in the original center were disappointed and protested. How do you suggest management should handle this problem?

Questions About the Study Project

1. In the project you are studying, discuss which of the following kinds of analyses were performed:
   a. PERT
   b. CPM/time–cost tradeoff analysis
   c. Scheduling with resource constraints
   d. CCPM
2. Discuss how they were applied and show examples. Discuss those applications that were not applied but seem especially applicable to the project.
3. How do you rate the risk of not finishing on time, and what are the factors contributing to this risk?
4. Were people (other than the project manager) required to make commitments on the duration of activities? Comment on the possibility of changing this behavior.

CASE 8.1 BRIDGECON CONSTRUCTION

Bridgecon Construction Company specializes in the design and construction of steel and concrete bridges. The first phase of the company's project management methodology, initiation, includes identification of project opportunities and assessment of its risks and alignment with strategic goals. Bridgecon's marketing department identified an opportunity: a well-known bridge architect recently completed the concept design for a cable-stayed bridge intended to cross over electrified railway lines. Senior managers felt the company could handle the project and decided to pursue it; this marked the beginning of the next phase, cost estimating.

The estimating team visited the site; reviewed available resources and skills; performed a detailed risk assessment; and prepared a preliminary plan for detail design, procurement, logistics, and construction. The phase includes Activities A and B in Table 8.6, which was necessary to prepare the bid for building the bridge. The phase concluded with a presentation to the customer, the rail authority.

The project manager and the estimating team met with the architect and structural engineers to acquaint themselves with the design. They then met with the subcontractors whom they might choose to construct the pilings and fabricate steel components. Following these meetings, the initial duration estimate and initial cost estimate were completed, as listed in Table 8.6.

The RFP for the bridge project stated that acceptance of the plan by the rail authority was one criterion for selecting a contractor. Early on, it became evident that starting with Activity D and until the completion of Activity S, operation of one of the railway lines under the bridge would be impaired, although an informal discussion with the rail authority indicated that that might be acceptable. During a subsequent meeting, however, the rail authority expressed concern that the impairment would last 17 weeks and requested hat Bridgecon find ways to reduce that time. The estimating team suggests the following possibilities:

- The duration of Activity N could be reduced from one week to half a week by using additional trucks. The additional cost would be $33,000.
- An alternative subcontractor for piling was approached. The subcontractor said it would be able to halve the time of Activity H for a total cost of $960,000.
- Two ways were identified to shorten the duration of Activity D. First, additional temporary workers could be employed. This would reduce the duration to 3 weeks and increase the cost

Table 8.6 Activities for constructing the cable-stayed bridge.

Activity	Activity Description	Initial Duration Estimate	Predecessors	Initial Cost Estimate ($1,000)
A	Detailed site investigation and survey	2	—	17
B	Detailed planning	6	A	16
C	Detailed design	6	B	557
D	Preparation of site	4	C	47
E	Relocate services	3	C	28
F	Re-align overhead track electrification	4	C, E	650
G	Access road and ramp construction	1	D	63
H	Piling	2	G	820
J	Construct foundations and abutments	3	H	975
K	Construct temporary supports to support bridge deck during construction	2	F, G	720
L	Fabrication planning of structural steel components	2	C	13
M	Manufacture structural steel components (off-site)	2	L	1320
N	Transport structural steel components and erect on-site	1	M	433
P	Erect pylons and fill with concrete	2	J	840
Q	Construct main span deck on pre-cast concrete beams	3	H, K, N, P	2800
R	Cable-stay installation and lift the bridge deck off temporary supports	3	Q	875
S	Removal of temporary supports	1	R	54
T	Electrical system installation	1	S	147
U	Roadway surfacing (paving)	2	S	142
V	Finishing and ancillaries	2	T, U	76
W	Commissioning—cut-over	1	V	14
X	Formal handover and ceremony	1	W	9
Y	Project sign-off	1	X	1
Z	Administrative closure	1	W	4
AA	Project end (milestone)	0	Y, Z	10621

to $147,000. Second, a team of workers highly skilled in this procedure plus their equipment could be reallocated from another project. Adding this team and temporary workers to the original team would allow the work to be completed in 1 week. The manager of the other project estimated the reallocation would cause him to forfeit an incentive fee of $150,000 for finishing his project early. The managers of the two projects agreed that, should the reallocation be made, the value of the incentive fee would be booked as a cost against the cable-stayed bridge project and transferred as a bonus to the other project.

- The duration of Activity F could be reduced to 3 weeks, but this would increase the activity's cost to $730,000. It could be reduced to 2 weeks but would cost $820,000.
- The duration of Activity Q could be reduced to 2 weeks, but the activity would cost $2,929,000.

QUESTIONS

1. Compile a list showing the reduced periods for impairment of the rail operation and the associated additional costs.
2. Comment on the implications that crashing might have on the risk of not meeting the committed due date.

CASE 8.2 LOGON PROJECT

After signing the contract, the management at Midwest Parcel Distribution (MPD) discovers that for many reasons, it would be advantageous to complete the project in 40 weeks. It is too late for MPD to "require" the contractor, Iron Butterfly Company, to complete it in that time, but nonetheless, it discusses the possibility with Iron Butterfly's project manager, Frank Wesley. Reviewing the network diagram (Figure 8.26), Frank checks the feasibility of this and then asks his managers and technical staff to give him three time estimates for every activity in the project; these are given in Table 8.7.

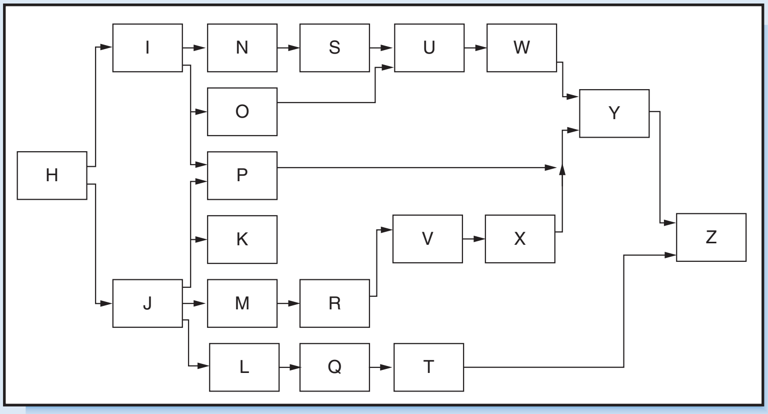


Figure 8.26
LOGON project.

Table 8.7 Time estimates for LOGON project.

Activity	Optimistic Duration (Weeks)	Most Likely Duration (Weeks)	Pessimistic Duration (Weeks)
H	10	10	10
I	8	8	16
J	1	6	6
K	4	4	4
L	2	2	2
M	2	4	5
N	4	4	10
O	5	5	5
P	5	5	5
Q	5	5	5
R	2	5	5
S	3	3	6
T	3	3	3
U	1	1	2
V	3	5	5
W	2	2	8
X	3	3	3
Y	8	8	8
Z	6	6	6

QUESTIONS

1. What is the probability of finishing the project within 40 weeks?
2. Do you foresee any significant risk of a delay that the previous calculation does not take into account?
3. Determine the most likely project duration.

CASE 8.3 PAPUA PETERA VILLAGE PROJECT

The Papua Petroleum Company is building a village to support workers for an oil field in Sumatra. The principal work of the project involves five work packages: build road, clear site, erect buildings, erect power generation plant, and build water purification system. Figure 8.27 is a high-level network diagram for the project.

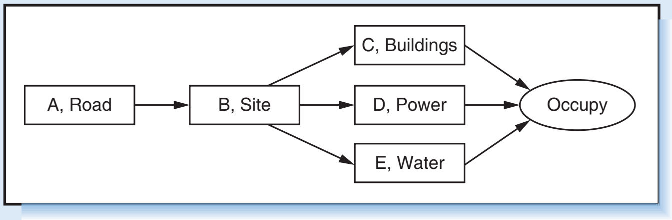


Figure 8.27
Papua Petera Village Project.

To explore ways to speed up the project, Papua asked its contractors to submit information about time and cost for crews working as many as three shifts a day. (Portable lighting technology would enable work to continue at nighttime for second and third shifts.) The contractors responded with the following estimates, which exclude costs for materials, supplies, components, and systems that are fixed regardless of work times.

Work package A: build road

- Road length, 10 km
- One shift is able to build 0.1 km of road
- First shift costs: labor, $4,000/day; equipment, $8,000/day
- Second and third shifts, cost per shift: labor, $6,000; equipment, $9,000/day

Work package B: clear site

- Using one shift, site can be cleared in 10 days; if two shifts, 5 days; if three shifts, 4 days
- First shift costs, labor, and equipment: same as Work package A
- Second and third shifts, cost per shift: same as Work package A

Work package C: erect buildings

Forty buildings will be constructed of three standard models, all about the same size. Each shift is able to construct three buildings per week. Assume 5-day work weeks.

- First shift costs: labor, $4,000/day; equipment, $1,000/day
- Second and third shifts, cost per shift: labor, $6,000; equipment, $1,500/day

Work package D: erect power generation plant, install power lines to buildings

Work package will take 10 weeks; with a second shift, it will take 5 weeks. Assume 5 days/week.

- Labor shortage does not allow a third shift
- First shift costs: labor, $6,000/day; equipment, $3,000/day
- Second shift, cost per shift: labor, $9,000; equipment, $4,200/day

Work package E: build water purification system, install water and sewer lines to buildings

Work package will take 8 weeks; with a second shift, it will take 4 weeks. Assume 5 days/week.

- Labor shortage does not allow a third shift
- First shift costs: labor, $5,000/day; equipment, $4,000/day
- Second shift, cost per shift: labor, $7,500; equipment, $5,500/day

The previous costs are all direct costs. Additionally is the indirect cost—the cost for management and administration of the overall project; this is estimated at $3,000/day for however long the project takes.

Given this information, Papua has asked project manager Abdul Ginting to estimate alternative total project costs and project durations for two cases: (1) the lowest cost alternative and how long the project would take, and (2) the shortest project duration alternative and how much the project would cost. Abdul is preparing his analysis and recommended course of action.

Notes

1. Goldratt A.Y. Institute, group email messages sent on March 17 and 18, 1999; Larry English, Habitat for Humanity, January 2007, Pretoria, South Africa; Habitat for Humanity, The Fastest House in the World, accessed January 2007 from www.habitat.org/newsroom/1999archive/insitedoc004016.aspx?print=true.
2. CPM was developed in 1957 by DuPont Company, Remington Rand, and Mauchy Associates for constructing a DuPont plant and first appeared in the article by its originators: Kelley J. and Walker M. *Critical Path Planning and Scheduling. Eastern Joint Computer Conference*. Boston, MA; 1959, pp. 160–173.
3. For a piecewise approximation for nonlinear relationships, see Wiest J. and Levy F. *A Management Guide to PERT/CPM: With GERT/PDM/DCPM and Other Networks*. Englewood Cliffs, NJ: Prentice-Hall; 1977, pp. 81–85. The relationship between number of workers and activity duration is nonlinear; that is, cutting the number of workers in half will not double the time but might increase it by, say, 50–150 percent, depending on the task. See Brooks F. *The Mythical Man Month: Essay on Software Engineering*. Reading, MA: Addison-Wesley; 1995, pp. 13–36.
4. The method first appeared in the article by the originators of PERT: Malcolm D., Roseboom J., Clark C. and Fazar W. Application of a Technique for Research and Development Program Evaluation. Operations Research 7, no. 5. *Operations Research*; 1959: 646–670.
5. See Miller R. *Schedule, Cost, and Profit Control with PERT*. New York, NY: McGraw-Hill; 1963, p. 58; Kerzner H. *Project Management: A Systems Approach to Planning, Scheduling, and Controlling*, 10th edn. Hoboken, NJ: John Wiley & Sons; 2009, p. 529.
6. See Krakowski M. PERT and Parkinson's law. *Interfaces* 5(1); November 1974; and Vazsonyi A. L'Historie de la grandeur et de la decadence de la methode PERT. *Management Science* 16(8) April 1970 (written in English). Other problems of PERT/CPM are described by Kerzner, *Project Management*, pp. 519–522; Miller. *Schedule, Cost, and Profit Control with PERT*, pp. 39–45; and Weist and Levy. *A Management Guide to PERT/CPM*, pp. 57–58, 73, 166–173. References to human behavior are in the critical chain literature referenced in this chapter.
7. See Van Slyke R. Monte Carlo methods and the PERT problem. *Operations Research* 11(5); 1963: 839–860.
8. Adapted with permission from Evans J. and Olson D. *Introduction to Simulation and Risk Analysis*. Upper Saddle River, NJ: Prentice Hall; 1998, pp. 111–120.
9. For information on Crystal Ball, see oracle.com; for @Risk, see www.palisade.com; for Arena, see www.arenasimulation.com; for Simul8, see www.simul8.com. (These are examples, not product endorsements; other firms provide risk analysis software as well.)
10. Viljoen P. *Goldratt Schools, Personal Communication*, Pretoria, SA; May 2007, May 2010, and April 2015.
11. Goldratt E. *What Is This Thing Called Theory of Constraints and How Should It Be Implemented?* New York: North River Press, Inc. 1990.
12. Pittman P. *Project Management: A More Effective Methodology for the Planning and Control of Projects*. Georgia: PhD dissertation, University of Georgia; 1994; Goldratt E.M. *Critical Chain*. Great Barrington, MA: North River Press; 1997.
13. Walker E. *Planning and Controlling Multiple, Simultaneous, Independent Projects in a Resource Constrained Environment*, Georgia: PhD dissertation, University of Georgia; 1998. A TOC method for allocating resources to multiple projects was developed in this study and subsequently has been developed further.
14. Steyn H. An investigation into the fundamentals of critical chain project scheduling. *International Journal of Project Management* 19(6); 2001: 363–369.
15. Goldratt. *Critical Chain*, p. 156.
16. Herroelen W. and Leus R. On the merits and pitfalls of critical chain scheduling. *Journal of Operations Management* 7; 2001: 559–577; Leach L. *Critical Chain Project Management*, 2nd edn. Norwood, MA: Artech House, Inc.; 2003; Geekie A. and Steyn H. Buffer sizing for the Critical Chain Project Management method. *SA Journal of Industrial Engineering* 19(1); 2008: 73–88.
17. Newbold R. *Project Management in the Fast Lane—Applying the Theory of Constraints*. New York: St. Lucie Press; 1988.
18. Tukel I., Rom W. and Eksioglu S.D. An investigation of buffer sizing techniques in critical chain scheduling. *European Journal of Operational Research* 172; 2006: 401–416; also see Trietsch D. The effect of systemic errors on optimal project buffers. *International Journal of Project Management* 23; 2005: 267–274; Shou Y. and Yeo K. Estimation of project buffers in critical chain project management. *Proceedings of the IEEE International Conference on Management of Innovation and Technology*, 2000, pp. 162–167.
19. Goldratt. *Critical Chain*.
20. For information on Prochain, see www.prochain.com; for Sciforma, see www.sciforma.com; for Concerto,

see www.realization.com. (These are examples, not product endorsements; other firms provide CCPM software as well.)

21. Viljoen. Goldratt Schools, Personal communication.
22. Turner J.R. *The Handbook of Project-Based Management*. London, UK: McGraw-Hill; 1993.
23. In Goldratt E. and Cox J. *The Goal*, 4th edn. Great Barrington, MA: North River Press; 2014; also in Goldratt E. and Fox R. *The Race*. Croton-on-Hudson, NY: North River Press; 1986. The notion of using the constraint (drum) to set the pace is described.
24. Adapted from training material of Realization. See www.realization.com.
25. Dass S. and Steyn H. An exploratory assessment of project duration in multiple-project schedules where resources are allocated by the theory of constraints method. *SA Journal of Industrial Engineering* 17(1); 2006: 39–54.
26. Cohen I., Mandelbaum A. and Shtub A. Multi-project scheduling and control: A process-based comparative study of the critical chain methodology and some alternatives. *Project Management Journal* 35(2); 2004: 39–50.

Chapter 9

Cost estimating and budgeting

Cost estimates, budgets, WBSs, and schedules are interrelated. Ideally, cost estimates are based upon the elements of the WBS and are prepared for each work package. When the cost cannot be estimated because an activity is too complex, the activity is broken down into smaller pieces until it can. When the work is poorly defined or uncertain, the estimate is initially based upon judgment and is later revised as more information becomes available. Project schedules dictate the resource needs and the expenditure rate, but the converse is also true: constraints on resources and working capital dictate the schedules. Imposing constraints on costs is necessary to create realistic project budgets; failing to do so results in projects being completed but at exorbitant expense or terminated prematurely due to lack of funds. Both occurrences are relatively commonplace.

Cost estimating and budgeting are sometimes thought to be the exclusive concerns of cost specialists and accountants, but in projects, they should be everyone's concern. Project participants who are closest to the sources of costs—engineers, systems specialists, architects, or others—should be involved in the estimating and budgeting process. Commonly, however, these people are uninvolved and, worse, disdainful of budgets and ignorant about how they work or why they are necessary.

The project manager must be involved. She does not need to be a financial wizard, but she does need to be skillful in organizing and using cost figures. The project manager oversees the cost estimating and budgeting process, often with the assistance of a *staff cost accountant*. On technical projects, a *cost engineer* (or, outside the United States, a *quantity surveyor*) reviews the deliverables and requirements, assesses the project from cost and technical points of view, and advises the project manager. Cost engineering is discussed later.

9.1 Cost estimates

The cost estimate can seal the project's financial fate. When project costs are overestimated (estimate exceeds likely actual costs), the contractor risks losing the job to a lower-bidding competitor. Worse is when they are underestimated (actual costs exceed estimate). A $50,000 fixed-price bid might win the contract, but obviously the contractor will lose money if the project ends up costing $80,000. Underestimating is often accidental—the result of being overly optimistic, although sometimes it is intentional—the result of trying too hard to beat the competition. In a practice called *buy in*, the contractor reduces an initially realistic estimate just enough to win the contract, hoping to cut costs or renegotiate a higher price after the work is underway. The practice is risky, unethical, and, sadly, commonplace.

In large capital projects, the tendency is to underestimate costs so as to get the funding needed to launch the project but then forget the estimate afterward and expect cost overruns to be funded.

But a very low bid can also signify that the contractor cut corners in the estimate, forgot to include things, or was just sloppy. The consequences for both client and contractor can be disastrous, ranging from financial loss to bankruptcy.

Cost estimates are the basis for the project budget. Once the project begins, actual costs are compared to estimated, budgeted costs as one measure of the project's performance. Without good estimates, it is impossible to know whether project costs are on track or how much the project will cost at completion.

9.2 Cost escalation

Estimating project costs can be difficult because the estimation process begins during project conception and before much is known about the project. The less well defined the project, the more difficult it is to estimate the costs and the greater the chances they will substantially differ from actual costs. As a rule, the estimate will be too low and the project will suffer a cost overrun. The amount by which actual costs grow to exceed initial estimates is referred to as *cost escalation*. Some escalation is normal, and up to 20 percent is common. Usually, the larger and more complex the project, the greater the potential for escalation. The costs of cutting-edge technology and research projects frequently escalate upwards of several hundred percent. The Concorde supersonic airliner exceeded the original estimate by a factor of five, nuclear power plants often exceed estimates by a factor of two or three, and NASA spacecraft sometimes by a factor of four to five.

The plot in Figure 9.1 shows percent cost overrun for 111 transportation-related projects spanning 80 years.[1] The study reporting these findings also looked at 246 other projects and got a similar picture. Clearly, overruns have been and remain common. How does that happen?

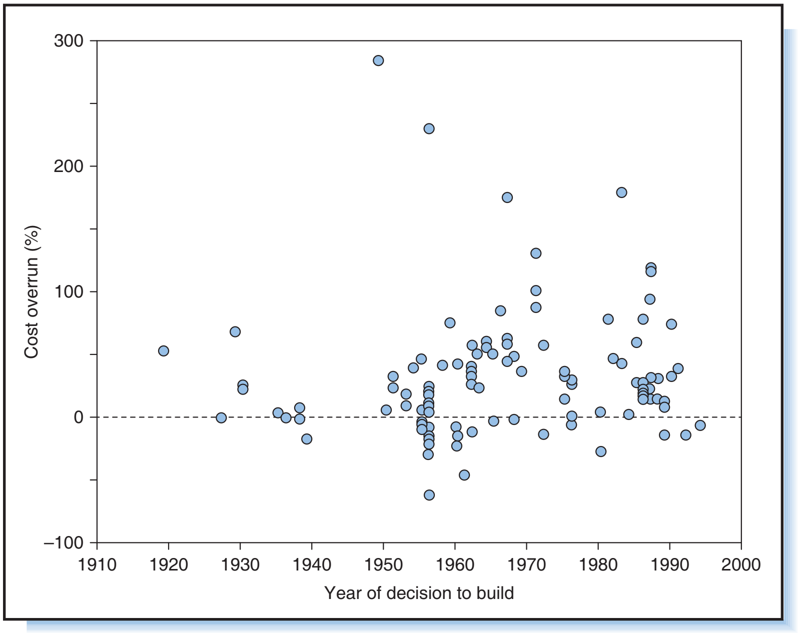


Figure 9.1

Projects versus percent cost overrun.

Source: Flyvbjerg B., Bruzelius N. and Rothengatter W. *Megaprojects and Risk: An Anatomy of Ambition*. Cambridge: Cambridge University Press; 2003, p. 17. Reprinted with permission.

Lack of information and uncertainty

Much of the information necessary for accurate estimates is simply not available when cost estimates are first needed. At NASA, for example, lack of well-defined spacecraft design and unclear definition of experiments is the principal reason for cost overruns. Not until later, during the definition phase, when designs are finalized and work activities are well defined, can material and labor costs be accurately estimated. In most development projects, many of the activities are unpredictable, of uncertain duration, or must be repeated. Despite the difficulty, management must strive for the clearest scope of work, project objectives, and requirements, because without them, it would be near impossible to obtain accurate cost estimates.

After the project is underway, possible product design changes, developmental barriers, strikes, and inflation will likely cause labor and material costs to increase. Whenever that happens, the project cost estimate should be updated to serve as a valid baseline to track project costs against.

Lack of information causes uncertainty. To allow for uncertainty in the estimate, an amount called a *contingency fund* or *budget reserve* is added to the original estimate.[2] This is the budget equivalent of the schedule *reserve* or *buffer* mentioned in previous chapters. The contingency amount is proportional to the uncertainty; the greater the uncertainty, the larger the contingency.

The project manager (and sometimes the project sponsor or steering committee) controls allocation of the contingency fund. The fund is intended primarily to offset small overruns arising from estimating errors, omissions, and minor design changes and schedule slippages. Each time the cost estimate is updated, so is the contingency fund. The fund is not a “slush” fund and should be cut from the project budget when no longer needed as intended; otherwise, project costs will tend to rise to expend whatever remains in the fund. Contingencies are discussed later.

Changes in requirements or design

Cost escalation also occurs due to scope creep—discretionary, nonessential changes made to system requirements. These changes come from *a change in mind*, not from oversights or mistakes that would make them imperative. The routine tendency is for users and contractors alike to want to upscale systems—to make “improvements” throughout the project life cycle. Such changes are especially common in the absence of thorough planning or strict control procedures.

Contracts occasionally include a *change clause* that allows the customer to make certain changes to contract requirements—sometimes for additional payment, sometimes not. The clause allows the customer flexibility to incorporate requirements not envisioned at the time of the original contract agreement. It can be exercised at any time, and the contractor is obligated to comply. But any change, no matter how small, causes escalation; it usually involves some combination of redesigning the product, reorganizing work, acquiring new or different resources, altering plans, or undoing or scrapping earlier work. The further along the project, the more costly the change. When accumulated, even small changes have a substantial effect on schedules and costs. Formal *change control* procedures, which are one way to reduce changes and contain escalation, are described in Chapter 13.

See Chapter 13

Economic and social factors

Even with good initial estimates and few changes, cost escalation occurs because of forces beyond anyone’s influence. Labor strikes, legal action by interest groups, trade embargoes, and material shortages, all of which serve to stifle progress and increase costs, cannot be precisely anticipated or factored into plans and budgets. Whenever work is suspended or interrupted, administrative and overhead costs continue to mount, interest and leasing costs on borrowed capital and equipment continue to accrue, and the date when payback begins and profit earned is delayed. Anticipating such problems and incorporating their impacts into the contingency fund is very difficult.

One economic factor that influences cost escalation is *inflation*. The contractor might want to offset this factor by inflating the price of the project but not be able to because of competitors' actions or federal restrictions on price increases. Some protection may be gained by including inflation protection clauses in the contract that allow wage and material cost increases to be appended to the contract price,[3] but the protection may be limited. Inflation is not one dimensional; it varies with the labor, materials, and equipment employed and by geographical region and country. Subcontractors, suppliers, and clients use different contracts with different inflation clauses that might be advantageous or disadvantageous to other parties in the project.

Inflation also causes cash flow difficulties. Even when a contract includes an inflation clause, payment for inflation-related costs must be tied to the publication of inflation indices, which always lags behind inflation. Contractors pay immediately for the effects of inflation but are not reimbursed for those effects until later.

Cost estimates are typically based upon prices at the time of estimating. Thus, whenever inflation rates become known, the estimates should be adjusted so as to provide a valid baseline from which to later identify cost increases and take corrective action. In long-term projects, future wage rates should be forecasted, starting with the estimated current wage costs and then applying inflation rates over the project's duration.

In international projects, costs escalate due to changes in *exchange rates*. When the costs are incurred in one currency but paid for in another, changes in the exchange rate will cause the relative values of costs and payments to change, possibly resulting in a cost escalation. This topic is discussed in Chapter 20.

See Chapter 20

Inefficiency, poor communication, and lack of control

Cost escalation also results from work inefficiency, poor management and supervision, poor communication, and weak control. In large projects especially, these lead to conflicts, misunderstandings, duplication of effort, and mistakes. This is *one* source of escalation where management has substantial influence. Careful work planning, monitoring of activities, and tight control, particularly as discussed in Chapter 13, help contain cost escalation.

See Chapter 13

Ego involvement of the estimator

Cost escalation also results from the *way* people estimate. Many people are overly optimistic and habitually underestimate the time and cost, especially for jobs with which they are inexperienced. Have you ever estimated the time it would take for *you* to paint a room or tile a floor? How long did it *really* take? Sometimes, of course, the opposite happens: worried about overrunning their estimate, they "pad" it. The more the estimator's ego is involved in the job, the less reliable the estimate.

Companies avoid this problem by employing professional cost estimators, who are not the same people as those who will do the work. Remember the earlier contention about involving project participants in planning the project? *Experienced* workers are usually good at estimating time and materials but less so at estimating costs. Therefore, the doers (those who do the work) should estimate the time and resources they will need, but the professionals should estimate the cost.

People sometimes confuse an estimate with *a goal*; they think an estimate is what a job *should* take (or what they have been told it *should* take), not an unbiased prediction of what it *will* take. A cost estimate should *never* be based upon a target or goal; thus, estimators must be positioned organizationally so they will not be coerced into providing the numbers that someone wants.[4]

Project contract

Different kinds of project contracts motivate or discourage escalation. Two of these in particular are relevant, fixed price and cost plus. A fixed-price agreement motivates the contractor to control accrued costs and, ideally, keep them below the contracted price. In contrast, a strictly cost-plus contract offers little motivation to control costs. In fact, when the profit is computed as a percentage of costs (rare these days), the contractor is actually motivated to "allow" costs to escalate. Other forms of contract agreements such as incentive contracts permit cost increases but provide financial motivation to the contractor to minimize escalation. The relative pros and cons of different contract types are discussed in Chapter 12.

See Chapter 12

Information and assumptions

Estimates are always based upon available information and assumptions, and these should always be cross-checked. Are the customer's and contractor's assumptions about the costs correct? Does everyone agree about the work, materials, and other factors to be covered in the estimate? Are the cost rates for labor, material, equipment, and services current? Is information about available facilities, equipment, systems, and services to be provided by the customer or other stakeholders accurate? Every cost estimate should explicitly identify all the cost factors used to produce it.

Bias and ambition[5]

It is human nature for the champions of projects to be optimistic. In fact, without champions, most big projects would never start, and everyone might be worse off. That optimism, however, can lead to overestimating the benefits and underestimating the costs. Promoters of big projects know that if a project is important enough, sufficient funding to complete it will materialize, no matter the size of the overrun.

Example 9.1: Escalation of the Bandra-Worli Sea Link Project

January 1999—Government Clears Worli-Bandra Cable Bridge
February 2001—Worli-Bandra Sea-link Enters Crucial Stage
October 2002—Bandra-Worli Sea Link Toll To Be Costlier
October 2003—Bandra-Worli Sea Link May Hit a Dead End
January 2004—Bandra-Worli Sea Link Project Under Threat
July 2005—Sea Link In Trouble over Extension
May 2006—Bandra-Worli Sea Link To Be Ready By 2008

The headlines quoted above from local newspapers refer to the Bandra-Worli Sea Link (BWSL) roadway and cable-stayed bridge in Mumbai—India's equivalent to San Francisco's Golden Gate Bridge. The 8-km bridge and its approaches bend 200 meters into the Arabian Sea to connect downtown Mumbai with its southern suburbs and reduce travel time by half to about 30 minutes. Although architecturally stunning and a boon to local drivers, it is a good example of large-scale project woes.

The project was approved in early 1999 following 7 years of study and was supposed to start in May, cost 650 crore (US$120M), and finish mid-2001. But work did not begin until December, and the estimated completion date had already slipped to mid-2002. Then came the monsoons, which brought the project to a near halt in 2000 and 2001. In late 2001, the project's prime consultant, Sverdrup, was dropped for failure to provide a "competent project engineer." The replacement, Dar Consultants, modified the bridge design, added 2.8 km to its length, and split the eight-lane main bridge into two four-lane roadways. By January 2002, the target completion date had slipped to March 2004. In October 2002 came the announcement that the project costs had increased by 50 crore, and due to a "paucity of funds," work had to be slowed, and the completion date slipped to September 2004. A year later, monsoons and rough seas again halted work, further delaying the completion date to 2005. Meantime, complaints grew from fishermen concerned about the link's interference with their boats and from environmentalists about its harm to marine ecology. In 2003, rains again stalled the project. The project's primary contractor, Hindustan Construction, requested an additional 300 crore to cover delays and design changes, but the government balked and offered to pay only 120 crore. The controversy stalled the project for another year, though eventually funds materialized and the project resumed. In June 2005, the completion date was reset to September 2006 and the project cost to 1,306 crore. In May 2006, the completion date was again pushed back to April 2008, but not until June 2009 was the bridge dedicated. In March 2010, all lanes opened to traffic. Estimated final cost: 1,600 crore (US$336M).

As illustrated, schedule delays and cost escalation are inextricably connected. The 11-year history of the BWSL project saw a 9-year schedule slip and 150 percent cost increase. Contributing factors included unknowns (weather), changes in scope and requirements (bridge and roadway design), social factors (livelihood and environmental impact concerns), economics (growing land values and interest), and management (dismissal of a major contractor).

9.3 Cost estimating and the systems development cycle[6]

Project cost estimating happens during all phases of the project life cycle.

The first estimate is made during project conception. Since very little hard cost information is available at that time, the estimate is the least reliable that it will ever be. Uncertainty about the project cost and duration may be large, as illustrated by the largest "region of time–cost uncertainty" in Figure 9.2. How much the project will *really* cost and how long it will *really* take are very much open to question. The project is compared to other similar projects, and an estimate is made based upon standards of what it should take—labor time, materials, and equipment—to do the job. When there are no similar projects or standards, initial estimates are largely "guesstimates" and might end up being nowhere close to actual costs.

If the project is unique and ill defined, uncertainty in cost estimates often dictates that contracts be of the cost-plus kind. As more aspects of the system and project are defined, the material costs, labor times, and labor rates can be nailed down, and cost estimates become more reliable. When the system and project are fairly routine, the estimates are more reliable, and contractors are willing to accept fixed-price or incentive-type contracts. Sometimes the awarding of contracts is delayed until designs are somewhat complete and it is possible to make somewhat accurate cost estimates. This of course requires contractors to do a lot of front-end work without assurances that they will be awarded the job. Contractors required to bid before they can attain reliable estimates must include a contingency fund in the estimate to cover the uncertainty.

As a project progresses into the middle and later phases—as work is being completed and money is being spent—cost estimates become more accurate. The shrinking time–cost uncertainty regions in Figure 9.2 illustrate this. As the uncertainty decreases, the amount in the contingency fund is reduced. For example, a contingency starting out at 15 percent of the base project estimate might be decreased

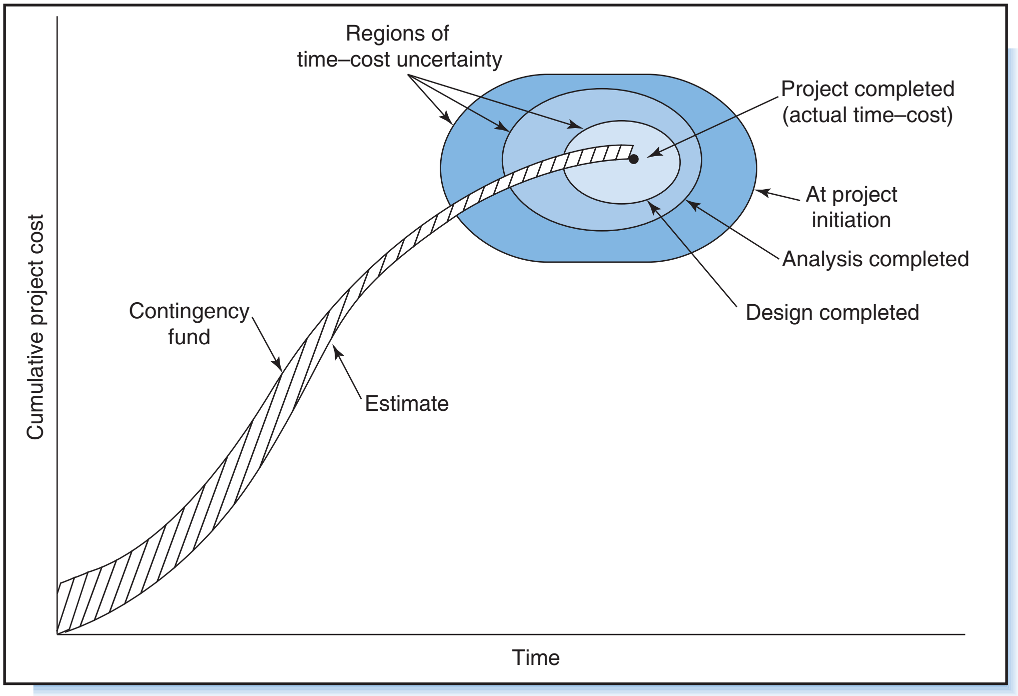


Figure 9.2
Time–cost graph showing cumulative project cost and regions of time–cost uncertainty.

halfway through the project to 8 percent, then to 3 percent at the three-fourths mark and then to 1 percent near final completion to cover minor corrections at sign-off.

See Chapter 4

As discussed in Chapter 4, in the phased or rolling-wave planning approach, a detailed plan is developed only for the most immediate, upcoming stage of the project, and that plan will include a cost estimate and cost commitments for that stage. At the same time, every attempt is made to look ahead and to develop a realistic cost estimate for the remainder of the project.

Once developed and approved, the estimate for the project becomes the budget and the baseline against which project progress and performance will be measured. It is thus bad practice to keep changing the estimate during the project because that destroys its purpose—to be the baseline against which to measure progress and control costs. As mentioned, however, sometimes escalation factors render the estimate obsolete and mandate that it be periodically revised.

9.4 Cost estimating process

Estimate versus target or goal

The word "estimate" is sometimes misconstrued as synonymous with "target" or "goal". It shouldn't be. Whereas an estimate is an attempted *realistic assessment* based upon known facts or stated assumptions about the work, resources needed, constraints, and the environment, a target or goal is a *desired* outcome. Other than by chance, the estimate will not be the same as the target or goal. That said, once computed, the estimate can be compared to a target value or goal, and the work activities, resources, and schedules revised to bring the estimate closer to the target. Never should the target be a simple plug-in of the estimate.

Accuracy versus precision

"Accuracy" represents the closeness of an estimated value to the actual value: the accuracy of a $99,000 estimate for a project that actually cost $100,000 is very good. In contrast, "precision" is the number of decimal places in the estimate. An estimate of $75,321 is more precise than one of $75,000 (though *neither is accurate* if the actual cost is $100,000). Accuracy matters more than precision: the aim is to derive the most accurate estimate possible.

Sometimes accuracy can be improved by employing a so-called *three-point estimate* that combines optimistic (a), pessimistic (b), and most likely (m) cost estimates to arrive at an expected cost estimate—analogous to the PERT approach for computing expected time:

$$C_E = \frac{a + 4m + b}{6}$$

Classifying work activities and costs

The cost estimating process begins by breaking the project down into work stages such as design, development, and fabrication or into work packages from the WBS. The project team, including members from involved functional areas and contractors, meets to discuss the work stages or packages and receive specific assignments.

The team looks for work tasks in the project that are similar to existing designs and standard practices and can readily be adopted and classifies all work as either *off-the-shelf* or *developmental*. OTS work implies use of something that already exists; it is not new but an adaptation or repetition of existing or similar systems or activities. Cost estimating for OTS is straightforward and uses known prices or records of material and labor costs. In contrast, developmental work implies starting from scratch, sometimes using trial and error, where the work to be done and resources needed are uncertain. Overruns in developmental work are common, largely due to inaccurate labor estimates. It is thus often beneficial to make use of OTS designs and technology wherever possible.

Estimated costs are classified as *recurring* and *nonrecurring*. Recurring costs happen more than once in the project and are associated with periodically repeated activities such as quality assurance and testing. Nonrecurring costs happen once and are associated with development, fabrication, and testing of one-of-a-kind items or procurement of special items.

In some projects, the project manager delegates responsibility for estimating to those responsible for the work, combines their estimates, and presents the final estimate to management or the customer. In others, the project manager coordinates estimating efforts among functional managers and aggregates the estimates. Although this typifies the estimating process, the actual approach depends on the project organization. It also depends on the information available and the required accuracy of the estimate. Most estimates are made using variants of four methods: expert judgment, analogy, parametric, and cost engineering.

Expert judgment

Expert judgment is an estimate provided by an expert—someone who from breadth of experience or expertise is able to provide a good ballpark estimate. It is a "seat of the pants" estimate used whenever lack of information precludes more rigorous cost analysis. Expert opinion is usually restricted to estimates made during the conception phase and for projects that are poorly defined or unique and for which there are no previous similar projects to compare.

Analogous estimate

An *analogous estimate* is developed by reviewing costs from previous similar projects. Often such an estimate is handy as a relatively fast reality check for estimates derived from detailed planning. The method can be used at any level: overall project cost can be estimated from the cost of an analogous project, work package cost can be estimated from analogous work packages, and activity cost can be estimated from analogous activities. The cost for a similar project or work package is analyzed and adjusted for differences between it and the proposed project or work package in terms of scale, locations, dates, and so on. If, for example, the analogy project was performed 2 years ago and the proposed project is to commence a year from now, the analogy project cost must be adjusted to account for inflation and price changes during the 3-year interim. If the analogy project was in California and the proposed project will be in New York, the cost estimate must be adjusted to account for regional differences in labor and material costs. If the scale (scope, capacity, or performance) of a proposed activity is twice that of the analogy activity, then costs from the analogy must be "scaled" up accordingly. But twice the size does not mean twice the cost, and the size–cost relationship must be uniquely determined.

Example 9.2: Estimating Project Costs by Scaling an Analogy Project

So-called process industries such as petrochemicals, breweries, and pharmaceuticals use the following formula to estimate the costs of proposed projects:

$$\text{Cost (proposed)} = \text{Cost (analogy)}[\text{Capacity (proposed)}/\text{Capacity (analogy)}]^{0.75}$$

where "proposed" refers to a new facility and "analogy" to an analogous existing facility. In practice, the exponent varies from 0.35 to 0.9, depending on the kind of process and equipment used.[7]

Suppose a proposed plant is to have a 3.5 million cum (cubic meter) capacity. Using an analogy project for a plant with 2.5 million cum capacity and a cost of $15 million, the estimated cost for the proposed plant is

$$\$15 \text{ million } [3.5/2.5]^{0.75} = \$15 \text{ million } [1.2515] = \$18.7725 \text{ million}$$

Because the analogy method involves comparisons to earlier similar projects, it requires extant information about prior projects. Companies that are serious about using the method gather cost documentation and retain it on a database that classifies costs according to type of project, work package, activity, and so on. When a new project is proposed, the database is accessed for cost details about similar projects and work packages. Of course, the basic assumption in the analogy method is that the analogy chosen is valid; sometimes that is where things go awry.

Example 9.3: A Case of Costly Mistaken Analogy[8]

In the 1950s and 1960s, when nuclear power plants first appeared in the United States, General Electric and Westinghouse, the two main contractors, together lost a *billion* dollars in less than 10 years on fixed-price contracts because they had underestimated costs. Neither had expected to make money on these early projects, but certainly they had not planned to *lose* so much, either. The error in their method was assuming that nuclear power plants are analogous to coal power plants—for which the marginal costs actually get smaller as the plants get larger. But nuclear power plants are not like coal power plants. For one thing, they require more safeguards. When a pipe springs a leak in a coal plant, the water is turned off and the plant shut down until the leak is fixed. In a nuclear plant, the water cannot be turned off or the plant shut down; the reactor continues to generate heat and if not cooled will melt, cause pipes to rupture, and radiation to disperse. The water-cooling system needs a backup system, and the backup system needs a backup. Typical of complex systems, costs for nuclear plants increase somewhat exponentially with plant size—but in the early years of nuclear power, nobody knew that.

Parametric estimate

A parametric estimate is derived from an empirical mathematical relationship. The method can be used with an analogy project to scale costs up or down (case in Example 9.2), or it can be applied directly without an analogy project when costs are a function of system or project "parameters." The parameters can be physical features such as area, volume, weight, or capacity, or performance features such as speed, rate of output, power, or strength. The method is especially useful when early design features are first being set and an estimate is needed quickly.

Example 9.4: Parametric Estimate of Material Costs

Warren Warehousing Company, a facilities contractor, needs a quick estimate of the material cost of a new facility. Company engineers investigate the relationship between several building parameters and the material costs for eight recent projects comparable in terms of architecture, layout, and construction material. Using the method of least squares (a topic covered in textbooks on mathematical statistics), they develop the following multiple regression model that relates material cost (y) to floor space (x_1, in terms of 10,000 sq. ft.) and number of shipping/receiving docks (x_2) in a building:

$$y = 201{,}978 + (41{,}490)X_1 + (17{,}230)X_2$$

The least-squares method for this model indicates that the standard error of the estimate is small, which suggests that the model provides somewhat accurate cost estimates when compared to the actual cost of each of the eight projects.

A proposal is being prepared to construct a 300,000 sq. ft. facility with two docks. The estimated material cost using the model is thus:

$$y = 201{,}978 + (41{,}490)(30) + (17{,}230)(2) = \$1{,}481{,}138.$$

Cost engineering

A *cost engineering* estimate is derived from a detailed analysis of individual cost categories at the work package or activity level. As a bottom-up approach, it provides the most accurate estimates of all the methods, but it also is the most time consuming. The method requires detailed work-definition information that often is not available early in the project. It begins with project activities or work packages (e.g. as created in the WBS) and divides each of them into cost categories. For small projects like Example 9.5, the approach is simple and straightforward.

Example 9.5: Cost Engineering Estimate for a Small Project

The manager for the DMB project is preparing a project cost estimate. He begins with eight project work packages he previously identified in the WBS and creates a Gantt schedule. Three labor grades will be working on the project; for each work package, he determined the labor grades involved and estimates the number of labor hours per week needed for each grade. The shaded boxes in Figure 9.3 show the hours per week per labor grade. For example, in weeks 1 and 2, Activity A will need 30 hours of labor grade 1 and 10 and 20 hours, respectively, of labor grade 2.

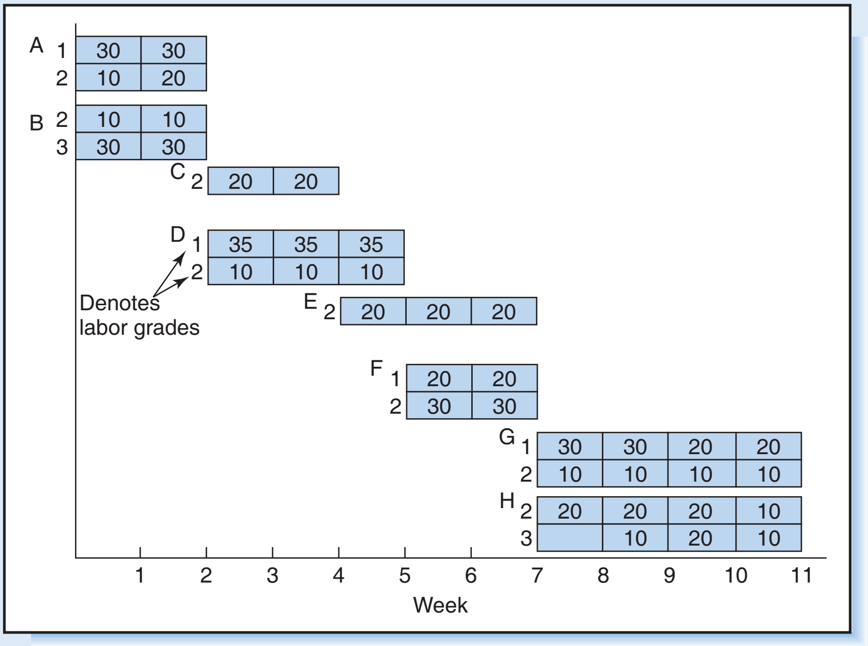


Figure 9.3
Schedule showing hours allocated to work packages by labor grade.

Table 9.1 Labor hours and non-labor costs.

Work	Total Hours per Labor Grade			Non-Labor Costs			
Package	**1**	**2**	**3**	**Material**	**Equipment**	**Subcontracts**	**Other**
A	60	30		$ 500			
B		20	60		$1,000		
C		40			500		$500
D	105	30			500		
E		60				$4,500	
F	40	60		8,000	1,000	5,000	500
G	100	40		1,500			500
H		70	40		1,000		1,500
Total	305	350	100	$10,000	$4,000	$9,500	$3,000

For each work package he also estimates the cost of material, equipment, supplies, subcontracting, freight charges, travel, and other non-labor costs. Table 9.1 summarizes the labor hours from Figure 9.3 and non-labor costs.

The sum of the non-labor costs is $26,500. The hourly rates for labor grades 1, 2, and 3 are $10, $12, and $15, and the overhead rates are 90 percent, 100 percent, and 120 percent, respectively. These overhead rates are *added* to the labor cost. (Determining overhead rates is discussed later.) Therefore, labor-related costs are:

$$\begin{aligned}
\text{Grade 1}: 305(\$10(100\%+90\%)) &= \$5,795 \\
\text{Grade 2}: 350(\$12(100\%+100\%)) &= \$8,400 \\
\text{Grade 3}: 100(\$15(100\%+120\%)) &= \underline{\$3,300} \\
& \$17,495
\end{aligned}$$

Therefore, the preliminary estimate for labor and non-labor costs is $17,495 + $26,500 = $43,995. Suppose the company routinely adds 10 percent to cover general and administrative expenses; this puts the cost at $43,995(1.1) = $48,395. If a 10 percent contingency fee is also added, the total cost estimate for the project is $48,395(1.1) = $53,235.

At the work package and lower levels, detailed estimates are sometimes derived with the aid of standards manuals and tables. Standards manuals contain time and cost information about the labor and materials needed for particular tasks. In construction, for example, the numbers of labor hours to install an electrical junction box or a square foot of wall section are both standards. To determine the labor cost of installing junction boxes in a building, the estimator multiplies the estimated required number of boxes times the labor standard per box and then multiplies that by the hourly labor rate. For software development, an estimator might apply the industry standard of one person-year to create 2,000 lines of bug-free code.

For larger projects, the estimating procedure is roughly the same as illustrated in Example 9.4 but more involved. First, the manager of each work package subdivides the work package into "basic" areas of work such as "engineering" and "fabrication." Supervisors in each basic area then estimate the hours and materials needed to do the work. The engineering supervisor might further divide work into tasks such as structural analysis, computer analysis, layout and installation drawings, and manuals, then for each task develop an estimate of the task duration and the labor grade or skill level involved. Similarly, the fabrication supervisor might subdivide the work to identify the needed materials (steel, piping, wiring), hardware, machinery, equipment, insurance, and so on, then estimate how much (quantity, size, length, weight, etc.) of each will be needed. Estimates of time and materials are determined by reference to previous similar work, standards manuals, and documents from analogy projects and by rules of thumb (e.g. "one hour for each line of code").

The supervisors submit their estimates to the work package manager, who checks and revises them, then forwards them to the project manager. The project manager and professional estimators on the project staff review the submitted estimates to be sure that no costs were overlooked or duplicated, everyone understood what they were estimating, correct estimating methods were used, and allowances were made for risk and uncertainty.[9] The estimates are then aggregated as shown in Figure 9.4 and converted into dollars using standard wage rates and material costs (current or projected). The project manager then adds in a project-wide overhead (to cover project management and administrative costs) and the company-wide overhead (to cover general company expenses) to arrive at a total-project cost estimate.

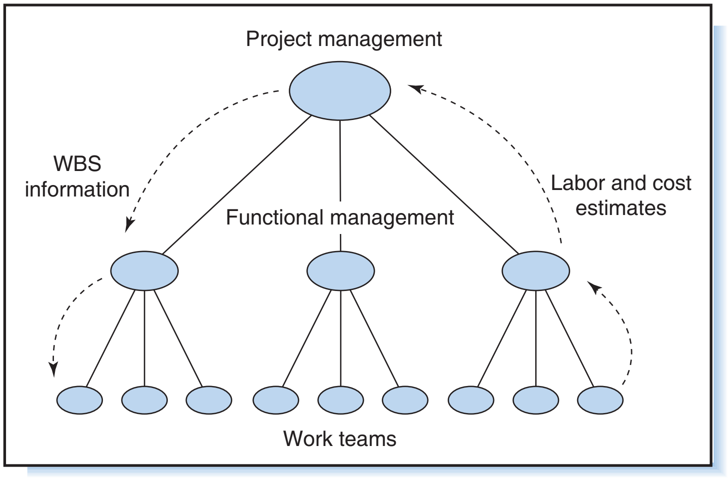


Figure 9.4
The estimating process.

The accumulation of work package estimates (upward arrows in Figure 9.4) to derive the project estimate is called the "bottom-up" approach.

Contingency amount

Contingency amounts are added to estimates to offset uncertainty. As mentioned, the more complex or poorly defined the situation, the greater the required amount. The contingency amounts can be developed for individual activities or work packages or for the project as a whole. *Activity contingency* is an amount estimated to account for "known unknowns" in an activity or work package, that is, sources of cost increases that could or likely will occur; they include allowance for design changes and increases in the scope, size, or function of the end-item and delays due to problems such as weather. Later, when the project budget is established, the contingency amount should be placed in a special budget, subdivided according to work packages, and strictly controlled by the project manager. When the sum of the activity contingencies is added to the total project cost, the result is the *base estimate* for the project cost.

Senior managers or the program manager sometimes add another amount to the baseline estimate, a project contingency or so-called *management reserve*, to account for "*unknown unknowns*"—external factors that affect project costs but cannot be pinpointed. Examples include unforeseen fluctuation in exchange rates, shortages in resources, and changes in the market or competition. The project manager has access to this contingency, although that access is controlled by the program manager or senior management. Adding the management reserve to the baseline estimate gives the *final cost estimate*—considered the *most likely* cost for the project. This estimate becomes the project budget.

Besides the activity and project contingencies, the *corporation* might set aside another amount just to cover overruns. This amount, the *overrun allowance*, is added to the final cost estimate to yield a cost where, as a rule, the probability of exceeding it is less than 10 percent. The overrun allowance is controlled by program manager or corporate managers and ordinarily is not available to the project manager without approval.

Top down versus bottom up

As mentioned, estimating can be done in one of two ways: top down or bottom up. Top down refers to estimating costs by looking at the project as a whole. A top-down estimate is typically based upon an expert opinion or analogy to other similar projects. Bottom up refers to estimating costs by looking at elements of the project—individual activities, work packages, and end-item components. Costs for each work package or end-item element are estimated separately and then aggregated to derive the total project cost. Example 9.5 is a bottom-up approach; Example 9.2 is a top-down approach. The approaches can be used in combination: portions of a project that are well defined can be estimated bottom up; other less-defined portions can be estimated top down. The cost of each work package can also be estimated either way—by breaking the package into small elements and estimating the cost of each (bottom up) or by making a gross estimate from analogy or expert opinion (top down). The bottom-up method provides much better estimates than the top-down method but requires more information and is more time consuming.

Use of top down or bottom up corresponds somewhat to the project life cycle. In project conception, the cost estimate might consist of no more than a top-down "ballpark" number to suggest the order of magnitude of the project cost. The estimate gives the customer or contractor a rough idea of the size of the cost. The method involves little effort, but the estimate is usually of low accuracy, and not much confidence is attached to it.

As the proposal is being prepared in the conception phase, the cost estimate is often based upon the top-down method while looking at previous but analogous projects and compensating for lessons learned and differences between them. The accuracy of the estimate depends upon the validity of the analogies and ability to distinguish differences and areas of uncertainty.

During the definition phase (and sometimes also during conception, depending upon the availability of reliable data information), the cost estimate is often prepared using the bottom-up approach. This method provides a fairly accurate estimate of the cost figures needed to establish the project budget and control accounts, discussed later.

Reconciling estimates

The project manager submits the final cost estimate to company management and/or the external project customer plus forecasts showing the effects of potential escalation factors such as inflation. Management or the customer compares the estimate against its own *gross estimate*, the goal or target set by management or the customer, and either accepts it or mandates a revision. If the gross estimate is larger, the project manager reviews the work package estimates for possible oversights or over-optimism. If the gross estimate is smaller, the project manager will likely be required to find ways to reduce the submitted cost estimate.

Reducing costs

What happens if the final cost estimate must be reduced? No one in the project will want to give up their share of the budget and lose funding or staff. Non-managers especially (engineers, scientists, systems analysts) are often unaware of the constraints and will resist cutbacks. Through diplomacy and negotiation, the project manager tries to convince everyone to look for ways to *reduce costs*. Failing that, she must convince them to accept any *imposed* reductions.

One way to reconcile differences between final and gross estimates is to impose an across-the-board cut on all estimates. This is poor practice because it fails to account for judgmental errors or excessive costs within just a few elements of the estimate, and it unfairly penalizes managers who tried to produce fair estimates and were honest enough not to pad them. Indiscriminate, across-the-board cuts induce everyone to pad estimates for their own protection.

Suppose you are the project manager and it is clear that top management's gross estimate is simply too small to do the project. There are two courses of action: either undertake the project and attempt wholeheartedly to meet the budget or hand the project over to another manager. If you decide on the former, you should document and report your disagreement to top management and, later, search for ways to reduce costs and complete the project within budget. If the contract is cost-plus, additional costs will be reimbursed, but if it is fixed-price and the budget is so underfunded as to require cutting corners or stalling the project, then you might recommend that the project be cancelled (or another person be appointed project manager). Not only is this good business practice, it is the ethical thing to do.

9.5 Elements of estimates and budgets

Both budgets and cost estimates state the cost of doing something; the difference is that the estimate comes first and is the basis for the budget. A cost estimate might have to be refined many times, but once approved, it becomes the budget and the amount for which the organization and work units then commit to performing the work. It is the agreed-upon amount for what the work should cost and the baseline against which actual expenditures will be compared.

Project budgets and fiscal operating budgets are similar; the difference is that the former covers the entire life of a project, the latter only a year at a time.

Estimates and budgets share the following elements:

- Direct labor expense
- Direct non-labor expense
- Overhead expense
- General and administrative expense
- Profit and total billing.

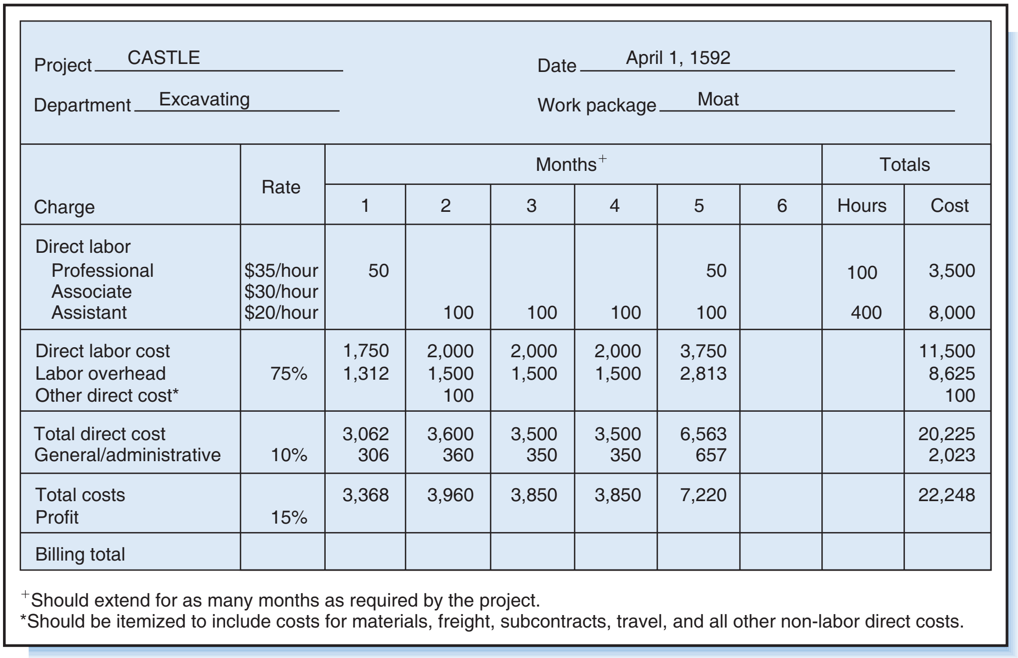
Direct labor expense[10]

Direct labor expense is the labor charge for the project. For each activity or work package, an estimate is made of the number of people or hours or days needed in each labor grade. This gives the distribution of labor hours or days required per labor grade. The labor hours for the various grades are then multiplied by their respective wage rates. The work package budget in Figure 9.5 shows the wage rates for three labor grades and the associated labor hours as distributed (time-phased) over a 6-month period. For example, the direct labor cost for an assistant in months 2–5 is $20 × 100 =$2000 per month.

When the wage rate is expected to change over the course of the work, a weighted average wage rate is used. In Figure 9.5, suppose the rate for an assistant is expected to rise from $20 to $25 in months 3, 4, and 5. Instead of $8,000 for the assistant, the labor cost would be 100($20) + 100($25) + 100($25) +100($25) = $9,500. The average wage rate for the assistant would thus be $9,500/400 hours = $23.75/hour.

Direct non-labor expense

Direct non-labor expense is the total expense of non-labor charges applied directly to the activity. It includes subcontractors, consultants, travel, telephone, computer time, material costs, purchased parts, and freight. This expense is represented in Figure 9.5 by the line "other direct cost." Material costs and



Project CASTLE
Date April 1, 1592
Department Excavating
Work package Moat

Charge	Rate	Months+						Totals	
		1	2	3	4	5	6	Hours	Cost
Direct labor									
Professional	$35/hour	50				50		100	3,500
Associate	$30/hour								
Assistant	$20/hour		100	100	100	100		400	8,000
Direct labor cost		1,750	2,000	2,000	2,000	3,750			11,500
Labor overhead	75%	1,312	1,500	1,500	1,500	2,813			8,625
Other direct cost*			100						100
Total direct cost		3,062	3,600	3,500	3,500	6,563			20,225
General/administrative	10%	306	360	350	350	657			2,023
Total costs		3,368	3,960	3,850	3,850	7,220			22,248
Profit	15%								
Billing total									

+Should extend for as many months as required by the project.
*Should be itemized to include costs for materials, freight, subcontracts, travel, and all other non-labor direct costs.

Figure 9.5
Typical 6-month budget for a work package.

freight charges include allotments for waste and spoilage and should reflect anticipated price increases; such sometimes appear as separate line items called *direct materials* and *overhead on materials*, respectively. Consultants and time on special equipment may appear as *support*.

Direct non-labor expenses also include necessities for installation and operation, such as instruction and maintenance manuals, engineering and programming documentation, drawings, and spare parts. Note that these are costs applied only for a *specific* project or work package and do not include general or overhead costs of doing business unless those costs are tied solely to the specific project.

On smaller projects, the direct non-labor expenses are individually estimated for each work package. In larger projects, a simple percentage rate is applied to cover travel and freight costs. For example, 5 percent of direct labor cost might be included as travel expense and 5 percent of material costs as freight. These percentages are estimated in the same fashion as overhead rates, discussed next.

Overhead, general, and administrative expenses

Direct expenses for labor and materials are easily charged to a specific work package, but other expenses cannot so easily be charged to specific work packages or even to specific projects. These expenses, termed *overhead* or *non-direct expenses*, are the costs of doing business. They include whatever is necessary to house and support the labor, including building rents, utilities, clerical assistance, insurance, and equipment. Overhead is usually computed as a percentage of the direct labor cost. Frequently, the rate is 100 percent but ranges from as low as 25 percent for companies that do most of their work in the field to over 250 percent for those with expensive facilities, laboratories, and equipment.

The overhead rate is computed by estimating the annual business overhead expense, then dividing by the projected total direct labor cost for the year. Suppose the total overhead for next year is projected to be $180,000.

If total anticipated direct labor charges are \$150,000, then the overhead rate is 180,000/150,000 = 1.20. Thus, for every \$1.00 charged to direct labor on a project, \$1.20 is charged to overhead.

Although this is the traditional accounting method for deriving the overhead rate, for projects, it results in an arbitrary allocation of costs, which is counterproductive for project cost control because most overhead cost sources are not tied to any particular project. More appropriate for projects is to divide overhead costs into two categories: *direct overhead* for costs that can be allocated in a logical manner and *indirect overhead* for costs that cannot. Direct overhead costs can be traced to the support of a particular project or work package; such costs are allocated *only* among the specific projects or activities for which they apply. For example, the overhead cost for a department working on four projects is apportioned among the four projects based on the percentage of labor time it devotes to each; none of the department's overhead cost is allocated to projects that it is not working on.

The other kind of overhead, indirect, includes general expenses for the corporation. Usually referred to as *general and administrative* expense, or G&A, it includes taxes, financing, penalty and warranty costs, accounting and legal support, proposal preparation, marketing and promotion, salaries and expenses of top management, and employee benefits. Some of these expenses apply to no projects in particular, and others apply to only to certain projects. For example, corporate-level overhead (e.g. salary of the president, which applies to no particular project) would be allocated across all projects; the project manager's overhead (e.g. salary of the project manager) would be allocated only among the projects she manages; departmental overhead (e.g. marketing and legal departments) would be allocated only to segments of specific projects to which they contributed. Often, G&A overhead is charged on a time basis, so the longer the project duration, the greater the G&A expense for the project.

In practice, the actual manner in which indirect costs are apportioned among project varies. Table 9.2 for the SETI Company shows three methods for distributing indirect costs between two projects, MARS and PLUTO.[11] Notice that although company-wide expenses remain the same, the cost of each project differs depending on the method of allocating indirect costs.

Customers want to know the allocation method used by their contractors, and contractors should know the allocation method used by their subcontractors. For example, Method I in Table 9.2 is good for the customers when the project is direct labor (DL) intensive but bad when it is direct non-labor (DNL) intensive. Method III is the opposite and gives a lower cost when the project is relatively non-labor intensive (i.e. labor costs are low but material and parts costs are high). This can be seen by comparing MARS (somewhat non-labor intensive) to PLUTO (labor intensive): for MARS, Method I yields a project cost of 162, but Method II yields a project cost of only 146.25.

Overhead costs appear in projects in different ways. Any overhead expense that *can* be traced to specific work packages should be allocated to them directly. In Figure 9.5, overhead expenses that can be tied *directly to the project* appear on the line "General/administrative." Remaining overhead expenses that cannot be traced to specific work packages are assigned to a special "overhead" work package. This can be a single overhead work package for the entire project or a series of packages, each tied to an individual project stage or phase.

Profit and total billing

Profit is the amount left over after expenses have been subtracted from the contractual price. It can also be an agreed-to fixed fee or a percentage of total expenses (15 percent in Figure 9.5), determined, in part, by the kind of contract, as discussed in Chapter 12. *Total billing* is the sum of total expenses and profit. Total billing and profit are included in estimates for the overall project, groups of work packages, and subcontracted work but usually do not appear on budgets for lower-level work elements. All these numbers reflect budgeted costs, not actual costs. A goal of project management is to execute the project as close to budgeted costs as possible, though actual costs and budgeted cost will always differ. The sometimes worrisome question is: by how much?

See Chapter 12

Table 9.2 Examples of indirect cost apportionment.

SETI Company: Company-Wide (Indirect Costs)		
Overhead (rent, utilities, clerical, machinery)	OH	120
General (upper management, staff, benefits, etc.)	G&A	40
	Indirect Total	160

Project Costs	MARS Project	PLUTO Project	Total
Direct labor (DL)	50	100	150
Direct nonlabor (DNL)	40	10	50
	90	110	200
		Direct Total	200
		Direct and Indirect Total	360

Three methods for apportioning indirect costs:
I. Total indirect proportionate to total direct costs

	MARS Project	PLUTO Project	Total
DL and DNL	90	110	200
OH and G&A	72	88	160
	162	198	360

II. OH proportionate to direct labor only; G&A proportionate to all direct costs

	MARS	PLUTO	Total
DL	50	100	150
OH on DL	40	80	120
DNL	40	10	50
G&A on (DL and DNL)	18	22	40
	148	212	360

III. OH proportionate to direct labor only; G&A proportionate to DL and OH and DNL

	MARS	PLUTO	Total
DL and OH and DNL	130	190	320
G&A	16.25	23.75	40
	146.25	213.75	360

9.6 Project cost accounting system

A project might consist of hundreds or thousands of elements—workers, materials, and facilities, every one of which must be estimated, budgeted, and controlled. To expedite the process, reduce confusion, and improve accuracy, you need a system to help compute the estimates; create, store, and update the budgets; and track the actual expenses. Such a system, called a *project cost accounting system* (PCAS), is initially set up by the project manager, project accountant, or project management office. The main focus of the PCAS is project costs, although it also assists tracking and controlling schedules and work progress. When the PCAS is combined with functions for project planning, control, and reporting, the whole system is referred to as the *project management information system* (PMIS). The PMIS is discussed in Chapter 13.

See Chapter 13

The PCAS is used throughout the project life cycle. During project conception and definition, it is used to accumulate work package cost estimates and produce the total project cost estimate. These estimates become the basis upon which project and work package budgets will be created.

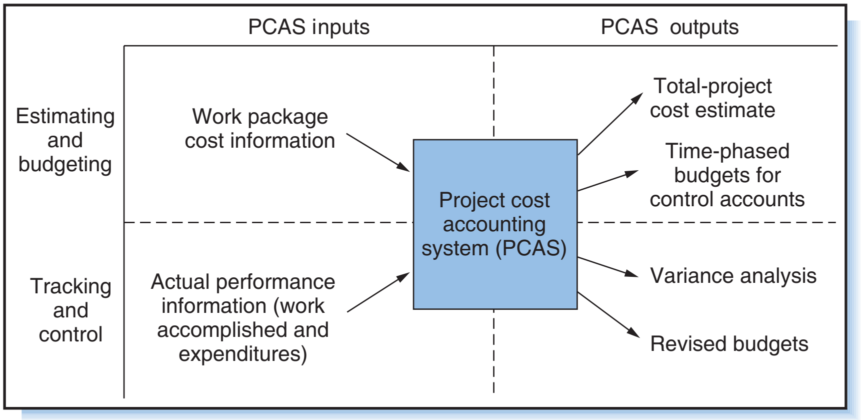


Figure 9.6
Elements of a project cost accounting system.

During project execution, the PCAS accumulates, credits, and reports project and work package actual expenditures. It creates time-phased budgets (example, Figure 9.5), which help managers monitor costs and verify that the work has been completed and charged. The system also enables budget revisions. The functions of the PCAS are summarized in Figure 9.6.

Example 9.6: PMIS for Estimating Labor Requirements and Costs[12]

Sigma Associates is a large architectural/engineering firm that developed its own PCAS, a module within the PMIS it uses for estimating, planning, and scheduling.

At Sigma, the project manager begins each potential project by creating a WBS to identify the main work packages. Using a menu in the PMIS, she reviews the history of similar work packages from previous projects and the kind and amount of labor they required. By entering factors related to project size, construction costs, and type of client, she can estimate the labor requirements for every activity in the project. Using the PMIS, the project manager combines these labor estimates with requirements for existing projects to produce a labor resource loading forecast; this enables her to determine whether sufficient labor is available. If it is not, the project manager uses the system to review options such as modifying the schedule, using overtime, or leveling resources (discussed in Chapter 7).

See Chapter 7

The project manager hands the labor requirements estimate to the project comptroller, who, through the PCAS, applies existing or projected hourly rates to every activity. The comptroller then adds in employee benefits and labor overhead to produce an estimate for direct labor cost.

With information from the company general ledger, the comptroller computes the overhead rate, which he uses to charge the project for its share of company-wide expenses. He then uses the PCAS to roll up all of the estimated expenses and create an estimated project budget. Last, the comptroller analyzes the estimated budget along with the project plan for profitability. If the budget and plan show a reasonable profit and the comptroller and project manager both agree to the budget, the project is accepted. If not, a different plan is sought that maintains the same high-quality standards but is more profitable.

Time-phased budgets

The project manager needs an easy way to monitor and control the project—to know where and when expenses are accruing, how well the project is progressing, and where problems are developing. One way is with a *time-phased budget* that consolidates the budgetary and schedule information to show the distribution of budgeted costs according to the project schedule. Figure 9.5 is an example; it shows the distribution of costs in a work package over months 1 through 6. The PCAS generates reports like this for each work package, thus enabling a project manager during project execution to compare budgeted costs for the work package with actual expenditures on a month-by-month basis.

In projects where a substantial portion of the costs originate from subcontracts and purchased items or services, a special time-phased budget is prepared for *procured* goods, work, and services. In large projects, this budget is controlled by a materials or procurement manager.

9.7 Budgeting using control (or cost) accounts

Budgeting and cost monitoring in small projects can be done using a single budget for the project as a whole. This budget, perhaps similar to the one in Figure 9.5, is used to compare actual costs with budgeted costs throughout the project.

On larger projects, however, a single, project-wide budget is too insensitive; making it difficult to quickly locate the sources of cost overruns once the project is underway and expenses accrue. The better way is to subdivide the project budget into smaller budgets called *control accounts* (or cost accounts), each representing a work package on the WBS. Large projects have tens of control accounts; very large projects have hundreds.

The control account is the basic project tracking element in the PCAS. The accounts are set up in a hierarchy, similar or identical to the WBS. The lowest-level account usually corresponds to a work package, although when the number of work packages is very large, one account might represent several work packages combined. Like work packages, each account might include:

- A work description
- A time schedule
- Who is responsible
- Material, labor, and equipment required
- A time-phased budget.

Control accounts are also established for project costs not readily attributable to any specific work package. For example, separate control accounts are established to cover expenses for materials or equipment for use by anyone or in any work package or for work such as administration, supervision, or inspection that applies across the entire project. These accounts are usually set up for the duration of the project or on a period-by-period as needed or as funds are appropriated.

With a PCAS and control-account structure, it is easy to monitor cost performance for each work package, group of work packages, and the project as a whole. For example, consider the ROSEBUD project and its contractor, KANE & Associates. Figure 9.7 shows the ROSEBUD project WBS and the KANE organization chart. The shaded boxes represent locations of control accounts; notice that each account represents all or part of a work package for which a functional area is responsible. Example: the Programming Department is responsible for work packages L and W; Engineering and Tech Support share responsibility for work package Y. (In the latter case, good practice is for one of the departments—Engineering or Tech Support—to take primary responsibility for the work package and to delegate the remaining responsibility to the other.)

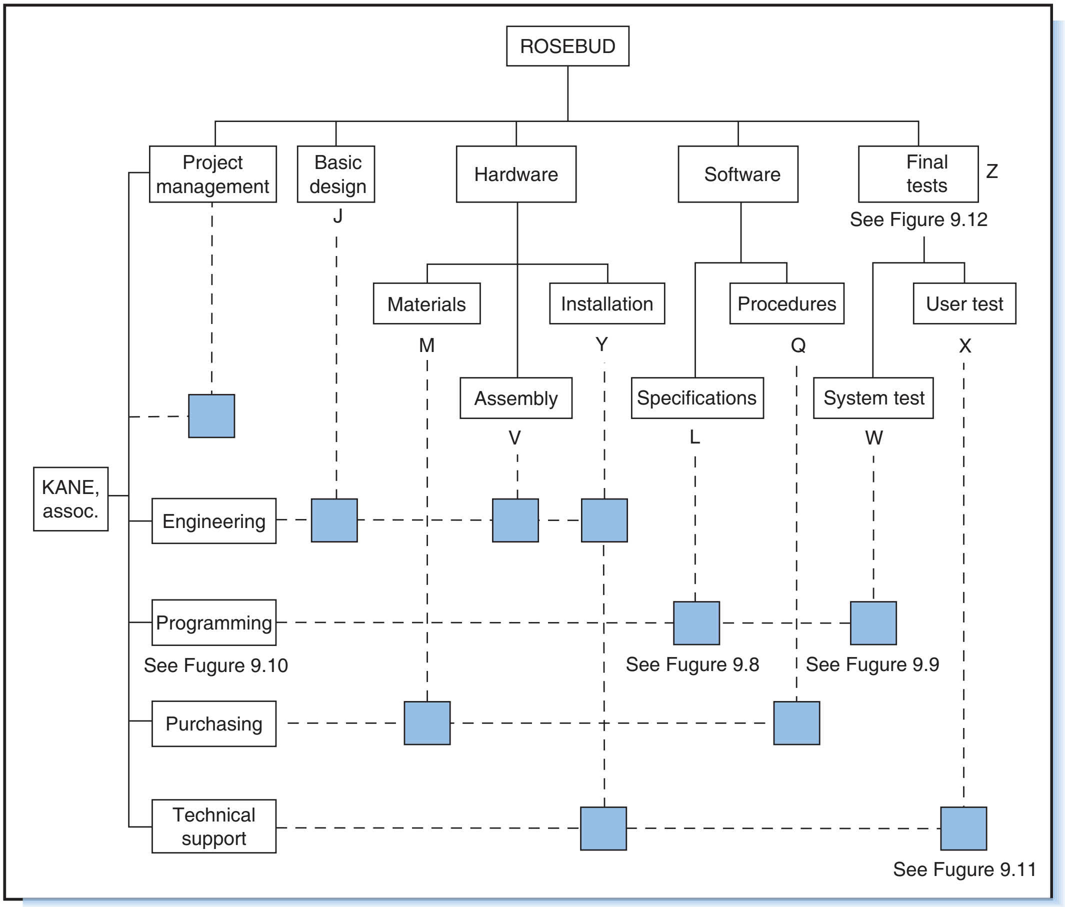
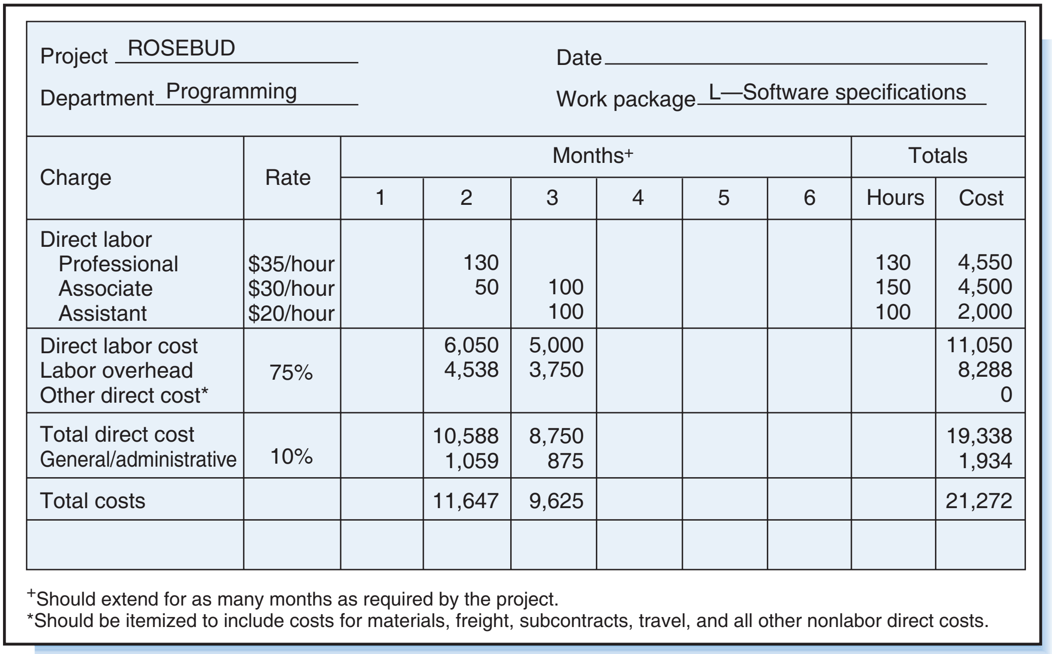


Figure 9.7
Integration of WBS and organization structure showing control accounts. (See Figures 9.8 through 9.12 for details.)

The WBS for ROSEBUD consists of nine work packages performed by four functional departments, plus an additional work package for project management. During the estimating phase, each department submits a cost estimate for the work packages in its part of the project. Upon approval, with additions for overhead and G&A, each department's estimate becomes a budget. In Figure 9.7, the ten shaded boxes represent departments/work packages for which initial cost estimates were made and, subsequently, budgets and control accounts were established. Figures 9.8 and 9.9 show, respectively, the time-phased budget portions of the control accounts for work packages L and W.

9.8 Cost summaries[13]

With the control account structure, Figure 9.7, high-level summary accounts can be developed by consolidating control accounts for the WBS and organizational hierarchies. Such consolidation is useful for monitoring the performance of individual departments and segments of the project. Consolidating the accounts in Figure 9.7 horizontally results in a control account for each functional department.

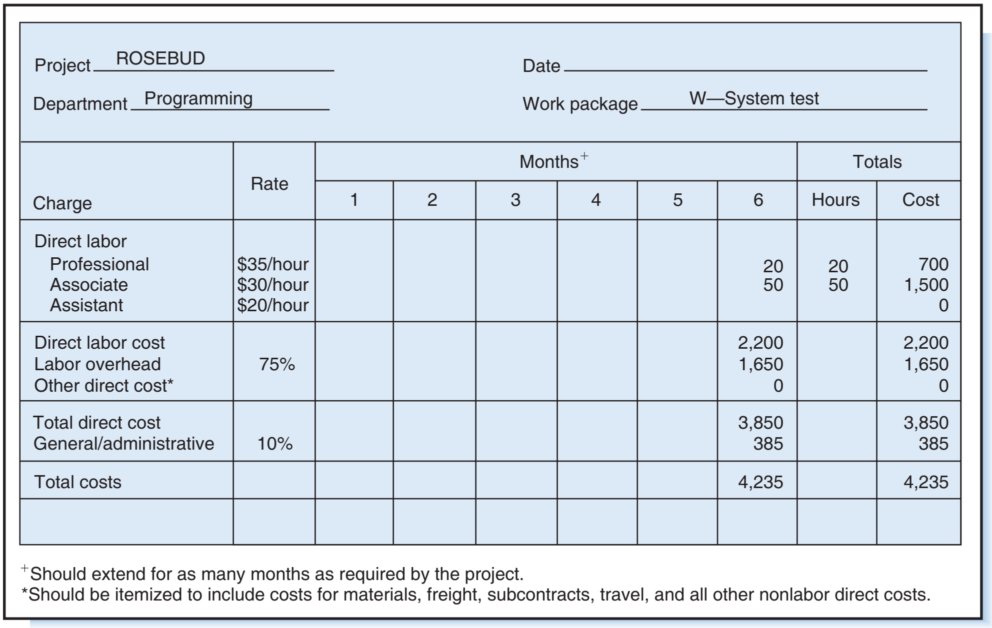


Project ROSEBUD
Date
Department Programming
Work package L—Software specifications

Charge	Rate	Months+						Totals	
		1	2	3	4	5	6	Hours	Cost
Direct labor									
Professional	$35/hour		130					130	4,550
Associate	$30/hour		50	100				150	4,500
Assistant	$20/hour			100				100	2,000
Direct labor cost			6,050	5,000					11,050
Labor overhead	75%		4,538	3,750					8,288
Other direct cost*									0
Total direct cost			10,588	8,750					19,338
General/administrative	10%		1,059	875					1,934
Total costs			11,647	9,625					21,272

+Should extend for as many months as required by the project.
*Should be itemized to include costs for materials, freight, subcontracts, travel, and all other nonlabor direct costs.

Figure 9.8
Budget for programming department for work package L.

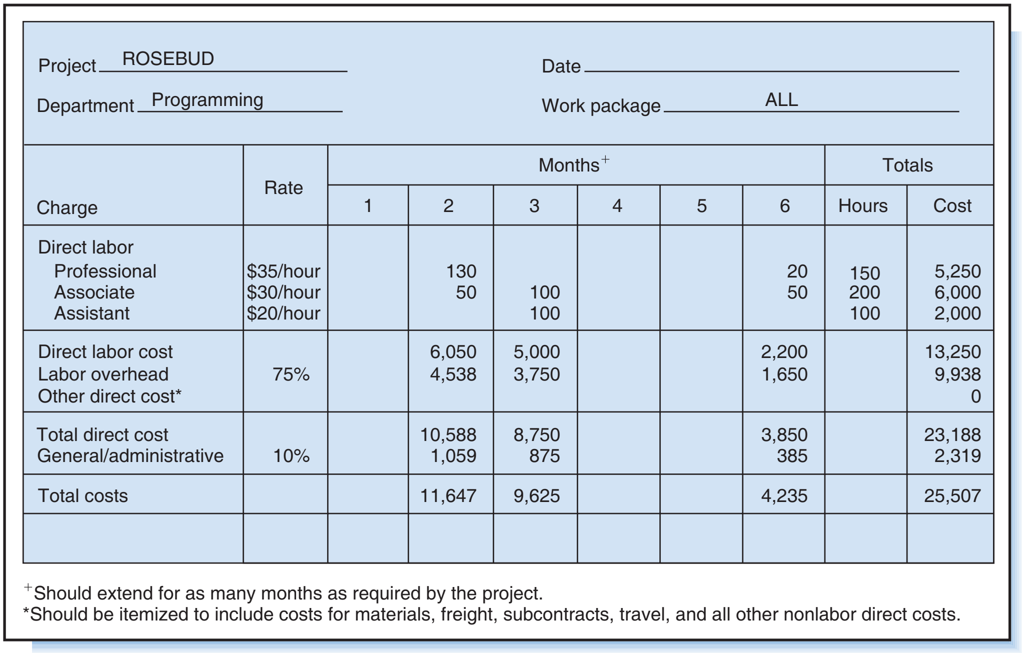


Project ROSEBUD
Date
Department Programming
Work package W—System test

Charge	Rate	Months+						Totals	
		1	2	3	4	5	6	Hours	Cost
Direct labor									
Professional	$35/hour						20	20	700
Associate	$30/hour						50	50	1,500
Assistant	$20/hour								0
Direct labor cost							2,200		2,200
Labor overhead	75%						1,650		1,650
Other direct cost*							0		0
Total direct cost							3,850		3,850
General/administrative	10%						385		385
Total costs							4,235		4,235

+Should extend for as many months as required by the project.
*Should be itemized to include costs for materials, freight, subcontracts, travel, and all other nonlabor direct costs.

Figure 9.9
Budget for programming department for work package W.



Project ROSEBUD
Date
Department Programming
Work package ALL

Charge	Rate	Months[+]						Totals	
		1	2	3	4	5	6	Hours	Cost
Direct labor									
Professional	$35/hour		130				20	150	5,250
Associate	$30/hour		50	100			50	200	6,000
Assistant	$20/hour			100				100	2,000
Direct labor cost			6,050	5,000			2,200		13,250
Labor overhead	75%		4,538	3,750			1,650		9,938
Other direct cost*									0
Total direct cost			10,588	8,750			3,850		23,188
General/administrative	10%		1,059	875			385		2,319
Total costs			11,647	9,625			4,235		25,507

[+] Should extend for as many months as required by the project.
*Should be itemized to include costs for materials, freight, subcontracts, travel, and all other nonlabor direct costs.

Figure 9.10
Budget for programming department.

Figure 9.10 illustrates: it is the time-phased budget for the programming department, which is the sum of the budgets for work packages L and W (Figures 9.8 and 9.9). Consolidating control accounts vertically through the WBS results in control accounts for individual work packages, clusters of work packages, or the project as a whole. Figure 9.12 is the time-phased budget part of the account for final tests portion of the project—the sum of the budgets for work packages W and X (Figures 9.9 and 9.11).

The PCAS and control-account structure permit costs to be summarized in a variety of ways: Figure 9.13 shows budgeted amounts aggregated vertically and horizontally, and Table 9.3 summarizes the budgeted cost elements for the five departments and nine work packages in the ROSEBUD project. Thus, through the PCAS and cost account structure, it is easy for a project manager to identify cost deviations from budget at the project level or the company level and to readily trace such deviations to the work packages and departments responsible for them. Chapter 13 will describe this more fully.

See Chapter 13

9.9 Cost schedules and forecasts[14]

Questions arise during project planning about how expenditures will vary throughout the project, which periods will have the heaviest cash requirements, and how expenditures will compare to income. To answer these and other such questions, it helps to anticipate the expected estimated "pattern of expenditures" throughout the project. Following are examples.

Project ROSEBUD
Date
Department Technical support
Work package X—User test

Charge	Rate	Months$^+$						Totals	
		1	2	3	4	5	6	Hours	Cost
Direct labor									
Professional	$35/hour						10	10	350
Associate	$30/hour						40	40	1,200
Assistant	$20/hour								
Direct labor cost							1,550		1,550
Labor overhead	75%						1,163		1,163
Other direct cost*						1,200	2,107		3,307
Total direct cost						1,200	4,820		6,020
General/administrative	10%					120	482		602
Total costs						1,320	5,302		6,622

$^+$Should extend for as many months as required by the project.
*Should be itemized to include costs for materials, freight, subcontracts, travel, and all other nonlabor direct costs.

Figure 9.11
Budget for work package X.

Project ROSEBUD
Date
Department Technical support; Programming
Work package (W + X) Final Tests

Charge	Rate	Months$^+$						Totals	
		1	2	3	4	5	6	Hours	Cost
Direct labor									
Professional	$35/hour						30	30	1,050
Associate	$30/hour						90	90	2,700
Assistant	$20/hour								0
Direct labor cost							3,750		3,750
Labor overhead	75%						2,813		2,813
Other direct cost*						1,200	2,107		3,307
Total direct cost						1,200	8,670		9,870
General/administrative	10%					120	867		987
Total costs						1,320	9,537		10,857

$^+$Should extend for as many months as required by the project.
*Should be itemized to include costs for materials, freight, subcontracts, travel, and all other nonlabor direct costs.

Figure 9.12
Budget summary for final tests.

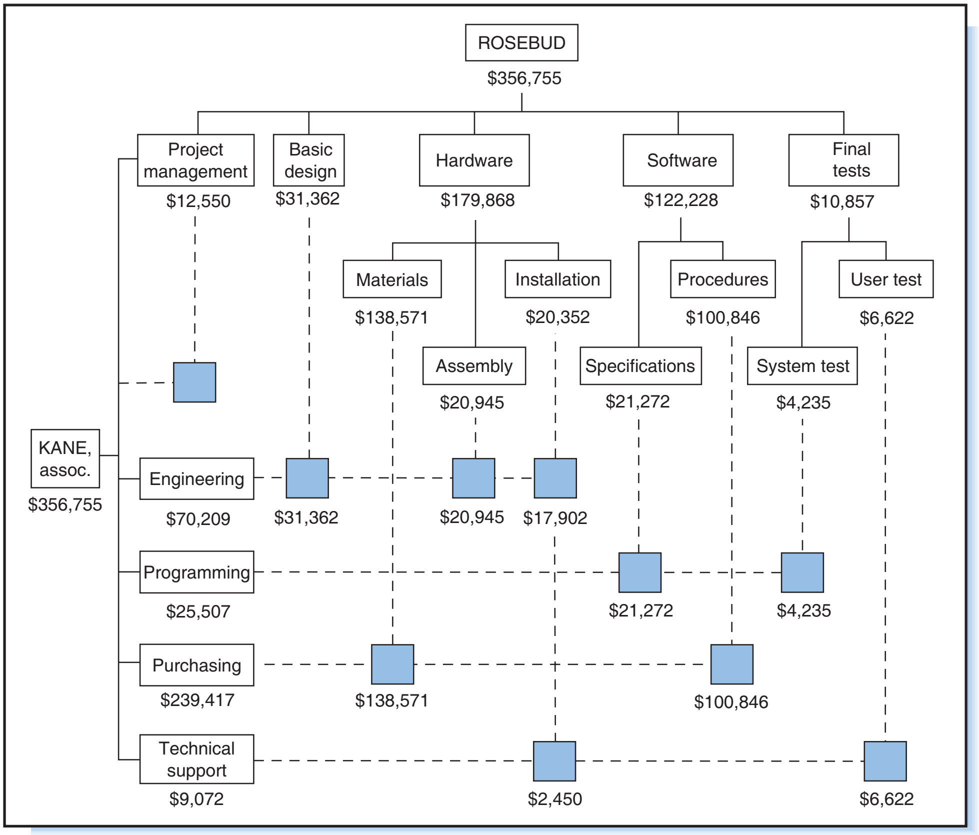


Figure 9.13
Aggregation of control account information by project and organization.

Cost analysis with early and late start times

A simplifying assumption used in cost estimating is that the costs in each work package are distributed uniformly. For example, a 2-week, $22,000 work package is assumed to have expenditures of $11,000 per week. With this assumption, it is easy to create a *cost schedule* that shows the cost *each week* of the entire project.

As an example, look at Table 9.4, which lists the work packages for the LOGON project and associated time and cost information. The weekly direct cost for each activity is the total cost divided by the time; for example, for Activity H, it is $100K/10 weeks = $10K/week.

Now look at Figure 9.14—the time-based network for the LOGON project based upon early start times. Using this network, the project cost *each week* can be computed by adding the costs for all activities scheduled in the week. (The procedure is the same as described in Chapter 7 for determining the resource loading.) According to Figure 9.14, during the first 10 weeks, only Activity H is scheduled, so the project weekly cost will be at $10K. Over the next 6 weeks, Activities I and J are scheduled, so the weekly cost is their sum, $16K + $8K = $24K. Further along, in weeks 17 and 18, four work packages—I, K, L, and J—are scheduled, so the weekly cost is their sum, $8K + $4K + $18K + $21K = $51K. The weekly expenses, shown in third column, Table 9.5, represent the forecasted *project cost schedule*.

See Chapter 7

Table 9.3 Cost summary for ROSEBUD project.*

	Labor($)				Overhead($)						
	Engineering	Programming	Purchasing	Technical Support	Engineering	Programming	Purchasing	Technical Support	Materials	General and Administrative	Total Cost
Total project	22,800	13,250	2,230	2,850	22,800	9,938	1,673	2,138	235,236	31,290	356,755
Project management											12,550
Activity J	7,200				7,200				14,111	2,851	31,362
Activity L*		11,050				8,288				1,934	21,272
Activity M			1,100				825		124,050	12,596	138,571
Activity Q			1,300				818		89,700	9,168	100,846
Activity V	8,200				8,200				2,641	1,904	20,945
Activity Y	7,400			1,300	7,400			975	1,427	1,850	20,352
Activity W		2,200				1,650				385	4,235
Activity X				1,550				1,163		602	6,622

*Refer to Figure 9.8 to see, for example, how costs in this row were developed

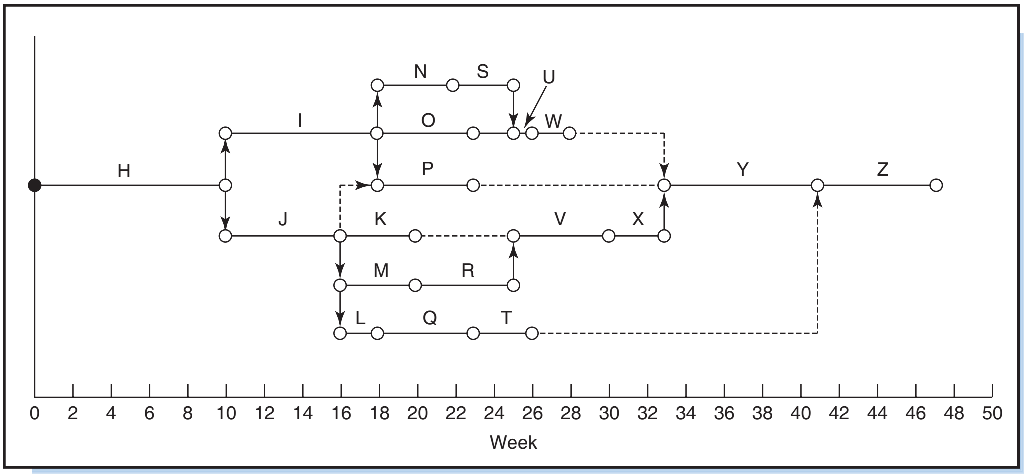


Figure 9.14
Time-based network for the LOGON project using early start times.

Table 9.4 Activities, time, cost, and labor requirements (result of work breakdown analysis).

Activity	Time (Weeks)	Total Cost ($K)	Weekly Direct Cost ($K)	Weekly Labor Requirements (Workers)
H	10	100	10	5
I	8	64	8	4
J	6	96	16	8
K	4	16	4	2
L	2	36	18	6
M	4	84	21	3
N	4	80	20	2
O	5	50	10	5
P	5	60	12	6
Q	5	80	16	2
R	5	0	0	0
S	3	0	0	0
T	3	0	0	0
U	1	14	14	9
V	5	80	16	14
W	2	24	12	6
X	3	36	12	6
Y	8	104	13	14
Z	6	66	11	5
	Total Direct Cost—$990K			

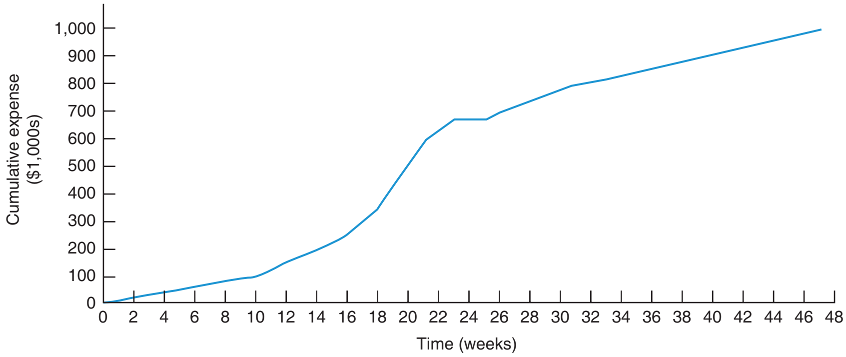
Table 9.5 LOGON project weekly expense using early start times ($1,000).

Week	Early Start Activities During Week	Early Start Weekly Expense	Early Start Cumulative Expense	Late Start Activities During Week	Late Start Weekly Expense	Late Start Cumulative Expense
1	H	10	10	H	10	10
2	H	10	20	H	10	20
3	H	10	30	H	10	30
4	H	10	40	H	10	40
5	H	10	50	H	10	50
6	H	10	60	H	10	60
7	H	10	70	H	10	70
8	H	10	80	H	10	80
9	H	10	90	H	10	90
10	H	10	100	H	10	100
11	I, J	24	124	J	16	116
12	I, J	24	148	J	16	132
13	I, J	24	172	J	16	148
14	I, J	24	196	J	16	164
15	I, J	24	220	I, J	24	188
16	I, J	24	244	I, J	24	212
17	I, K, L, M	51	295	I, M	29	241
18	I, K, L, M	51	346	I, M	29	270
19	K, M, N, O, P, Q	83	429	I, M	29	299
20	K, M, N, O, P, Q	83	512	I, M	29	328
21	N, O, P, Q	58	570	I, R	8	336
22	N, O, P, Q	58	628	K, I, R	12	348
23	O, P, Q	38	666	K, R	4	352
24	—	0	666	K, R, N	24	376
25	—	0	666	K, R, N	24	400
26	U, V	30	696	N, O, V	46	446
27	V, W	28	724	N, O, V	46	492
28	V, W	28	752	S, O, V	26	518
29	V	16	768	S, O, P, V	38	556
30	V	16	784	S, O, P, V	38	594
31	X	12	796	U, P, X	38	632
32	X	12	808	W, P, X, L	54	686
33	X	12	820	W, P, X, L	54	740
34	Y	13	833	Y, Q	29	769
35	Y	13	846	Y, Q	29	798
36	Y	13	859	Y, Q	29	827
37	Y	13	872	Y, Q	29	856
38	Y	13	885	Y, Q	29	885
39	Y	13	898	Y, T	13	898
40	Y	13	911	Y, T	13	911
41	Y	13	924	Y, T	13	924

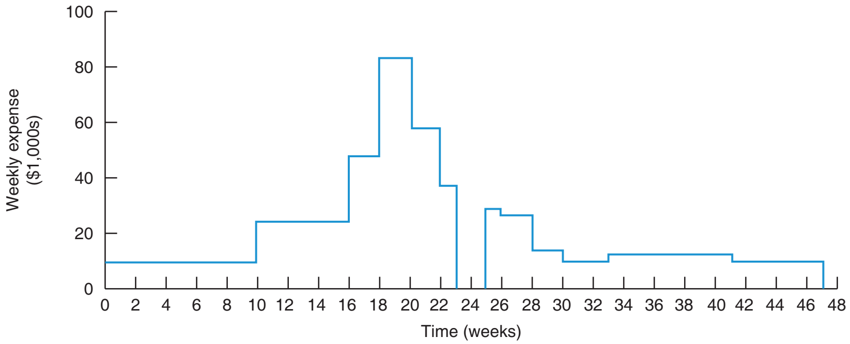
Week	Early Start Activities During Week	Early Start Weekly Expense	Early Start Cumulative Expense	Late Start Activities During Week	Late Start Weekly Expense	Late Start Cumulative Expense
42	Z	11	935	Z	11	935
43	Z	11	946	Z	11	946
44	Z	11	957	Z	11	957
45	Z	11	968	Z	11	968
46	Z	11	979	Z	11	979
47	Z	11	990	Z	11	990

The fourth column, cumulative expense, is the forecasted total project cost as of any given week. Cumulative and weekly expenses are graphed in Figure 9.15.

Using the same procedure, the forecasted project cost schedule based on *late* start times can be prepared. Figure 9.16 is the time-based network for LOGON using late start times. In Table 9.5, the last two columns are the late-start weekly and cumulative costs.



Cumulative expense forecast (Table 8.5)



Weekly expense schedule (Table 8.5)

Figure 9.15
Planned weekly expenses and cumulative expenses for the LOGON project.

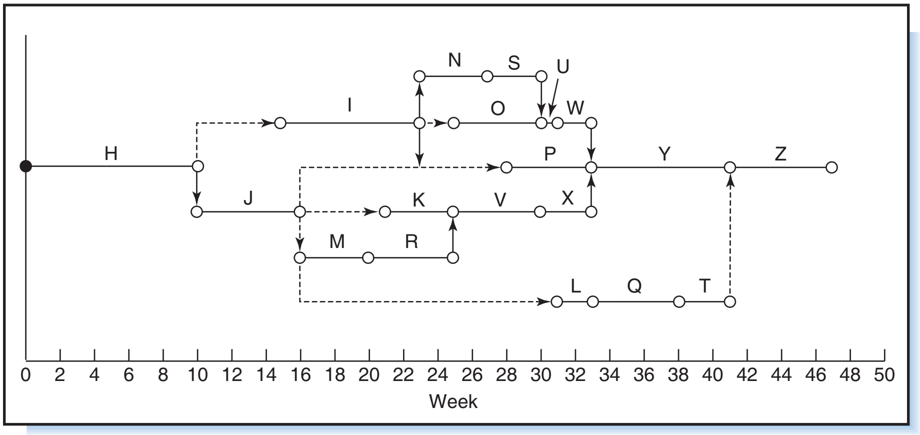


Figure 9.16
Time-based network for the LOGON project using late start times.

Given the early and late cost figures in Table 9.5 the effects of delaying activities on project costs can be analyzed. By comparing weekly costs based on early start times with those from late start times, shown in Figure 9.17, the influence of schedule changes on project costs is readily apparent. The shaded region in the top part of the figure—the *feasible budget region*, which is based on the early and late cumulative expenses—shows the range of budgets permissible by changes in the project schedule. The lower part of the figure shows the impact on weekly costs from delaying activities.

See Chapter 7

When funding restrictions constrain project expenditures, cost schedules reveal places where the schedule must be changed. For example, Figure 9.17 shows a peak weekly expense of $82,000 in weeks 18 and 19. If a weekly budget ceiling of $60,000 per week were imposed on the project, then late start times would be preferred because they result in a more "level" cost profile and peak expense of only $54,000 in weeks 32–33. The method for leveling resources discussed in Chapter 7 is applicable to leveling project costs, where costs are treated simply as just another resource.

Effect of late start time on project net worth

Owing to the time value of money, the net present worth of work done farther in the future is lower than the same work if done earlier. Thus, delaying work in a lengthy project can provide savings in the present worth of project costs. For example, suppose the expected duration of the LOGON project is 47 *months* (rather than 47 weeks as assumed previously). If the annual interest rate is 24 percent, compounded at 2 percent per month, the present worth for the project would be $649,276. This is computed by using the monthly expenses in Table 9.5, column 3 (again, assuming the "weekly" shown to be monthly instead) and discounting them back to time zero. Now, when the late start times and the corresponding numbers in column 6 are used instead, the present worth is only $605,915—a savings of $43,361.

Does this mean that activities should be delayed until their late start dates? Not necessarily. Remember, delaying activities consumes slack time and leaves less time to deal with problems that could delay the project. Thus, whether to delay work should also depend on the *certainty of the work*. Activities that are unlikely to encounter problems can be started later to take advantage of the time value of money. Activities that are less familiar, such as research and development work, should be started earlier to retain slack that might be needed to absorb unanticipated delays. This assumes the critical path method; CCPM uses resource buffers, which preclude the need for slack. Also, whether to delay work should depend on

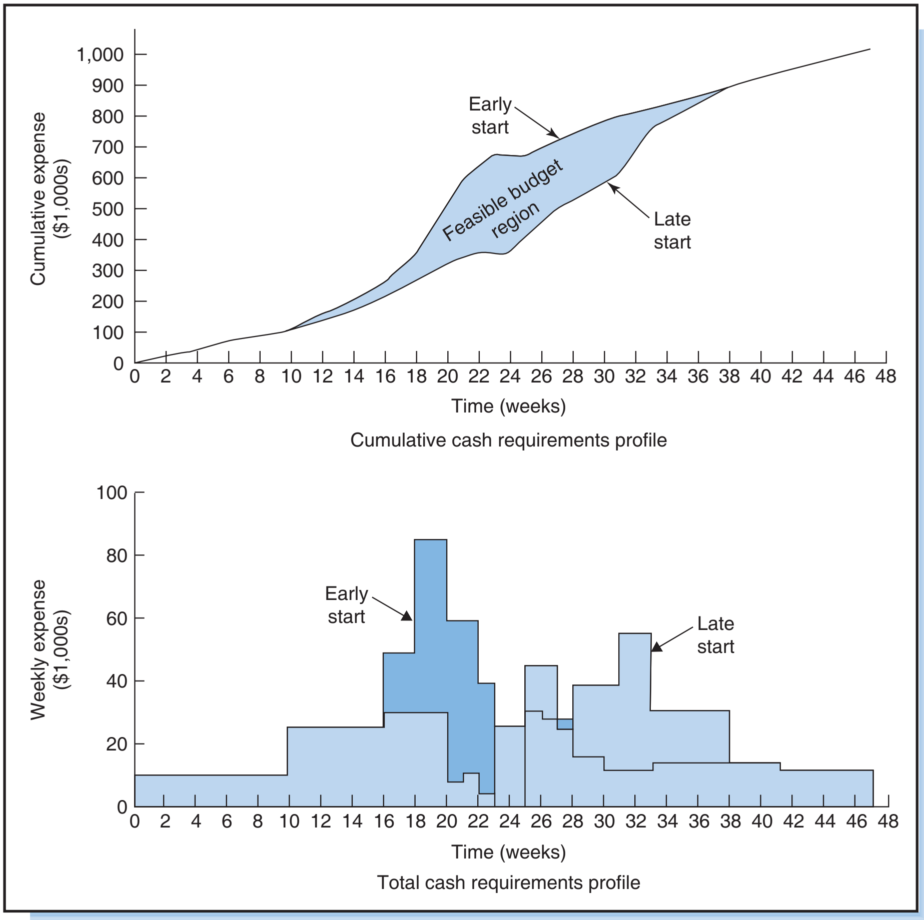


Figure 9.17
Comparison of expenses, early versus late start times.

the schedule of customer payments. If payments are tied to project milestones and impact cash flow, then work tied to those milestones should not be delayed.

Cash flow

A problem project managers often face is maintaining positive cash flow, that is, ensuring that the cumulative cash inflows (payments received) exceed the cumulative cash outflows (payments made). Ideally, differences between cash in and cash out throughout the project will be small.[15] The project manager must do a juggling act, balancing income from the customer (such as milestone payments) or other funding sources with expense payments for labor, subcontractors, materials, and equipment. To help maintain this balance, the manager can, for example, take advantage of the time lag between when materials and equipment are acquired and when payments for them must be made.

Figure 9.18 shows an example of forecasted cash flow. All contractually agreed-to sources of income over the life of the project are compared to all foreseeable expenditures, direct and indirect, as well as

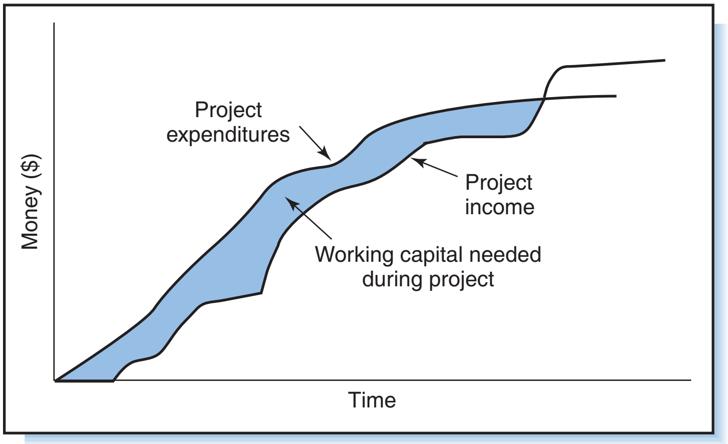


Figure 9.18
Balancing project income and expenditures.

any penalty costs or scheduled payments—should the project be completed late. The deficit between forecasted income and estimated expenditures represents the amount of *working capital* needed to meet payments for expenditures. Based upon this forecast, a *funding plan* should be created to ensure sufficient working capital will be available throughout the project.

As mentioned, customer payments are sometimes made at milestones tied to completion of deliverables or project phases. Such payments help the contractor to cover its costs. The drawback, however, is that, should the project encounter serious problems, an unscrupulous contractor, having already received several payments, can simply walk away from the job and leave the customer in a fix! One way the customer can keep "hold" on the contractor is to withhold a significant portion of the agreed-upon payment, called *retention money*, until all work is satisfactorily completed. Another way is to withhold a portion of the final payment, called a *performance guarantee*, for a period following handover of the end-item until all defects discovered by the customer have been rectified.

9.10 Life-cycle costs

Life-cycle costs represent all the costs of a system, facility, or product throughout its life, cradle to grave. The concept originated in military procurement when managers realized that costs to develop and implement a system represent but the tip of the cost iceberg and that the costs to operate (e.g. fuel consumption) and maintain (e.g. parts replacement) it are usually far greater. Whereas the emphasis in this chapter has been on *project costs*, that is, costs incurred during the *project* phases of definition and execution, LCC include costs *after the project* and for the remainder of the system life cycle—the operation phase and eventual disposal of the end-item (and, occasionally, the conception phase, too).

Anticipating the LCC is necessary because it influences many decisions. For example, suppose three contractors submit proposals to build a plant, and each proposal contains not only the plant's construction cost but also its expected operating costs. If the bids are similar in terms of plant features and construction costs, the proposal with the lowest plant operating costs will likely win.

See Chapter 3

The LCC similarly affect decisions regarding development projects, and the economic analysis in feasibility studies (Chapter 3) should consider *all costs* for acquisition, operation, maintenance, and disposal of the systems to be developed. For example, most US aerospace manufacturers in the 1970s were hesitant to develop a supersonic commercial aircraft because of cost and environmental impact concerns. Costs to develop and produce the aircraft were projected to be very high, as were costs for operation and maintenance. Among the concerns were whether enough people would pay the high ticket prices necessary for the airlines to make a profit and whether enough airlines would purchase the aircraft for the manufacturers to make a profit. Ultimately, many felt the answer was no on both counts. In the United States, Congress cancelled subsidies to the companies developing the aircraft, and the program was dissolved. Meantime, the Europeans decided differently and went on to develop and manufacture the Concorde, only 14 of which went into service. Although Concordes flew for nearly 27 years (the last one was retired in 2003), the LCC were never recouped. No one made a profit, and had the governments of Great Britain and France not provided subsidies, the airlines and manufacturers would all have lost money.

Key design decisions affecting the operation and maintenance of a system are made early in the project life cycle—during conception and definition. A product with a high development cost and purchase price becomes appealing only if it can be designed to have a relatively low operating cost. For example, a more fuel-efficient vehicle might be higher priced than less efficient vehicles, but customers readily pay the premium knowing that over the vehicle's life, they will recoup it through fuel savings and lower pollution. Of course, estimating LCC involves making assumptions about the technology, market, and product demand and relies on historical costs of similar systems and projects; still, it is a sensible way to assess projects, especially when there is a choice between alternative designs or proposals.

The LCC should also account for the time necessary to develop, build, and install the end-item, that is, the time *before* the facility or system becomes operational or the product is "launched" to market. Time is important: it determines how soon the end-item will start generating revenues, gaining market share, and accruing profits or other benefits. The higher costs of speeding up the project are compared to the benefits gained from an earlier completion or product launch. Similarly, the *cost of disposal* at the end of the life cycle is also estimated; for facilities such as mines and nuclear power plants that require a formal shut-down and rehabilitation process after their useful lives, this cost can be substantial.

Analysis of LCC is also necessary for setting targets on development and operating costs and making design tradeoff decisions to achieve those targets. Following is an example:

Example 9.7: Life-Cycle Costs for an Operational Fleet of Spaceships

This illustration extends previous SpaceShipOne examples, but the numbers are purely hypothetical (and certainly too low). Having gained experience from SpaceShipOne, a larger spaceship and mothership are to be designed. The new spaceship will carry a pilot plus four paying passengers, go as high as 120 km, and be capable of 20 flights per year over an operational life of 5 years. The cost of developing and producing four of these spaceships and two motherships is estimated at $80 million. Meantime, a survey indicates that the number of people worldwide willing to pay the $190,000 ticket price to fly on these spaceships is at least 1,000 per year.

A "spaceline" that will use and maintain the spaceships is being created for a startup cost of $10 million. Operational costs for the spaceline consist of two parts: annual costs for ground operations (reservations, personnel, ground facilities, etc.)—$2 million/year; and per-flight costs for flight operations (fuel, parts, repairs, etc. for the spaceship and the mothership)—$0.4 million/flight. These costs are assumed constant for every year and flight, although realistically, they would vary up or down depending on inflation, the learning curve, efficiencies, and economies of scale as more spaceships are added to the fleet. Annual revenues are assumed constant, too, though they will likely grow as additional spaceships are made operational. Given these costs and ignoring other factors (e.g. time value of money), what is the LCC for the venture?

Assumptions

Four spaceships @ 20 flights/year each = 80 flights/year (320 passengers/year, which lies well within the estimated annual demand); 5 years of operation.

Costs

Development and manufacturing: $80 million
Spaceline startup: $10 million
Ground operations: $2 million/year
Flight operations: $0.4 million/flight
Ticket price: $190,000 (marketing slogan: "Now YOU can go to space for under $200,000!")

LCC Model

LCC ($ million) = Development and production cost + Startup cost + Operating cost (5 years)
= $80 + $10 + {[5 yr × $2] + [5 yr × 80 flights × $0.4]} = $260 million
Total revenues ($ million) = (5 yr × 80 flights × 4 passengers × $0.190) = $304 million.

Bottom line: Assuming the assumptions are correct, revenues will exceed costs by $44 million.

All the numbers are estimates, but some are more certain than others. For example, based upon experience with SpaceShipOne, the development cost might be fairly certain, but due to lack of long-term operational experience the per-flight cost is fairly uncertain. Startup and ground operations costs, if analogous to airline operations (a big *if*), might be somewhat certain, although passenger demand might be fairly uncertain.

The LCC plays an important role in system design and development. The LCC can be modeled and a sensitivity analysis of the model performed to see what happens if costs increase or decrease to show best case, most likely, and worst case scenarios. The model can be used to determine by how much and in what combination the costs must vary for the enterprise to become lucrative (or disastrous).

The LCC model can also be used to set cost targets. If the decision is made to proceed with the $80 million development and production cost, then the project must be planned, budgeted, and controlled so as stay close to that amount. If the per-flight cost is set at $0.4 million, the project must strive to develop vehicles that will cost no more than that to operate. This will affect innumerable design decisions pertaining to many details. Early on, the design analysis must consider major alternatives (e.g. to carry five or six passengers, not four) and the expected costs, revenues, and benefits for each.

See Chapter 15

The best and only truly comprehensive approach to estimating and analyzing LCC is with a team composed of people that represents all phases of the system development cycle—a cross-functional team of designers, builders, suppliers, and users, that is, a *concurrent engineering team*, as discussed in Chapter 15.

Impact of early decisions on life-cycle costs

The importance of carefully defining requirements and the end-item system and preparing the project plan—in other words, devoting careful attention to decisions made in Phases A and B of the project—is illustrated in Figure 9.19, which shows the percent of life-cycle costs *committed to* versus stages of the project. For example, the figure shows that as much as 80 to 90 percent of a product's LCC is determined by decisions made in the project's concept and design stages (coinciding with Phases A and B), which is well before the product will be produced and used. This means that whatever the total product

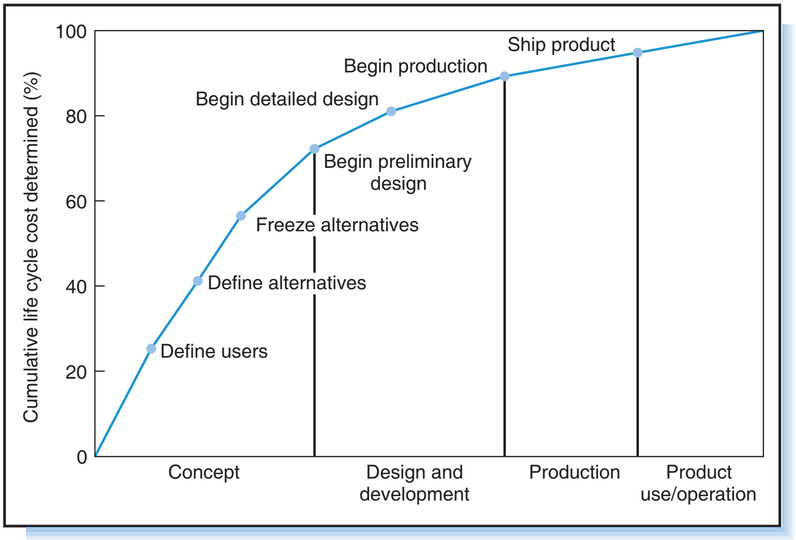


Figure 9.19
Percent of cumulative life-cycle cost set during stages of the systems development life cycle.

LCC, 80–90 percent of it is based upon choices made in those two stages of the project.[16] Unless those decisions correctly account for what will happen later during production and operation, the result will be a protracted systems development effort, delayed launch of the product, and higher than necessary production and operating costs.

9.11 Summary

Cost estimation and budgeting are part of the project planning process. Cost estimation logically follows work breakdown and precedes project budgeting. Accurate cost estimates are necessary to establish realistic budgets and to provide standards against which to measure actual costs; they are thus crucial to the financial success of the project.

Costs in projects have a tendency to escalate over time. Defining clear requirements and work tasks, employing skilled estimators, being realistic in estimating, and anticipating escalation causes such as inflation all help to minimize escalation.

Estimate accuracy is partly a function of the stage in the project life cycle during which the estimates are prepared; the further along in the cycle, the easier it is to produce accurate estimates. However, good estimates are needed early in the project, and accuracy can be improved by clearly defining project scope and objectives and subdividing the project into small tasks and work packages. In general, the smaller the work element being estimated and the more standardized the work, the greater the accuracy of the estimate. The aggregate of cost estimates for all the work elements plus overhead costs becomes the cost estimate for the overall project.

The approved estimates become budgets after contingency reserves have been added. The project budget is subdivided into smaller budgets called control accounts. Control accounts are derived from the WBS and project organization hierarchies and are the budget equivalent to work packages. In large projects, a project cost accounting system is useful for aggregating estimates and maintaining a system of control accounts for budgeting and control.

Cost schedules are derived from time-phased budgets and show the pattern of costs and expenditures throughout the project. They are used to identify cash and working capital requirements for labor, materials, and equipment.

Forecasted project expenditures and other cash outflows are compared to schedule payment receipts and income sources to predict cash flow throughout the project. Ideally, expenditures and income are balanced so that the contractor can maintain a positive cash flow. The forecasts are used to prepare a plan that guarantees adequate funding support for the project.

Review Questions and Problems

1. Why are accurate cost estimates so important, yet so difficult, in project planning? What are the implications and consequences of overestimating costs? Of underestimating costs?
2. Define cost escalation. What are major sources of cost escalation?
3. What is the purpose of a contingency fund (management reserve)? How is the contingency fund used and controlled?
4. Describe what the term "phased (rolling wave) project planning" means.
5. How do changes in requirements cause cost escalation?
6. How does the type of contractual agreement influence the potential for cost escalation?
7. What is the relationship between phases of the project life cycle and cost escalation?
8. What are life-cycle costs, and how are they different from project costs?
9. Explain the difference between a cost estimate and a cost target. What are the problems in confusing the two—in using cost targets as cost estimates?
10. Explain the difference between accuracy and precision. Give two examples that illustrate the difference.
11. For each of the following estimating methods, briefly describe the method, when it is used, and the estimate accuracy it provides:
    a. expert opinion
    b. analogy
    c. parametric
    d. cost engineering.
12. Describe the process of using the WBS to develop cost estimates. Discuss "top-down" versus "bottom-up" estimating. How are work package estimates aggregated into total project cost estimates?
13. What is the role of the functional units and subcontractors in cost estimating?
14. Describe the different kinds of contingency amounts and the purposes each serves.
15. Describe the PCAS. What is its purpose and how is it used in project planning?
16. What is a time-phased budget? What is the difference between a budget and a cost estimate?
17. Distinguish recurring costs from nonrecurring costs.
18. What are six cost elements shared by most estimates and budgets?
19. How are direct labor expenses determined?
20. What expenses are included under direct non-labor?
21. How is the overhead rate determined?
22. What is a control account, and what kinds of information does it contain? How does a control account fit into the structure of the PCAS?
23. How are control accounts aggregated horizontally and vertically? Why are they aggregated like this?
24. How are time-based forecasts prepared and how are they used?
25. What are the reasons for investigating the influence of schedules on project costs? What is the feasible budget region?

26. What might happen if top management submitted a bid for a project without consulting the business unit or department to be involved in the project?
27. Refer to Case 6.1, the Barrage Construction Company, in Chapter 6. The project manager Sean Shawn employed the analogy with adjustment method to estimate the cost of constructing a three-car garage. Specifically, he started with the cost of an average two-car garage, $43,000, and increased it by 50 percent to $64,500. Comment on the likely accuracy of the three-car garage estimate. Suggest a different approach that might yield a more accurate cost estimate, and then use this approach and made-up time and cost figures to compute the estimate. Argue why your estimate is better than Sean's. See Chapter 6, Figure 6.19, for Sean's WBS.

See Chapter 6

28. The example in Table 9.2 shows three possible ways of apportioning total direct costs. Using the same example, suppose the direct non-labor cost and G&A are broken down as follows:

	Direct Non-Labor			
	MARS	PLUTO		G&A
Materials	30	5	Freight	8
Other	10	5	Other	32
	40	10		40

Assuming all remaining costs shown in Table 9.2 are unchanged, compute the project costs for MARS and PLUTO using the following apportioning rules:

a. Overhead (OH) is proportionate to direct labor (DL).
b. Freight G&A is proportionate to materials.
c. Other G&A is proportionate to DL, OH, DNL, and freight.

29. Chapter 8 discussed the impact of crashing activities and the relationship of schedules to cost. The CPM method assumes that as activity duration is decreased, the direct cost increases owing to the increases in direct labor rates from overtime. Overhead rates also may vary, although the overhead rate is often *lower* for overtime work. For example, the overhead rate may be 100 percent for regular time but only 20 percent for overtime. In both cases, the overhead rate is associated with the wage rate being used.

See Chapter 8

Suppose that in the MARS project in Table 9.2, 1,000 direct hours of labor are required at $50 per hour, and the associated overhead rate is 100 percent for regular time. Now suppose the overhead rate is 10 percent and overtime wage rate is time-and-a-half. Compare the project cost if it were done entirely on regular time with the cost if it were done entirely on overtime. Which is less expensive?

30. Use the following table and the network in Figure 9.20 to answer questions about the ARGOT project:

Activity	Time (Wks)	Weekly Cost ($K)	Total ($K)
A	4	3	12
B	6	4	24
C	3	5	15
D	4	5	20
E	8	3	24
F	3	4	12
G	2	2	4
			111

a. Compute the ESs and LSs for the project. Assume T_s is the same as the earliest project completion date.
b. Construct a time-based network for the project such as Figure 9.14 (use early start times).
c. Construct two diagrams similar to those in Figure 9.15 showing the weekly and cumulative project expenses.

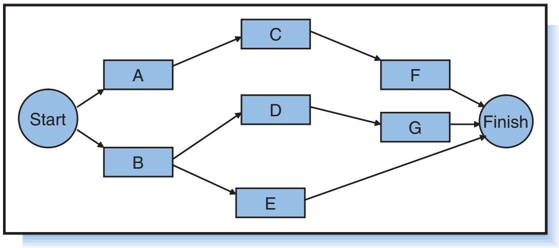


Figure 9.20
ARGOT project network.

31. Using the data in problem 30, repeat steps b and c using late start times. Then identify the feasible budget region using the cumulative curves.
32. Explain retention money and performance guarantee.

Questions About the Study Project

1. How were project costs estimated? Who was involved? Describe the process.
2. When did estimating take place? How were estimates checked and accumulated? How were they related to the WBS?
3. What, if any, were the principal causes of cost escalation in the project?
4. Was a life-cycle cost analysis performed? If so, who did it, when, and using what methods? How did the analysis affect the design, development, and production of the project deliverables or main end-item?
5. How often and when were cost estimates revised during the project?
6. How were overhead costs determined? What basis was used for establishing overhead cost rates?
7. How were estimates tallied to arrive at a total project cost estimate? Who did this?
8. What kind of project cost accounting system was used? Was it manual or computerized? Describe the system and its inputs and outputs. Who maintained the system? How was it used during the project?
9. Describe the process of creating the project budget. Show a sample budget (or portion thereof).
10. How were management and supervisory costs handled in the budget?
11. Was the project budget broken down into control accounts? If so,
    a. How were they related to the work packages and WBS?
    b. How were they tied into the PCAS?
12. What kinds of costs summaries were prepared? Who were they sent to? How were they used? Show some examples.
13. Did the PCAS produce time-phased cost schedules and forecasts? Show some examples. How were they used by the project manager?
14. Were life-cycle costs a consideration in the project? Explain.

CASE 9.1 LIFE-CYCLE COSTS FOR FLEET OF TOURIST SPACESHIPS

At the time of writing, Burt Rutan and Sir Richard Branson had teamed up to form The Spaceship Company, which will develop and manufacture commercial spacecraft (SpaceShipTwo, or SS2), launch aircraft (WhiteKnightTwo, or WK2), and support equipment. Branson's "spaceline," Virgin Galactic, will handle the operations for space tourist flights. Their hope is to eventually reduce by half the proposed initial ticket price of $190,000.

No information has been released about development and operating costs for the spaceline and equipment, so the figures used in this case are guesses. Refer to Example 9.7 for *hypothetical* life-cycle costs for the spaceline and spaceship fleet but assume the following changes to the numbers:

- Five spaceships, seven passengers per spaceship.
- Development and manufacturing costs, $120 million.
- Flight operations cost: $0.5 million/flight.
- Ticket price: $190,000 for passengers on the first 100 flights, then $150,000 for passengers on the next 100, and $100,000 for passengers on flights thereafter.

QUESTIONS

1. Assuming all other numbers from Example 9.7 are the same, what is the "bottom line" profit of the venture for 5 years of operation?
2. If the profit goal is $70 million,
   a. What is the maximum development and production cost for the fleet?
   b. What is the maximum per-flight operational cost (note: assume $120 million development/production cost)?
3. Brainstorm. What are some ways that the development cost might be reduced? What are some possible design decisions for the spacecraft and mothership that would reduce the per flight operational cost? Next, research articles and news releases about SS2 and WK2 to see what the developers, Scaled Composites and The Spaceship Company, have been doing to contain costs.

CASE 9.2 ESTIMATED COSTS FOR THE CHUNNEL PROJECT[17]

Before construction began on the English Channel Tunnel (Chunnel) Project, the banks underwriting the project hired consulting engineers to review cost estimates prepared by the contractors. The consultants concluded that the tunneling estimates were 20 percent too high. Their analysis was based on comparisons of costs from recent European tunnel projects, including 50 German railroad tunnels ranging in length from 400 m to 11 km, to the Chunnel, which would be 49 km in length. The costs of the tunnels ranged from £55 to £140 per cum (cubic meter) of open tunnel; the cost of the Chunnel was estimated at £181 per cum on the British side of the channel and £203 on the French side (the difference owing to more difficult conditions on the French side). The Chunnel is actually three interconnected tunnels—one for trains going in each direction and a smaller service tunnel in between them. Note, however, that the cost estimates are per cubic meter of tunnel, so *presumably*, differences in tunnel lengths and diameters are not major factors. Why might the estimates for the Chunnel be so much higher per cum than the costs for the analogy projects? Discuss possible, logical adjustments to the analogy tunnel project costs to arrive at a cost estimate for the Chunnel.

CASE 9.3 FIONA’S ESTIMATE FOR THE GORGY PROJECT

Fiona McDonald is preparing the cost estimate to accompany Highwire Systems’ bid proposal for the Gorgy Project. Her ballpark guess is that the project should take about 2 years and cost $3 million; however, to help prepare the estimate, she creates a WBS (Figure 9.21).

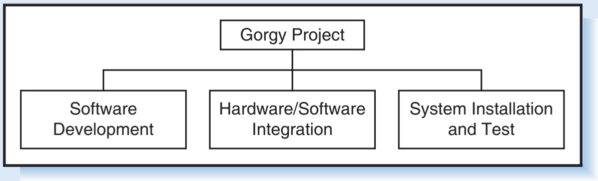


Figure 9.21
Gorgy Project.

She estimates the costs for the three work packages as follows:

Development	$2 million
Integration	$1 million
Installation/Test	$1.5 million
Project	$4.5 million

Although the total estimate is 50 percent more than her ballpark guess, she believes it is probably more accurate because it was developed “bottom up.”

She gives the estimate to Shireen Ghophal, Highwire Systems’ manager of contracts, who asks her, “Fiona, how did you arrive at the individual costs for the $4.5 million?” Fiona explains, “The development cost, $2 million, that was simple: I based it on the number provided in the RFP for what the development portion of the project should cost based on the customer’s experience from working with developers in similar projects. Besides, the number seemed ample to me, and since it was the only cost figure provided in the RFP, I considered it as sort of a mandate for the maximum development cost. As far as the integration cost, well, I looked at the customer’s hardware and software we’d be working with as listed in the RFP, and I compared it with the other projects we’d done with similar equipment and systems and what those projects cost. Finally, for installation and test, I reviewed six projects I’d completed in the last few years and their costs. Costs for installation and test ranged from $0.6 to $2 million, with $1.3 million average. So $1.5 seemed reasonable.”

Shireen replies, “Well, I ordinarily don’t question your work. But are you sure you’ve covered everything in the project in the work breakdown? Do the three work packages include *everything*? And don’t we usually do a site visit to inventory the customer’s equipment and systems that we’ll have to work with? Do you trust the RFP? Do they really know what they have? And looking at the project, it’ll take maybe 2 to 3 years. It’ll be a big project. Are you sure you and your staff will be able to manage and coordinate everything for that cost?”

Fiona responds, “Everything is covered. As far as the site visit is concerned, the proposal is due next week and we don’t have time. We’ll have to go with what they say in the RFP. As for installation, based on my experience, the average installation/test cost was $1.3 million. I picked $1.5 million to be safe and cover any overages in development cost.”

Then Shireen repeats, “And what about the coordination and integration effort?” to which Fiona replies, “Yes, that will probably be huge, but I’m pretty certain that if we get the contract, Highwire will let me hire maybe ten additional experienced analysts/engineers for my management staff. As you know, we’ve run over on our last several projects and I’ve been arguing all along I just need more people to help coordinate and keep things under control.”

Shireen suspects that Fiona’s cost estimation approach is rather simplistic and leaves ample room for error. List at least four inadequacies in her approach and places where the estimates can go wrong.

CASE 9.4 MELBOURNE CONSTRUCTION COMPANY, D

Bill Asher, the estimator for Melbourne Construction Company, is currently estimating the days required to install the wall footings in the foundation of a hotel building. As is common for many of the activities in construction projects, he will develop the estimate using labor productivity standards.

Architectural drawings for the hotel indicate that the square foot contact area (SFCA) for the formwork footings is 13,340 sq. ft. (1,239 m^2). Installation of footings is considered "standard," so Bill refers to a manual of labor hour standards to estimate the total labor hours required for the task. The manual indicates that for the footings specified for the hotel, the standard is 0.066 labor hours per SFCA.[18]

1. Given the SCFA standard and the estimated SCFA for the footings, what is the estimated labor hours to install the footings?
2. The company intends to assign ten workers to install the footings. Assuming an 8-hour workday, what is Bill's estimate for the number of days needed to complete this task? (Note: an assumption here is that for each additional worker assigned to a task, the task duration decreases proportionately. This is an important assumption, since in many projects the task durations are not proportionate to the number of workers. Adding workers will not necessarily shorten task times and might even increase them.)

Notes

1. Flyvbjerg B., Bruzelius N. and Rothengatter W. *Megaprojects and Risk: An Anatomy of Ambition*. Cambridge: Cambridge University Press; 2003, p. 16.
2. See Archibald R.D. *Managing High-Technology Programs and Projects*. New York, NY: John Wiley & Sons; 1976, pp. 167–168.
3. Harrison F. *Advanced Project Management*. Hants, England: Gower; 1981, pp. 172–173, gives an example of an escalation clause.
4. Politically, how independent should the estimators be? So independent, says DeMarco, that the project manager has "no communication with the estimator about how happy or unhappy anyone is about the estimate." DeMarco T. *Controlling Software Projects*. New York, NY: Yourdon Press; 1982, p. 19.
5. Flyvbjerg, Bruzelius and Rothengatter. *Megaprojects and Risk: An Anatomy of Ambition*.
6. Harrison. *Advanced Project Management*, pp. 154–161.
7. Dingle J. *Project Management: Orientation for Decision Makers*. London: Arnold and John Wiley & Sons; 1997, p. 105.
8. Pool R. *Beyond Engineering: How Society Shapes Technology*. New York, NY: Oxford University Press; 1997; Heppenheimer T.A. Nuclear power. *Invention and Technology* 18(2); Fall 2002: 46–56.
9. A complete discussion of the cost review procedure is given by Kerzner H. *Project Management: A Systems Approach to Planning, Scheduling, and Controlling*, 10th edn. New York, NY: Van Nostrand Reinhold; 2009, pp. 592–595.
10. See ibid., Chapter 14, for discussion of labor costing in projects.
11. This example is derived from a similar one in Rosenau M. *Successful Project Management*. Belmont, CA: Lifetime Learning; 1981, pp. 89–91.
12. This example is derived from Wilson T. and Stone D. Project management for an architectural firm. *Management Accounting*; October 1980: 25–46.
13. The kinds of cost summaries used often depend on the kind available in the software, though many software packages permit customizing of reports.
14. Wiest J. and Levy F. *A Management Guide to PERT/CPM,* 2nd edn. Upper Saddle River, NJ: Prentice Hall; 1977, pp. 90–94.

15. Harrison. *Advanced Project Management*, p. 185, notes that balancing cash in foreign contracts is difficult because "In many cases, the profits from [currency dealings] can exceed the profits from the project; [if funds are] not managed effectively, the losses from foreign currency commitments can bring about large losses on a project and lead to bankruptcy."
16. Smith P. and Reinertsen D. *Developing Products in Half the Time*. New York: Van Nostrand Reinhold; 1991, pp. 224–225.
17. Fetherston D. *The Chunnel*. New York, NY: Times Books; 1997, pp. 141–142.
18. *RS Means Labor Rates for the Construction Industry*, 41st edn. Norwell, MA: RS Means; 2013.

Chapter 10

Project quality management

I have offended God and mankind because my work didn't reach the quality it should have.

—Leonardo da Vinci

Besides meeting the budget and schedule, project success depends on how well a project meets performance requirements. Performance requirements generally are based upon project stakeholders' needs and expectations about the functioning and performance of the project end-item or deliverables. A "high-quality" project is one that meets performance requirements, satisfies the needs and expectations of all key stakeholders, and causes no harm elsewhere.

10.1 The concept of quality

In the 1950s, *quality* was viewed as the process of inspecting products that had already been produced and separating the good ones from the bad. But in the current business environment, so the thinking goes, you have to *prevent* defects and failures rather than inspect for them; that is, you cannot right a wrong by inspection. You have to build in *processes* to ensure things are done right the first time, every time, and a culture where everybody is quality focused.

But in the competitive pursuit, project teams often seek ways to accelerate schedules and cut costs, even though this sometimes results in rework, mistakes, greater workload for the project team, and a "quality meltdown." They become preoccupied with lowering costs and shortening schedules, even though "the bitterness of poor quality lives long after the sweetness of cheap price and timely delivery has been forgotten."[1]

An example is the space shuttle Challenger. On January 28, 1986, defective seals allowed flames to breach a joint in a rocket motor and ignite the main fuel tank shortly after launch, causing an explosion and killing the seven astronauts onboard. While engineers had previously warned about the risk of this happening, the launch proceeded as scheduled because of a promise to politicians; for the sake of meeting a schedule, quality was compromised.

The London Tower Bridge, Figure 10.1, offers a contrast.[2] It opened in 1894, 4 years late and costing nearly twice the estimated £585,000. But more than a century later, it has withstood the test of time. Originally designed and built to enable pedestrians and horse-drawn vehicles to cross the Thames River, it now carries 10,000 vehicles per day and is a major tourist attraction. It has survived floods and

Figure 10.1
London Tower Bridge.
Source: iStock.

pollution—problems its original designers never considered. In terms of time and cost, the project was a failure; in terms of quality, it has been a raving success.

What is quality?

Quality is meeting specifications or requirements—but it means more than that. While meeting project specifications will usually prevent a customer from taking a contractor to court, it alone cannot ensure the customer will be pleased or even satisfied with the end result or the contractor will receive gratitude, win repeat business or make a profit.

Ideally, a project aims *beyond* specifications and tries to fulfill customer expectations—including those not articulated; it aims at delighting the customer. Project managers sometimes assume, wrongly, that customer needs, expectations, and requirements are readily evident or will require little effort to research and specify.

Fitness for purpose

The term *quality* implies that a product or deliverable is *fit for the intended purpose*; this can involve a wide range of criteria such as performance, safety, reliability, ease of handling, maintainability, logistical support, and no harmful environmental impacts. Beyond fitness, however, the customer will also consider a product's *value for money* and whether it is priced right for the intended purpose. Optimizing only one aspect of a product—fitness for purpose, value for money, or strategic benefit to the organization—will not necessarily result in an optimal product. The project manager must seek to balance the multiple aspects of a product and define specifications to reflect that balance.

Absence of defects

Quality also implies an absence of defects, which is why people often associate the terms *quality* and *defect*. A defect is a *nonconformity*—a problem or mistake—something other than what the customer had expected. One way to achieve quality is to identify and correct as many nonconformities as possible—and to identify them as soon as possible. In general, the longer a nonconformity persists before it is discovered, the more costly it is to remedy or remove it. It might be relatively easy and inexpensive to fix a defect in a component part, but it is usually more expensive to fix it after the component has been put into an assembly, and even more expensive after the assembly has been imbedded inside a system. A defect is most expensive when it causes a product or system malfunction or failure while in use by the customer.

But "absence of defects" requires qualification, and the presumption that zero defects equates to high quality is not always true. A quality project is one that satisfies multiple requirements, and devoting too much attention to any particular one, such as eliminating *all* defects, may detract from fulfilling other more important requirements.[3] For example, in most projects, the requirements relate to time, cost, and performance. When the schedule must be maintained, trying to remove *all* defects can prove exceptionally costly. The customer might prefer to keep to the budget and schedule rather than eliminate all defects. Of course, in some cases, it is necessary to try to eliminate every defect.[4] Even the most minor defect in a critical component of an air traffic control system or artificial human heart can result in injury or loss of life. The point is, it depends on the customer. Often the customer prefers a deliverable to be completed on time, at lower cost, and with a *few* minor defects than completed late, at higher cost, but with no defects.

Good enough quality

In removing defects, emphasis is on those that would prevent the system from meeting its most important requirements. This is the concept of "good-enough quality"—the default criteria when priorities on performance requirements, time, and cost preclude meeting all the requirements and force the project team into meeting only the most important ones. Says Bach, creating systems "of the best possible quality is a very, very expensive proposition, [though] clients may not even notice the difference between the best possible quality and pretty good quality."[5] The customer, of course, must be able to judge what is "good enough," and to do that must be constantly updated about project progress, problems, costs, and schedules.

In the ideal case, everyone on the project team contributes to quality; each:

1. Knows what is expected of her
2. Is able and willing to meet those expectations
3. Knows the extent to which she meets the expectations
4. Has the ability and authority to take necessary corrective actions.

Such conditions require quality-focused leadership, training, and motivation efforts. Once everyone starts contributing, however, attention to quality should become automatic and require little influence from the project manager.

What quality is *not*

Quality implies that the product is fit for the purpose. But fit for purpose does not necessarily relate to the product's expense, reliability, or features, all of which refer to the product's *grade*. In other words, *quality* and *grade* are not the same. For example, coal mines produce different grades of coal. The highest grade is used in steelmaking, while lower grades are used in chemical products and power plants. Even though coal for a power plant is lower grade than that for steelmaking, it is the appropriate—hence best-quality—coal for the purpose; it would be inappropriate and uneconomical to use higher-grade coal in power plants. Of course, companies that mine the coal should strive for *high-quality processes* to deliver all grades of coal to meet the specifications of all their customers, including price and delivery specifications.

Quality movements and progress

The "quality revolution" started in the 1950s in Japan, in part under the influence of Dr. W. Edwards Deming, an American consultant. He proposed a quality philosophy that included continuous improvement, skills training and leadership at all levels, elimination of dependency on inspections, reliance on single-source rather than many-source suppliers, and use of statistical techniques. Since then, a number of other quality movements have come and gone—some that could be described as fads. The most lasting and popular movement since the 1980s is *total quality management* (TQM). TQM is a set of techniques and more—it is a mindset, an ambitious approach to improving the total effectiveness and competitiveness of an organization. The key elements of TQM are identifying the mission, goals, and objectives of the organization; acting in ways consistent with those goals and objectives; and focusing on customer satisfaction. TQM involves the total organization, including teams of frontline workers and visible support from top management. Quality problems are systematically identified and resolved to continuously improve processes. In projects, this purpose is served by project reviews and closeout sessions, discussed in this and later chapters.

Complementing TQM is the management philosophy of *lean production* (LP). LP gives recognition to the fact that quality problems typically originate from "broken processes," and it provides methods and tools to analyze processes and expose and eliminate sources of waste in processes. It includes relatively easy-to-implement methods to improve quality and reduce costs and lead times.[6] The most difficult aspect of implementing LP is developing a culture wherein employees everywhere have the authority and skills to continuously improve their processes—an unusual concept for many organizations. Principles of LP originated at Toyota and have been successfully adopted around the world. In some industries (e.g. autos and electronics), virtually all the big players have adopted lean production. In project environments, LP methods are being applied to product development and construction. Some of these methods are described in Chapter 14.

See Chapter 14

Another quality movement called *Six Sigma* originated in the 1980s at Motorola and was later popularized by General Electric. The term "Six Sigma" refers to the fact that in a normal distribution, 99.99966 percent of the population falls within -6σ to $+6\sigma$ of the mean, where "σ" is the standard deviation. If the quality of a process is controlled to the 6σ standard, there would be less than 3.4 *parts per million* defects in the process—near perfection!

But the Six Sigma movement goes beyond statistics and is a philosophy for reducing process variability. It includes two five-step processes, one for improving existing processes and another for designing new processes and products, both aimed at 6σ quality levels. The first process, called *DMAIC*, for define, measure, analyze, improve, and control, involves the steps of defining the best actions to improve a process, implementing those actions, tracking the results, and reducing defects so that fewer outcomes fail to meet specifications. The second process is called *DMADV*—define, measure, analyze, design, and verify. In projects, the Six Sigma approach translates into defining clear deliverables that relate to the mission of the organization and are approved by management. In some companies, the DMAIC process is the project methodology and defines the stages of the project.

Project quality management

Project quality means quality of the project end-item, deliverable, or product. Quality of the end-item or product starts with clearly defined system requirements or specifications agreed upon by both contractor and customer. If the contractor feels the customer has provided requirements that are unrealistic, he should review them with the customer and alter them so the desired end result can be achieved realistically. The agreed-upon specifications should reflect the customer's expectations for the product's fitness for the intended purpose and any negotiated compromises. Comprehensive specifications for the deliverable should be included in the project scope definition.

Project quality management includes management processes as well as techniques to reduce the risk that products or deliverables will not meet requirements. The following sections discuss these processes and techniques.

10.2 Project quality management processes

Project quality management has three processes: quality planning, quality assurance, and quality control (Figure 10.2). *Quality planning* guides future quality activities; it sets the requirements and standards to be met and the actions necessary to meet them. *Quality assurance* performs the planned quality activities and ensures the project utilizes processes necessary to meet quality standards and end-item requirements. *Quality control* ensures that quality assurance activities are performed according to quality plans and that requirements and standards are being met. Think of quality control as the "medicine" to eliminate existing nonconformities and quality planning and assurance as the "healthy lifestyle" to prevent nonconformities in the first place.

As shown in Figure 10.2, project quality control links quality planning and quality assurance to ensure that quality assurance happens according to the quality plan. Quality assurance aims to ensure appropriate quality standards for a project and to take advantage of learning opportunities from completed projects to improve on future projects. Also shown in Figure 10.2 are tools and techniques relevant to quality planning, quality assurance, and quality control, as well as references to other chapters that provide more information on some of these.

Quality planning

Quality planning should provide confidence that everything necessary to ensure quality has been taken care of. It has two aspects: (1) establishing quality management procedures and policies for the entire organization and (2) establishing a quality plan as part of the execution plan for each project.

Responsibility for establishing organization-wide policies and procedures to improve project quality typically falls on functional managers, especially the quality manager. Projects often employ quality standards that already exist, such as the ISO 9001 standard (a quality management system).[7] For design and development projects, this standard prescribes that an organization shall set procedures for (1) the design and development stages; (2) the necessary reviews, verifications, and validations appropriate to each of the stages; and (3) the responsibilities and authorities for the stages.

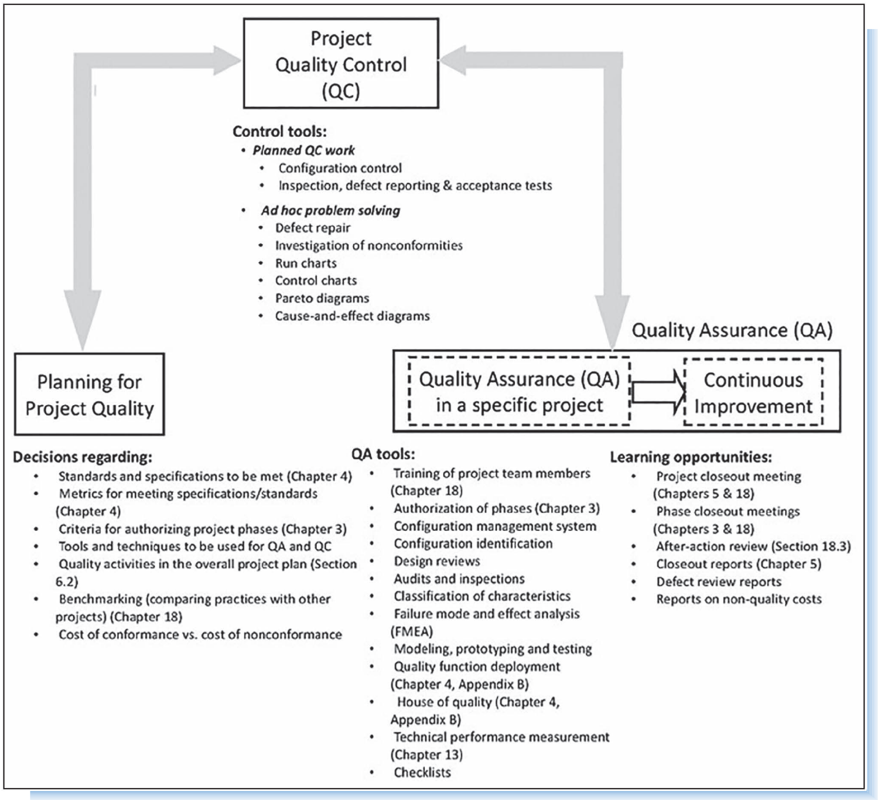


Figure 10.2
The project quality management process.

Costs of quality

Since quality is always related to value for the money spent, quality planning should consider the costs and benefits of quality activities. A *cost–benefit analysis* is performed to evaluate the proposed quality activities. Money spent on quality assurance and control should be justified in terms of expected savings or benefits from fewer or eliminated nonconformities.

The costs of quality are classified as prevention, appraisal and control (*costs of conformance*), and internal failure and external failure (*costs of nonconformance*):

1. Prevention: costs of training, design reviews, and activities aimed at preventing errors; includes cost of quality planning.
2. Appraisal and control: costs of evaluating products and processes, including product reviews, audits, tests, and inspections.
3. Internal failure: costs associated with nonconformities discovered by the producer; includes costs for scrap, rework, and retest.
4. External failure: costs incurred as a result of product failures after delivery to the customer; includes costs for replacements, warranty repairs, liability, lost sales, and damaged reputation.

While the costs of quality can be as little as 2 percent of earnings for a company with a good quality management system, they can exceed 20 percent for a company with a poor quality management system.[8] It therefore makes sense to invest in a good system, that is, to spend more on design reviews, audits, training, modeling, and testing so as to spend less on internal and external failures.

For projects, the costs of prevention, appraisal, control, and internal failure are incurred during the project; costs associated with external failure come after the project is completed. The costs of conformance (prevention, appraisal, and control) are among the many the project manager must justify to management and the customer and include in the project plan and budget.

Project quality management plan

The project quality management plan (quality plan) is an important component of the project execution plan discussed in Chapter 6. A central tenet of what is called "quality by design" is that quality can be planned and that many problems can be prevented by the way it is planned. Creating a quality plan, therefore, is important to the successful execution of projects.

See Chapter 6

Identifying, scheduling, budgeting, and assigning responsibility for quality assurance and control activities is done utilizing the same principles and methods as for other project activities, discussed in Chapters 4 through 9. The plan addresses the quality management approach of the project and indicates the stakeholders involved and how the project would respond to any changes in customer needs. It typically references relevant organizational policies and procedures (e.g. configuration management system and classification of characteristics procedures—both discussed later) and how they would be implemented in the project.

If not covered sufficiently in a project management methodology, the plan should indicate how each of the project phases would be initiated and authorized and how phases and the entire project would be closed out.

The plan should address all relevant elements indicated in Figure 10.2, including how the project team will ensure that the quality requirements as stated in the specifications and standards would be met. This can typically include:

- Any models to be produced and tested and associated test specifications, procedures, and reports
- Inspections, equipment required for inspections, calibration of equipment, and required reports
- Final acceptance tests, including when they would take place, and test specifications, procedures, and reports
- Any required design reviews, the purpose of each, people involved, and outputs required
- Audits
- Checklists
- Techniques that would be used, for example, failure mode and effect analysis (FMEA) or control charts.

The plan can also indicate how non-conformances, customer complaints, and corrective actions would be handled. It should clearly indicate the person primarily responsible for each task and the roles and responsibilities of others involved. The responsibility matrix discussed in Chapter 6 can be used for this purpose.

See Chapter 6

Quality assurance

Project quality assurance relates to the execution of the project quality management plan and aims to reduce the risks of not meeting desired features or performance requirements of deliverables.

As shown in Figure 10.2, quality assurance covers the following:

1. Activities done *in a specific project* to ensure that requirements are being met and the project is being executed according to the quality plan.
2. Activities that contribute to the continuous improvement of current and *future projects* and to the project management maturity of the organization.

Quality assurance should provide confidence that everything necessary is being done to ensure the appropriate quality of project deliverables.

Continuous improvement and project post-completion reviews

Continuous improvement is the foundation to progress: without it, humankind would not have moved beyond the Stone Age. Project organizations strive to continually improve their technical operations and managerial processes, in part by conducting a formal *post-completion review* for every project. The review happens upon completion of the project or, better, upon completion of each phase of the project. Its purpose is to understand what happened and to learn lessons that can be applied to other projects and avoid repeating mistakes.

The project manager's responsibility during reviews is to facilitate candid and constructive discussion about what happened—what worked and what did not—and to make sure that everyone participating is heard. The discussion is formally documented and a list of lessons learned created. This process, though essential for continuous improvement, is often neglected because people lose interest as the project winds down or as they become busy on new, upcoming projects. As a result, organizations repeat mistakes, reinvent the wheel, and do not learn from their experiences.[9] Post-completion reviews are covered more in Chapter 5; they play an important role in knowledge management, discussed in Chapter 18.

See Chapters 5 and 18

Quality control

See Chapter 13

Quality control is the ongoing process of monitoring and assessing work and taking corrective action so as to achieve the planned quality outcomes (requirements and specifications). It also verifies that quality assurance activities are being performed as specified in the quality plan. Quality control is one aspect of *project control*—a topic of Chapter 13 but included here for continuity.

Quality control can be contrasted to *scope validation*: whereas scope validation refers to the acceptability of project deliverables *by the customer*, quality control refers to conformance to specifications as set *by the contractor*. Scope validation includes confirming the *acceptability* of specifications and standards, but quality control refers to verifying adherence to previously set specifications and standards.

The quality control process includes inspections to verify that deliverables are meeting specifications, plus acceptance tests before handover of deliverables to the customer. In the event that a minor feature does not meet specification, the contractor might request a waiver or deviation. A *waiver* applies to an unplanned condition that is discovered only *after* the item has been produced. It authorizes a temporary nonconformity, such as a scratch discovered on the paint of a hardware item. A *deviation* is also a temporary departure from specification, but it is discovered *before* production. For example, if a specified material is temporarily unavailable, the contractor can apply for a deviation to allow an alternative material to be used. A third form of deviation from specification is a *modification*; this is a change to specification that is considered permanent.

Control activities as illustrated in Figure 10.2 include both planned quality control activities and ad hoc problem solving. Planned activities include, for example, inspections on a construction site, tests on a product component, or audits to ensure a supplier is using correct materials. Ad hoc problem solving refers to handling problems and risks as they emerge. Techniques for analysis and problem solving are discussed later.

Quality control cannot happen in isolation; it must be integrated with scope control, cost control, schedule control, and procurement control. Thus, in the same way that the quality plan should be integrated with other aspects of the project plan, quality control should be integrated with the other aspects of project control.

Quality of procured items

Quality requirements for off-the-shelf items procured from suppliers are set by industry standards, in which case the main criterion for choosing a supplier is price. To buy a batch of standard items such as bolts, the procurement officer obtains price quotes from multiple suppliers and picks the lowest. When the batch arrives, an inspector checks the bolts to determine if they are acceptable. But to procure a system or item that must be newly developed, there likely is no industry standard. In that case, the purchaser has to work with the supplier and assist in planning for the quality assurance and control to ensure the item meets specifications.

Of course, even for procurement of standard items, far better than selecting the lowest-price supplier is selecting one that has proven capability and willingness to meet the contractor's requirements and then seeking to develop a mutually beneficial long-term relationship with the supplier. The two parties work together as partners and share responsibility for each other's success. Establishing this kind of relationship is not always easy, especially when the supplier is much larger than the contractor or does not value the relationship or consider the contracted work a priority.

Contractors often invest heavily to make sure they can procure subsystems and components of the appropriate quality. A contractor often has a special vendor quality section within its procurement division to manage quality assurance of all its procured items—including their development and manufacture or construction. The purpose of this section is to assist in selecting suppliers, monitor suppliers' processes to ensure quality, and perform inspections and acceptance tests of purchased items. Other responsibilities are described next.

Example 10.1: Companies Working Together for Quality Assurance and Control

Company A develops and manufactures mining vehicles. It is working on a new vehicle and must choose a supplier to develop, manufacture, and support a transmission for the vehicle. The company's vendor quality section and procurement staff review proposals from supplier candidates and select Company B to provide the transmissions. Company A's engineering division develops a functional specification for the transmission that includes performance characteristics, maintenance requirements, interfaces with other parts of the vehicle, and test requirements. Its vendor quality section then works with Company B's engineers to ensure they will be using appropriate processes for cost-effective compliance with the specification and that they will test all transmissions according to Company A's functional specification for compliance to performance before shipment.

10.3 Techniques for quality assurance in system development

This section further explains the items in Figure 10.2. In phased project planning, authorization of a phase implies that plans for the phase have satisfied pre-specified criteria, including that the plans include sufficient measures for quality assurance. System developers employ a variety of such measures, as discussed in this section.

Configuration management[10]

During design and development of a system, vast amounts of information are generated for use in the design process and later in manufacturing (or construction), maintenance, and support. The information can include hundreds or thousands of documents (specifications, schematics, drawings, etc.), each likely to be modified in some way during the project. Keeping track of all the changes and knowing which version is the most current for every item can be difficult. Thus, any project aimed at delivering a technical product needs a system or process to keep up with and manage all the information; such is the purpose of *configuration management*.

Configuration management includes policies and procedures for monitoring and tracking design information and changes and ensuring that everyone involved with the project (and, later, the end-item's operation) has the most current information. Policies and procedures that form the configuration management system for a project should be included in the quality plan. As with all procedures, the best configuration management system is whatever permits the desired level of control and is the simplest to implement. The two main aspects of configuration management are configuration identification and configuration control.

Configuration identification

See Chapter 2

Configuration identification is an inherent part of systems design and involves defining a system's overall structure and its subsystems and components. Mentioned in Chapter 2, any subsystem, component, or part that is to be tracked and controlled as an individual entity throughout a system's life cycle is identified as a *configuration item*. A CI can be a piece of hardware, a manual, a parts list, a software package, or even a service. Any part of the system that is procured is also treated as a CI. Every physical and functional characteristic that defines and is important for controlling the CI is identified and documented. Ultimately, every functional and physical element of the end-item system should be associated in some way with a CI, either as a CI in its own right or as a component within a subsystem that has been identified as a CI. Ideally, each CI is small enough to be designed, built, and tested by a small team.

The master copies (electronic or paper) of the configuration documents for every CI are retained in a single, secure location (the "configuration center") and managed by someone *not* involved in the functions of design, construction, manufacture, or maintenance. (Documentation about design premises, assumptions, and calculations are not considered configuration documents and are retained elsewhere by the design authority.)

Any modifications, waivers, or deviations to a CI are recorded so that all CI documents reflect the "as-built" status of the system. In the case of a deliverable such as a building, ship, or other one-of-a-kind system that becomes operational, the "as-built" specification will later be used in its operation and maintenance. Where multiple units are produced (e.g. cars, airplanes, appliances) and modifications and improvements are introduced over time, the specific configuration for each individually produced unit must be known, which requires that each specific CI in the product must be traceable to its specific "as-built" specifications. This is necessary so that, for example, the correct spare parts, training, and operating manuals can be supplied, and problems can be traced and analyzed in the event of accidents, customer complaints, or claims regarding product liability. This concept of "traceability" was introduced in Chapter 4 and is illustrated in the following example.

See Chapter 4

Example 10.2: Traceability and the Apollo Spacecraft[11]

To establish the reliability of an item, either many units of the item are tested until one fails, or the required reliability is designed in through methods of engineering analysis. Regardless, to ensure reliability, everything about the item must be known—its manufacturing process, the composition of its parts and materials, and even the sources of those materials. For the Apollo space mission, the goal of achieving mission success was set at 99 percent and crew survivability at 99.9 percent. To meet such high-level goals, every CI (subsystem, component, part, etc.) as it moved through the design and manufacturing process was accompanied with a package of documents that established its genealogy and pedigree. The saying went, "If you ordered a piece of plywood, you wanted to know from which tree it came." Half-inch bolts for the Apollo spacecraft involved an 11-step manufacturing process with certification tests at each step. Every bolt was subjected to rigorous testing, as were the steel rods from which they were made, the billets from which the rods were rolled, and the ingots from which the billets were forged. Everything about the processes and tests for the bolts was documented, including the source of the iron for the bolts—Minnesota—and even the *mine* and the *mine shaft*. Such extreme tracking and control is necessary to ensure high reliability and enable problem diagnosis in case things go wrong. But it comes with a price, though, which is why bolts available for 59 cents at the hardware store cost $8 or $9 apiece on rockets and spacecraft.

Configuration control

The topic of configuration control, the second aspect of configuration management, relates more to quality control than quality assurance, but we cover it here for the sake of continuity. The design of a system is normally specified by means of several documents such as performance specifications, drawings, manuals, and testing procedures that are generated during the design process. As the design evolves, these documents are subject to change, so a scheme is needed to manage and keep track of the changes. Such is the purpose of configuration control.

Configuration control is based on the following principles:

1. Any organization or individual may request a modification, waiver, or deviation.
2. The proposed change and its motivation are documented. Standard documents exist for this purpose: for modifications, the document is called a *change proposal*, *change request*, *change order*, or *variation order*.
3. The impact of the proposed change on system performance, safety, and the environment is evaluated; so is its impact on other hardware items, software, manuals, and methods of manufacturing or construction and maintenance.
4. The change is assessed for feasibility, which includes estimating the resources needed to implement the change and the impact of the change on schedules.
5. The group responsible for approving or rejecting the change is the *configuration board* (CB) or *configuration control board* (CCB). The board usually includes the chief designer and representatives

from manufacturing or construction, maintenance, and other important stakeholders and often is chaired by the project manager or program manager.

6. Upon approval of the proposed change, the work to implement the change is planned. The plan includes actions with regard to the disposition of anything that might be affected by the change, including spare parts, equipment and processes for manufacturing or construction, and manuals and other documentation.
7. The implemented change is monitored and controlled to ensure it complies with the approved change proposal.

See Chapter 13

Change requests are sometimes classified as Class I or Class II. Class I requests can be approved by the contractor or the developer; Class II must be approved by the customer.

Configuration control is an aspect of project control and, in particular, change control, both discussed in Chapter 13.

Design reviews

See Chapter 13

The project manager must ensure that the proposed design is acceptable in all respects; such is the purpose of *design reviews*—to ensure that the users' requirements and assumptions have been correctly identified and that the proposed design is able to meet the requirements in an appropriate way. Design reviews (not to be confused with *general project reviews*, described in Chapter 13) provide confirmation of design assumptions (e.g. load conditions) and other information used in the design process and design calculations. Ideally, they ensure that all important life-cycle aspects of the end-item have been addressed and pose no unacceptable risks. In particular, reviews check the designs for:

1. omissions or errors
2. compliance with regulations, codes, specifications, and standards
3. cost of ownership
4. safety and product liability
5. reliability
6. availability
7. ability to be constructed or manufactured (manufacturability)
8. shelf life
9. operability
10. maintainability
11. intellectual property rights
12. ergonomics.

See Chapters 4 and 15

The reviews involve representatives from all disciplines and functions, users who will be connected to the deliverable throughout its life cycle, and, often, outside designers and subject matter experts. (This relates to concurrent engineering, discussed in Chapters 4 and 15.) For example, in addition to the designers, the design review for a chemical plant, mine, or factory would include representatives from:

- The organization that will operate the facility
- The technical support area that will be maintaining the facility
- The construction company and manufacturers of plant equipment
- The marketing, procurement, legal services, and quality areas that will occupy, make use of, or have to deal with the consequences of the facility.

Design reviews conducted early in the conceptual phase involve representatives from only a few functions; as the project progresses, representatives from more functions are involved. For the design of a simple part or component, a single review upon completion of design but before manufacture might be sufficient, but for the design of a complex system, it would be necessary to convene several reviews at successive stages of the project.

Formal reviews

Formal design reviews are planned events, usually chaired by the project manager or someone else *not* directly involved in the design of the end-item. Projects aimed at developing and delivering a product commonly have four reviews:

1. *Preliminary design review*: review of the functional design to determine if the concept meets the basic operational requirements.
2. *Critical design review*: review of the details of the hardware and software design to ensure they conform to the preliminary design specifications.
3. *Functional readiness review*: (for mass-produced products only), evaluation of tests performed on early produced items to check the efficacy of the manufacturing process.
4. *Product readiness review*: comparison of manufactured products to specifications to ensure that design control documents will result in products that meet requirements.

Formal reviews serve other purposes, too: minimize risk, identify uncertainties, ensure technical integrity, and assess alternative engineering approaches. Unlike peer reviews or informal reviews (discussed in Chapter 13), formal reviews are overseen and conducted by a group of outsiders who use information accumulated by the project team. These outsiders are technical experts who are familiar with the end-item and workings of the project and project organization but are *not* formally associated with the project organization or its contractors. Since a formal review may last for several days and require considerable preparation and scrutiny of results, the tasks and time necessary to prepare and conduct the review and obtain approvals should be incorporated in the project schedule. The schedule should also allow time for possible corrective actions resulting from the review.

See Chapter 13

Since one prerequisite for each design review is thorough design documentation, common practice is to convene a "pre-review meeting" during which the design team provides the review team with an overview of the proposed design; documentation explaining the design premises, philosophy, assumptions, and calculations; and specifications and drawings. The review team is then allowed time (typically 14 days) to evaluate the design and prepare for the formal review meeting. The review team sometimes uses a checklist to ensure that everything important is covered. In recent years, the Internet has become an effective medium for conducting design reviews.[12]

Informal design reviews

Although formal reviews are essential, the project manager should encourage informal design reviews, which are informal discussions among designers and between designers, manufacturers, and other stakeholders. Good suggestions can originate anywhere, but it is up to the designer to decide whether to use them. Draft designs, reports, and other deliverables should be shared regularly (and, ideally, voluntarily) among peer designers and others for informal review. In a healthy quality culture, teams use *brainstorming* to evaluate and edit not only designs but also reports and deliverables of all kinds. The principle behind brainstorming is to freely generate as many ideas as possible and to withhold any form of evaluation or criticism until after numerous ideas have been generated. Only later are the ideas assessed and the good ones separated from poor ones.

Example 10.3: Formal and Internal Reviews in the Mars Pathfinder Project[13]

See Chapter 13

All major NASA projects require formal reviews by outside review "boards." These reviews are crucial, since a project's termination or continuation can depend on the board's findings. For the Mars Pathfinder (see Example 13.3, Chapter 13) project, the review board comprised 25 consultants and seasoned managers from NASA and Jet Propulsion Laboratory (JPL, the site responsible for most of the Pathfinder design work), none of whom was associated with the project.

Preparation for a formal review can take an enormous amount of time, and managers for the Pathfinder project estimated that preparation for one review, the *critical design review*, would require about *6 weeks* of dedicated attention. This would divert time from the actual management of the project, which, paradoxically, could increase the likelihood of the project falling behind schedule and failing the review. To prepare for the formal review, project manager Brian Muirhead ordered an internal review.

In contrast to formal reviews, internal peer reviews address a narrow range of topics and require only a few days' preparation. The value of these reviews lies in making sure that everyone understands the decisions being made, nothing is overlooked, and the project is kept on track. Over 100 internal reviews were conducted during Pathfinder's 3-year development phase.

The internal review in preparation for the critical review revealed many problems—including lack of progress in defining system interfaces, rapid growth in the weight of the Mars lander, and a shortage of good engineers—and did little to inspire confidence about the project's ability to pass scrutiny in the critical design review.

The verdict from a critical design review is an all-or-nothing decision: the project either passes or fails. Failure initiates a cancellation review that can result in project termination. A project such as Pathfinder could be canceled if it overruns the budget by as little as 15 percent. Beyond determining the future of a project, formal design reviews serve another purpose: to give the project a kick in the pants. Preparation for each review is laborious and forces the project team to make decisions about unresolved issues. Formal reviews may be held three or four times during the project.

The critical design review board for Pathfinder was not happy with many aspects of the project, but they did not recommend project cancellation. They approved the project but instructed Pathfinder's managers to be more critical of designs, focus less on performance and more on cost, and stop obsessing over business innovations. These recommendations later proved useful and helped make Pathfinder one of the most successful projects in the history of space exploration.

There is always more than one means to an end, and no designer, regardless of competency, can be expected to think of all of them. It is human nature for people to feel less than enthusiastic about others' ideas and to resist suggested changes to their own, but mature designers appreciate the design review process in terms of the networking experience, innovative ideas gained from others, and reduced risks. Less mature designers, however, tend to feel insulted or intimidated by the process. The design review process seeks to achieve "appropriate quality" and a balanced compromise between insiders' and outsiders' ideas and to refrain from faultfinding or perfecting minor details.

Audits

Unlike design reviews, which relate specifically to the design of a product, audits are broad in scope and include a variety of investigations and inquiries. The purpose of audits is to verify that *management processes* comply with prescribed processes, procedures, and specifications regarding, for example, system engineering procedures, configuration management systems, warehousing and inventory control systems, and safety procedures. They are also used to verify that *technical processes* such as welding adhere to prescribed procedures and to determine *project status* based upon careful examination of certain critical aspects of the work. Any senior stakeholder such as the customer, program manager, or executive can request an audit. Like formal design reviews, audits are relatively formal and normally involve multifunctional teams; unlike design reviews where innovative ideas can originate, they focus strictly on verifying that processes are being implemented as required. The auditor can be an internal staff or an external party, whoever is deemed credible, fair, honest, and unbiased.

Audit preparation begins with the auditor and the stakeholder who requested the audit agreeing on the audit's scope and schedule and the audit team's responsibilities. The auditor prepares for the audit by compiling checklists and sometimes attending a briefing session to learn about the project. A typical thorough audit investigation will take one or two weeks. Within a few days after the audit, the auditor prepares a report that describes any nonconformities found, the importance of the nonconformities, the circumstances under which they were found and the causes (if known or determinable), and suggestions for corrective action. While the focus is on uncovering nonconformities, the report might also note any commendable findings.

Example 10.4: Unsafe Scaffolding Audited

The safety officer of a construction company requested a safety audit of scaffolding at a work site. An external consultant was hired to perform the audit, and a US Department of Labor standard was used as the requirement. The audit report, produced 10 days after the audit started, indicated that all except one of the processes followed in the design and construction of the scaffolding met requirements. The scaffolding, however, failed the audit because no written evidence could be produced about the footing of the scaffolding to prove that a registered/licensed engineer had found it sound, rigid, and capable of carrying the maximum intended load without settling or displacement. Work on the site was stopped pending an engineering investigation on the footing. Executive management subsequently requested engineering reports on scaffold footing from all other sites.

Classification of characteristics

A project end-item or deliverable is "specified" or defined in terms of a number of characteristics or attributes, including functional, geometric, chemical, or physical properties. Characteristics—often specified quantitatively—usually include tolerances of acceptability. In a complex system, numerous characteristics are defined on drawings and other documents. The Pareto principle (discussed later) states that the large majority of problems are caused by relatively few sources. Therefore, the cost-effective way to address quality assurance is to attend to the few characteristics that most impact quality problems or failures. This is not to say that other characteristics are ignored but that limited resources for inspection and testing should first be directed at those items classified as most crucial or problematic.

Characteristics are typically classified into four categories: *critical*, *major*, *minor*, and *incidental*. The *critical* classification is reserved for characteristics where a nonconformance would pose safety risks or lead to system failure. Quality plans often specify that items with critical characteristics be subjected to 100 percent inspection. The *major* classification is for characteristics where nonconformance would cause the loss of a major function of the deliverable. The *minor* classification is for characteristics where nonconformance would lead to small impairment of function or inconvenience with manufacturability or serviceability. Nonconformance of characteristics classified as incidental would have minimal effect.

The classifications are assigned by the designers of each system in collaboration with designers of the next higher-level system and interfacing systems and staff from manufacturing or construction. Together they analyze design characteristics regarding safety and other requirements and classify them using a set of ground rules.

Classification of characteristics should not be confused with the classification of *defects*. In a welded structure, for example, the specified characteristics might include the "absence of cracks or impurities" in the weld metal. A crack (defect that could cause catastrophic failure) would be classified as "critical," whereas a small amount of impurity in the weld (defect that would not affect the structural integrity) would be classified as "minor."

Characteristics classifications are sometimes listed in a separate document, although it is more practical to show them directly on drawings and other specifications using symbols such as "C" for critical, "Ma" for major, "Mi" for minor, and so on. Absence of a symbol normally indicates the lowest priority. Only a very small percentage of characteristics should be classified as critical. A large percentage classified as critical could be a sign of poor design: when everything is critical, nothing in particular is critical!

Characteristics classification serves as a basis for decisions regarding modifications, waivers, and deviations at all levels of a system. For example, the characteristics classification for a higher-level system provides guidance to designers of the system's lower-level subsystems and components. Classifying the braking performance of an automobile as critical (e.g. an automobile traveling 25 miles per hour should be able to stop within 40 feet on dry pavement) tells the braking system's designers to classify the brake's components as critical as well. Failure mode and effect analysis sometimes plays a role in the classification process.

Failure mode and effect analysis

A system can fail as the result of a variety of conditions such as the short-circuiting, cracking, collapsing, or melting of its components or inadequate, missing, or incorrect steps and procedures in its design, production, or operation. *Failure mode and effect analysis* (FMEA) is a technique to determine the conditions (modes) under which a system might fail and what effects the identified failures would have on the system's performance, safety, and environment.

The FMEA procedure is normally used during the early stages of system development and involves the following steps:

1. List the *relevant components* (or *items/functions*) of the system.
2. Identify all the *possible ways* that the component or system might *fail* (*failure modes*). This is best done by a team brainstorming the failure modes. For each mode, the causes and conditions under which it can likely occur are also listed.
3. Assign a *probability* of occurrence to each failure mode.
4. Describe and assess the probable *effects* (or impacts) of each failure mode on the performance and safety of the system and on the environment.
5. Assess the *severity* or seriousness of the effects.

6. Compute the *criticality* of each failure mode. Criticality is a function of both the probability of the failure and the seriousness of the effects.
7. Prepare a plan to circumvent the failure mode, mitigate the effects of failure, or respond in case the failure occurs. When conformance to a specific characteristic is necessary to prevent failure, the characteristic is classified as critical.

Table 10.1 illustrates: In the columns "Sev" (severity), "Prob" (probability), and "Det" (detectability—would the failure be difficult to detect?), each failure mode is rated 1 to 10. Risk priority number (RPN) is the criticality of the failure mode, computed as:

$$\text{RPN} = \text{Sev} \times \text{Prob} \times \text{Det}$$

Items are then prioritized by RPN, with highest RPN first.

Although a failure by itself might not be critical, combined with other failures, it could be very serious. The Chernobyl disaster is an example where a chain of errors (each alone not very serious) led to catastrophic failure—the meltdown of a nuclear reactor. Thus, FMEA must consider *combinations* of failure modes as well as individual failure modes. Besides use in design and engineering analysis, FMEA can also be used to identify issues affecting project costs and schedules and as a tool in project risk management, described in Chapter 11.

See Chapter 11

Modeling and prototyping

Designers use various kinds of models—full-scale physical mockups, scale models, mathematical models, computer simulation models, breadboards, and full-scale prototypes—to learn how a final product, system, or subsystem will look and perform. Models and prototypes are also used in marketing to enable customers to "envision" the product or system. A full-scale wooden or plastic mockup of the cab for a truck or the cockpit of an airplane, for example, helps the producer sell the product and obtain suggestions or criticisms about it.

In product development projects, models help reduce the risk of failure to meet technical requirements. Table 10.2 shows the kinds of models built and tested in the project phases and the kinds of risks they eliminate. Projects for the development of large processing plants often use models in a similar fashion (Table 10.3). Models for such projects usually start out as laboratory equipment but grow in complexity and capacity to enable a pilot operation that leads to a demonstration plant that functions as a commercial unit.

The kind of model used depends on the information needed versus the expense of creating and using the model. For a small product comprising only a few components, building and testing a full-scale model that closely resembles the final product is usually cost effective; for a large, complex system, usually it is not, and computer simulation models and physical mockups are better.

Example 10.5: Modeling the Form and Fit of Boeing 777 Components[14]

One of the most pervasive problems in the development of large aircraft is aligning vast numbers of parts and components so that no interference or gaps between them happen during assembly. In the mid-1980s, Boeing invested in three-dimensional computer-aided design/computer-aided manufacture

Table 10.1 FMEA table.

System ____________________
Subsystem ____________________
Component ____________________
Design Lead ____________________
Core Team ____

Potential
Failure Mode and Effects Analysis
(Design FMEA)
Key Date ________________________

FMEA Number ________________
Prepared By ________________
FMEA Date ________________
Revision Date ________________
Page __________ of _________

Item/ Function	Potential Failure Mode(s)	Potential Effect(s) of Failure	Sev	Potential Cause(s)/ Mechanism(s) of Failure	Prob	Current Design Controls	Det	RPN	Recommended Action(s) Completion Date	Responsibility and Target Actions Taken	Action Results				
												New Sev	New Occ	New Det	New RPN

(CAD/CAM) technology that would enable designers to see components as solid images and simulate their assembly into subsystems and systems on computer screens. By 1989, Boeing had concluded that "digital preassembling" of an airplane could significantly reduce the time and cost of rework that usually accompanies introducing a new airplane into the market. In 1990, Boeing began involving customers, design engineers, tool makers, manufacturing representatives, and suppliers in the concurrent engineering design process of its 777 twinjet program (see Example 4.5, Chapter 4). The physical geometry of the plane's components was determined using CAD/CAM technology instead of physical mockups, which are time consuming and expensive to build. This reduced changes and rework in the 777 program to 50 percent less than earlier programs.

See Chapter 4

Table 10.2 Phases for development of products.

Project Phase	Model Built and Tested	Objectives Relating to the Elimination of Risks	Risks Eliminated
Concept	Exploratory development models (XDMs) (or breadboard models); such models could be built for the entire system or for specific high-risk subsystems	Proof that the new concept would be feasible	The risk that the concept would not be feasible
Verification	Advanced development models (ADMs)	Proof that the product would perform according to specifications and interface well with other systems (form, fit and function)	The risk that the performance of the system and its interfaces with other systems would not be acceptable
Development	Engineering development models (EDMs) manufactured from the intended final materials	Proof of reliability, availability, and maintainability	The risk of poor operational availability
Ramp-up	Pre-production models (PPMs)	Proof that the product could be manufactured reliably in the production facility and could be deployed effectively	The risk of unforeseen problems in manufacturing

System inspection and testing

A variety of inspections and tests are performed to ensure that components and the end-item system meet requirements. Often, the tests are performed using models and prototypes, especially in the development of new products and systems.

Table 10.3 Phases for development of process plants.

Project Phase	Objective
Laboratory experiments	To prove the basic concept
Pilot plant	To learn how the process works when scaled up To provide inputs for the design of the final plant
Demonstration plant	To provide a full-scale plant that demonstrates to potential customers the economic feasibility as well as operational aspects

Tests falls into three categories: tests conducted by the *contractor* to make sure that the system design (1) meets user requirements and (2) is being followed by the producer or builder and (3) tests conducted by the *customer* and others to ensure the system meets user requirements and other contractual agreements.[15]

The first category of tests is aimed at validating the design. If these tests reveal inadequate performance because of faulty or poor design, then the design stage must be repeated; if they reveal problems because of faulty requirements, then the requirements definition stage also must be repeated. Since repeating steps is costly and time-consuming, the tests should be devised so as to catch problems as early as possible. Of course, even if the design is perfect, if the builders cut corners on materials and procedures or do not conform to the design, the system will be inadequate; hence, the second category of tests is necessary to verify that the builders are correctly following the design and that materials and workmanship meet specifications. The final category of tests consists of trials, reviews, and audits conducted by the customer to ensure that user requirements have been met and that test documentation is complete and accurate. These tests, conducted by the user personnel who will operate the system, may expose design deficiencies that project designers and engineers overlooked.

Testing should follow the sequence of components first, subsystems next, then the whole system last; this will minimize the need to redesign an entire system because of faulty components. Each part is tested to ensure it functions individually; components formed from the parts are tested to ensure each component works; subsystems formed from the components are tested to ensure each subsystem performs; finally, the full system formed from all the subsystems is tested to ensure it meets the user's performance requirements.

Tests are performed against earlier developed system objectives, systems specifications, and normal user requirements. Sometimes, in addition, they are performed in *excess* of specifications for normal conditions to determine the actual capacity or point of failure of the system. In *stress tests*, an increasingly severe test load is applied to the system to determine its capability to handle heavier than probable conditions, sometimes until the system fails. In *fatigue tests*, the system is subjected to an increasing load or repeated cycles until it fails; this is done to determine the system's ultimate capacity. Contracts for development projects sometimes not only specify design requirements and performance criteria but also the types of tests to verify them. Often the criteria and conditions for the tests are specified in the quality plan.

Documentation inspection

Projects employ a variety of testing and inspection methods to eliminate defects from documents and code. The following illustrates one approach used in design engineering and software development projects.

Example 10.6: Team Inspection Process[16]

The purpose of the team inspection process is to improve quality, shorten development time, and reduce costs by avoiding defects. The development team meets in a group to review the requirements documents, design documents, and software code. Members are assigned roles during the meeting:

- *Moderator*: oversees the inspection procedure and records defects spotted in the document or code.
- *Reader*: reads the document or code, line by line.
- *Inspector(s)*: person who is most knowledgeable about the document or code, has the most information, and is best able to detect errors.
- *Author*: person who created the document or code.

The author of the document or code initiates the process by scheduling an inspection meeting and providing every member of the team with a copy of the document or code and any supporting documentation at least 2 days before the meeting.

Each inspection meeting lasts for about 2 hours, during which an average team can inspect 10–15 pages of text or 400 lines of code. Defects are documented, and the team decides whether it should meet again after the defects have been corrected. The process is considered complete when the inspector signs off on the corrections and the material is approved.

To reduce the chances of other project teams making similar mistakes, mistakes and defects discovered are entered into a database for common reference.

10.4 Techniques for quality control

Quality control involves performing the tasks defined in the quality management plan and taking any necessary corrective actions to ensure quality. It involves a variety of techniques, as discussed next.

Inspection and acceptance testing of the final product

Whereas testing of models and prototypes provides information for use in design and development, acceptance testing of the final product or other deliverables verifies that the product meets specifications. Characteristics classified as critical are always inspected, but those classified as minor or incidental are not. In automobile production, for example, the braking and steering performance of every vehicle is tested. For mass-produced products, a few units might be subjected to destructive tests (i.e. tested until they break). Products that are produced one of a kind or in a small batch are subjected to nondestructive testing.

Although testing the end results from a *production process* does not fall under the realm of *project* quality management per se, any development project where the resulting product is to be mass-produced would include specifying the testing procedures and other quality assurance processes to be used in producing that product. Product designers who are intimately familiar with key characteristics of the product and its components are best suited to specify the ways to check the quality of the product and its components after production begins. For items produced in high volume, sampling is a common way to reduce the cost of inspection: based on the results from testing a few samples, the quality of the entire batch or process can be statistically inferred. Obviously, sampling is the only choice when testing destroys the product.

Tools of quality control

In the 1980s, Kaoru Ishikawa of Tokyo University defined the basic tools of quality control.[17] The tools aim at identifying the sources of defects and nonconformities in products and processes, but they are applicable for identifying sources of and resolving problems of all kinds, including problems associated with risks. Developed in a production environment (Kawasaki Steel Works), the tools discussed subsequently are nonetheless applicable to projects.[18]

Run chart

See Chapter 13

A run chart is a graph of observed results plotted versus time to reveal possible trends or anomalies. The plot of schedule performance index versus cost performance index illustrated in Figure 13.11 is a form of run chart that tracks project performance and shows if it is improving or worsening in terms of schedule and cost.

Control chart

Control charts are widely used for tracking and controlling repetitive processes and detecting process changes. For projects that include the development of production processes, one deliverable would be specifying the relevant charts for controlling the quality of the process. Readers involved in projects aimed at the delivery of repetitive operating systems should refer to books on statistical control techniques such as *Juran's Quality Control Handbook*.[19]

Pareto diagram

Vilfredo Pareto, a nineteenth-century Italian economist, formulated "Pareto's law" of income distribution, which states that the income and wealth distribution in a country follows a regular pattern: 80 percent of the wealth is owned by 20 percent of the people. This principle, dubbed the "80/20 rule," has since been found to apply in principle to a wide variety of situations, including those relating to quality. Quality consultant Dr. Joseph Juran in the late 1940s posited that the large majority of defects result from a relative few causes; thus, for economic reasons, it makes sense to identify the vital few causes of most defects and to direct the most effort at removing them.

Figure 10.3 is a Pareto diagram: the histogram on the bottom of the diagram shows the number of problems versus the sources of the problems; the diagonal line across the figure is the cumulative effect of the problems (corresponding to scale on the right). As shown, the first kind of problem accounts for 43 percent of all problems; the first and second combined account for 70 percent. Thus, resolving just the first two kinds of problems would eliminate 70 percent of the problems.

Cause-and-effect diagram

Problems are often best addressed through the collective experience of project teams. Team members brainstorm ideas about the causes of a problem, and these causes are recorded on a *cause-and-effect* (CE) diagram (also called a *fishbone* or *Ishikawa* diagram), which is a scheme for arranging the causes for a specified effect in a logical way. Figure 10.4 shows a CE diagram to determine why a control system

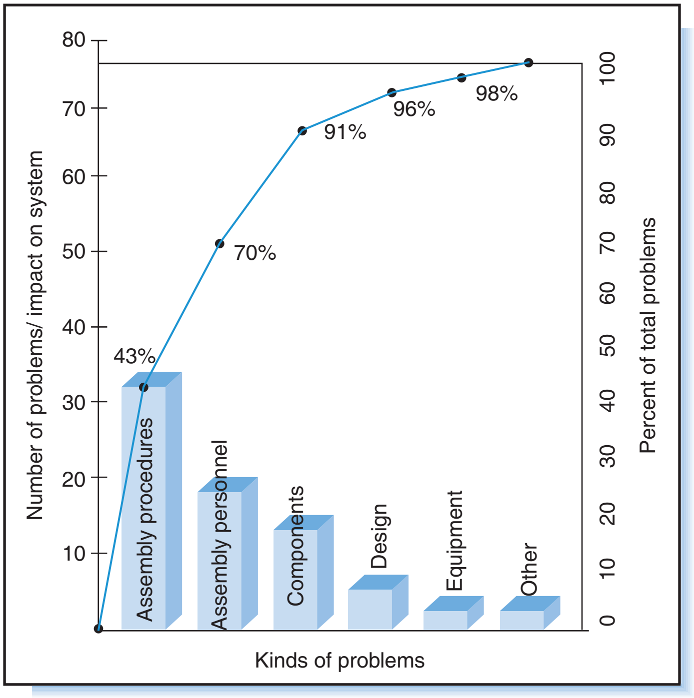


Figure 10.3
Pareto diagram.

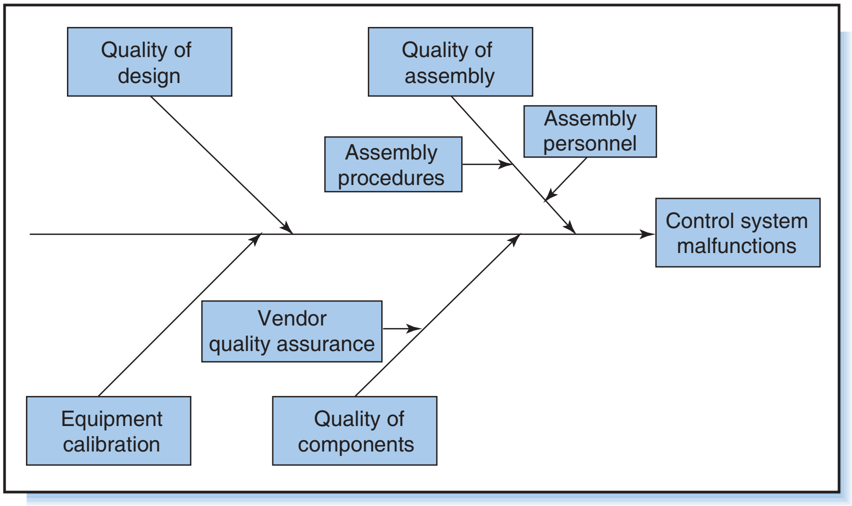


Figure 10.4
Cause-and-effect (fishbone or Ishikawa) diagram

malfunctions. As the team generates ideas about causes, each cause is assigned to a specific branch (e.g. "assembly procedures" to the branch Quality of Assembly). CE diagrams and brainstorming can be used in two ways: (1) given a specified or potential outcome or problem (*effect*), to identify the potential *causes*, and (2) given a cause, to identify the outcomes (*effects*) that might ensue. Identifying the causes is an obvious first step to resolving problems. CE diagrams are also used in risk analysis, and an example is given in Figure 11.2 in Chapter 11.

See Chapter 11

Other tools for quality assurance and control

Many planning and control methods described elsewhere in this book also apply to quality assurance and control. For example, much quality assurance effort in a product design project is directed at keeping the project team focused on customer requirements and preventing distortion or misinterpretation of those requirements as the project moves between stages, departments, and people. Quality function deployment, discussed in Appendix B to Chapter 4, serves just such a purpose. Technical performance measurement, discussed in Chapter 13, can also be considered a tool for quality assurance.

See Chapters 4 and 13

Checklists—for preparing plans and doing inspections, testing, and design reviews—and FMEA are also quality tools; they help prevent important issues from being overlooked. Of course, a disadvantage of checklists is that people tend to overly rely on them and ignore things not on the list. So, the last item on every checklist should be "Now, list all the possible important things not already on this list and check them too!"

10.5 Summary

Project schedules, budgets, and quality management address the three dimensions of project goals: to finish on time and on budget and satisfy requirements. Project quality accounts for an end-item's compliance to specifications, fitness for the purpose, and customer expectations. It does not necessarily imply the highest grade, most product features, or even zero defects; what it does imply is whatever is considered "best" in terms of customer expectations about the end-item's intended use.

Quality management includes three processes: *quality planning*, *quality assurance*, and *quality control*. Quality planning is a part of project planning and involves setting standards and specifications to be met, identifying quality-related activities in the project, and scheduling and budgeting these activities. Quality assurance is performing the planned quality activities and ensuring that the project utilizes whatever resources necessary to meet the requirements. Quality control is the ongoing process of monitoring and appraising work for quality assurance and taking corrective action. It is a part of project control and includes inspection, testing, and ad hoc problem solving.

Project quality management has benefited from the quality philosophies of TQM and Six Sigma, both of which emphasize continuous improvement. Continuous improvement in a project environment is supported by the quality assurance process, post-project reviews, and documented lessons learned. It has also benefited from the statistical methods and basic problem-solving tools used for manufacturing and production. Beyond these, however, project quality management benefits from techniques applicable to all engineering and technical endeavors, including design reviews, configuration management, characteristics classification, and FMEA, as well as experimenting with models and prototypes. Many of the techniques apply also to project risk management, the subject of the next chapter.

Review Questions

1. Describe your understanding of "quality."
2. A Rolls-Royce is considered a high-quality vehicle. Is this always true? Consider different users and uses.
3. How does *compliance to specification* differ from *satisfying requirements?*
4. What is the difference between *satisfying requirements* and *fitness for purpose?* Explain.
5. Explain the difference between *quality* and *grade*.
6. How does the role of the quality manager (a functional manager) regarding quality planning differ from that of the project manager?
7. The schedule indicating lectures, exams, and so on for a college course can be considered a CI. Explain why there should be only one master copy. How does the same principle apply to an engineering drawing?
8. Indicate for each of the following whether to apply for a modification, a deviation, or a waiver:
    a. The supplier of oil filters to an automobile manufacturer says it plans to terminate production of a filter to be used on a car that is under development.
    b. An inspector discovered a kink in reinforcing steel. A structural engineer says that, while the steel will not comply with her drawings, the kink would have no negative effect on the strength of the steel.
    c. A damaged ship has to be repaired. The corrosion-protective coating specified is not available, although a more expensive (but acceptable) coating is available.
9. Describe the differences between design reviews and audits.
10. Discuss how design reviews contribute to the approach of concurrent engineering.
11. Explain how a narrow tolerance on a manufacturing drawing differs from classifying the characteristic as critical or major.
12. Explain how classification of *characteristics* differs from classification of *defects*.
13. Discuss the relationship between project quality management and project risk management.
14. Describe how FMEA in this chapter resembles the risk management approach described in Chapter 11.
15. Perform an FMEA analysis on an electric kettle with cord and plug.
16. How do customer tests for acceptance differ from tests used to obtain design information?
17. How would you expect the bars of a Pareto diagram to change as the result of an improvement program?
18. How does the information on the x-axis of a Pareto diagram used in project control differ from the information on the x-axis of a Pareto diagram used to analyze defects in a mass production environment?
19. Describe the pros and cons of CE diagrams.

See Chapter 11

Questions About the Study Project

1. In which ways would you be able to uncover customer expectations that have not been articulated explicitly?
2. Describe the quality plan for the investigation project. If there was none, develop one. Include all aspects discussed in the section on the project quality management plan that are relevant to the specific project.

3. Discuss how the quality plan is (would be) integrated with the schedule, budget, risk management plan, and, if applicable, with the procurement plan.
4. Identify project budget items that aim to reduce the cost of external failures.
5. Draw a CE diagram and a Pareto diagram to illustrate a project management problem that you have experienced in your study project.
6. Compile a list of "lessons learned" for the project and indicate how these lessons could contribute to more successful future projects.

CASE 10.1 CEILING PANEL COLLAPSE IN THE BIG DIG PROJECT

See Chapter 16

(For more about the Big Dig Project—Boston's Central Artery/Tunnel Project, see Chapter 16, Example 16.5 and Case 16.3.)

Boston, July 1, 2006—four concrete panels weighing about three tons each fell from the ceiling of a Big Dig tunnel, crushing a woman in a car to death. The accident occurred in a 200-foot section that connects the Massachusetts Turnpike to the Ted Williams Tunnel. Said the Modern Continental Company, the contractor for that section of the project, "We are confident that our work fully complied with the plans and specifications provided by the Central Artery Tunnel Project. In addition, the work was inspected and approved by the project manager."[20]

The panels, installed in 1999, are held with metal trays secured to the tunnel ceiling with epoxy and bolts. The epoxy-bolt system is a tried-and-true method: holes are drilled into the concrete ceiling, cleaned, and filled with high-strength epoxy; a bolt is screwed into the hole; as the epoxy cures it bonds to the bolt. "That technique is used extensively," said an engineering professor at the Massachusetts Institute of Technology.[21] For work like this, he said, safety "redundancies" are added, that is, enough epoxy-and-bolt anchors are used to hold the ceiling panels even if some failed. But in the connector tunnel, he contended, too few anchors were used. "They didn't have enough to carry the load. There was no room for error." He added, however, the evidence was preliminary and such a conclusion would be premature.

Some of the bolts in the ceiling wreckage had very little epoxy, and three of them had none. State Attorney General Thomas Reilly's investigation is focusing on whether the epoxy failed or construction workers who installed the bolts misused or omitted the epoxy. An accident caused by improper installation or errors in mixing the epoxy, he said, would implicate the tunnel's design and designers. (Epoxy requires on-site mixing before use.) He added that some documents reflected "substantial dispute" among engineers over the anchor system's adequacy to support the weight of the ceiling panels.

Seven years before the accident, safety officer John Keaveney wrote a memo to one of his superiors at contractor Modern Continental Construction Co. saying he could not "comprehend how this structure can withhold the test of time."[22] He said his superiors at Modern Continental and representatives from Big Dig project manager Bechtel/Parsons Brinckerhoff (B/PB) assured him the system had been tested and proven. Keaveney told the *Boston Globe* he began to worry about the ceiling panels after a third-grade class toured the Big Dig in 1999. While showing the class some concrete ceiling panels and pointing to the ceiling bolts, a girl asked, "Will those things hold up the concrete?" "I said, 'Yes, they will hold,' but then I thought about it."

Some have argued that the investigation should look at the tunnel's design: why were the concrete panels so heavy, weighing 2½ to 3 tons apiece? Why were they there at all? And why did the failure of a single steel hanger send six to ten of the panels crashing down? Eyewitness reports indicate the accident began with a loud snap as a steel hanger gave way, which set off a chain reaction that caused other hangers holding up a 40-foot steel bar to fail and send 12 tons of concrete smashing below. Were the bars under-designed to handle the weight?

Investigators are also looking at whether the wrong epoxy may have been used.[23] Invoices from 1999 show that at least one case of quick-drying epoxy was used to secure ceiling bolts rather than the standard epoxy specified by the designers; this epoxy holds 25 percent less weight than standard epoxy.

Additional issues raised during the investigation include the following:[24]

- Design changes that resulted in using heavier concrete ceiling panels in the connector tunnel than in the Ted Williams Tunnel.
- Lack of steel supports in sections of the connector tunnel ceiling to which bolts holding the concrete panels could have been connected.
- Possible tunnel damage caused by blast vibrations from nearby construction of an office tower.
- Use of diamond-tipped drill bits, instead of carbide bits, in drilling holes for the bolts (epoxy may not hold as well in smoother holes drilled with diamond bits).
- Impact of cold weather during installation of the epoxy–bolt system.

B/PB, the project management contractor, said in a statement "Determining the causes of this specific failure will require a thorough forensic analysis of design, methods, materials, procedures, and documentation." As investigators scrutinize the history of the $14 billion project, criticism is reviving that Massachusetts lacked adequate supervision of private contractors. B/PB was involved in both the design and construction efforts—an arrangement some say may have compromised oversight. "There was no one checking the checkers," said one US representative. Wrote one blogger, "I wouldn't want to be the registered engineer whose signature is on the design. It will be his fault if the materials and workmanship are found not to be up to specifications. But who knows if it is his fault. This is a huge mess and the whole bunch of them, engineers, managers, inspectors, and testers, should be investigated."[25]

QUESTIONS

1. With 20–20 hindsight, draw a CE (fishbone, Ishikawa) diagram to illustrate possible causes and effects. Include the possible causes mentioned in the case. The diagram should have been developed before construction; therefore, also indicate other possible failure modes and other causes you can think of. How would the diagram (developed after the accident) be of value during litigation?
2. List the characteristics that should have been classified as critical.
3. Propose guidelines for a process to ensure that the epoxy would provide sufficient bonding to the concrete ceiling.
4. Explain the role that configuration management should have played in preventing the accident.
5. What role could modeling/prototyping, laboratory tests, checklists, and training have played?
6. Explain how someone within B/PB would be accountable regardless of the findings of a forensic investigation. Would B/PB be off the hook if a subcontractor were found guilty?
7. What would the implications have been if the engineer who signed off on a specific design was an engineer-in-training instead of a registered engineer?
8. Comment on the relationship between project quality management and project risk management. How could risk management have prevented the accident? How does project quality management relate to project cost management?
9. Comment on the contribution that inspection and audits could have played.

CASE 10.2 FIFA 2010 WORLD CUP SOUTH AFRICA™[26]

Ten South African cities were selected for hosting the FIFA 2010 World Cup soccer games. In some cities, existing soccer stadiums had to be upgraded, while in others, new stadiums had to be built at a cost of approximately R17b (approximately US$2.4b). A centerpiece stadium for the games is the newly constructed Cape Town Stadium shown in Figure 10.5. The requirements for the one-off FIFA matches typically far exceed what would be required by stadium owners after the games ended. For example, for each stadium, FIFA required provision for 2,000 journalists for the final game, whereas an ordinary international match would draw only about 200; normally a stadium would require about ten broadcasting positions, but FIFA required 150. It therefore made sense to design facilities for normal use after the games and to meet the temporary FIFA requirements by adding temporary items called "the Overlay." The Overlay, which would be removed after the event, included extra commentary positions, press desks, security equipment, hospitality and other tents, as well as numerous additional cables and other equipment. It was obviously easier to design accommodations for the Overlay in new "greenfield" stadiums than in existing stadiums that had to be upgraded.

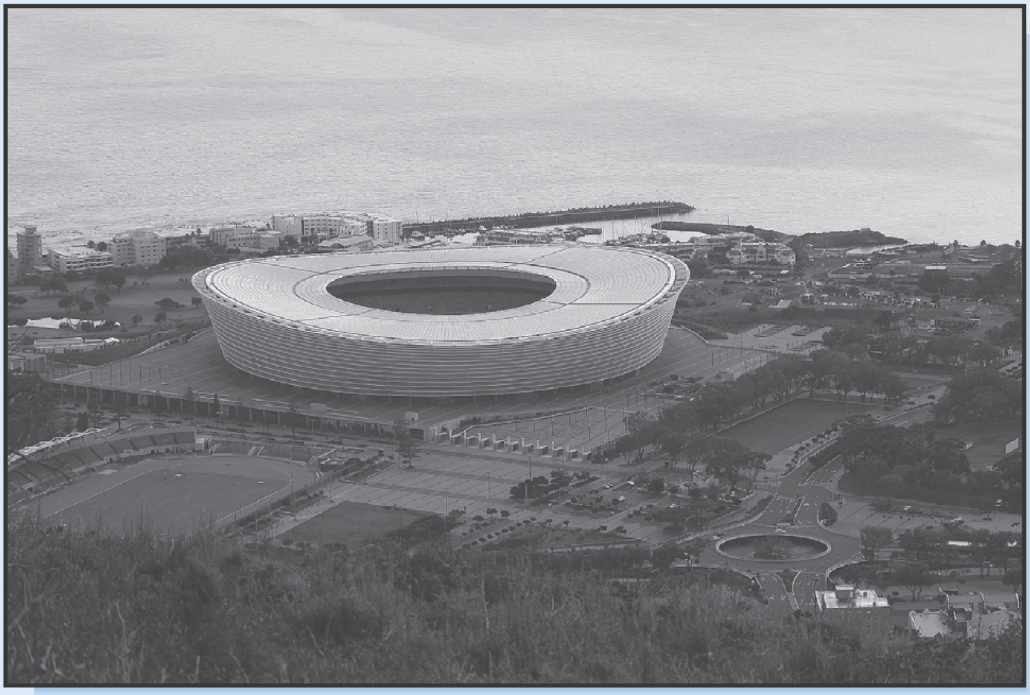


Figure 10.5
Cape Town Stadium used for 2010 FIFA World Cup.
Source: iStock

The major stakeholders in the design and construction of the stadiums are listed in Table 10.4. These stakeholders had to interface with each other and with additional parties such as national security services, police, local transport organizations, and owners of land and buildings, including schools.

Table 10.4 Main stakeholders in FIFA 2010 and their roles.

Stakeholders	Roles
FIFA (International Federation of Association Football) (French: *Fédération Internationale de Football Association*)	Main customer
Host cities and their planners	Provide infrastructure, including match venues, training venues, and roads
Stadium owners (in some cases, the sporting bodies owned the stadiums, but most were owned by the host cities)	Customers with requirements regarding their properties
SA Government (Treasury and Department of Sport)	Financial guarantees
Task team appointed by the South African Government	Monitor and control finance on behalf of Government
South African Football Association (SAFA)	Arrange the World Cup on behalf of FIFA
Local Organizing Committee (LOC)	Arrange World Cup on behalf of SAFA Design, construct and finance the Overlay
LOC Technical Team (reporting to LOC Executive Committee and Board)	Inform host cities about FIFA and Government requirements and assist with interpretation of requirements. Combine the technical guides from: • TV host broadcaster • Hospitality rights holder • Media rights holders • FIFA Marketing and Security • LOC constituent groups. Prepare a technical guide to assist the host city planners on the requirements. Monitor and report to the LOC Executive Committee and Board regarding: • Quality • Progress • Finance • FIFA compliance.
Stadium designers and construction companies	Design and construction of stadiums
Host city professionals	Design and construction of the precinct (surrounds) and the access roads
Overlay contractors (designers and suppliers), appointed by the LOC	Specifications and supply of overlay items

The FIFA publication "Football Stadiums Handbook" provides guidelines for planning and executing FIFA events and is updated after each World Cup event. Members of the Local Organizing Committee (LOC) visited Europe several times to learn from the 2006 FIFA World Cup event held in Germany and the Euro 2008 event held in Austria and Switzerland. One LOC member commented that items on the "wish list" for the 2006 World Cup in Germany had become the norm for the 2010 World Cup.

The stadiums were constructed by companies appointed by the host cities, while contractors for the Overlay were appointed by the LOC. Some subcontracts for the Overlay were controlled by the Overlay contractor, while others, such as security, electric power, backup electricity, water supply and waste water drainage, were controlled by other parties. While the Overlay contractors reported to the LOC, the host cities authorized their contractors to take over spaces to construct the Overlay. The different parties—the LOC and their Overlay contractors, the host cities and their stadium contractors—worked in the same spaces and at the same time but with different responsibilities and reporting structures. This proved a challenge to coordinate work and caused some conflict.

When a stadium was nearly completed, all of the relevant stakeholders were required to attend an on-site inspection and to agree to the sign-off. Several such events were properly recorded by minutes and photographic recordings.

Progress reviews and audits to ensure that all stadiums and other spaces were FIFA compliant were mainly performed by the LOC Technical Team. FIFA, LOC, and government constituent groups also regularly met with members of the host cities to assess and assist them with FIFA compliance. These meetings were chaired by FIFA, though one member of the technical team later remarked: "This was a mistake—OC should have taken control." In between meetings, the relevant stakeholders would assemble in Johannesburg and take "virtual tours" of the sites; the host cities would present their progress through multimedia means, which included a satellite link with FIFA Headquarters in Zurich, Switzerland. This process ensured that the host cities and their technical teams were fully aware of the requirements, and it afforded them the opportunity to discuss any concerns they had with the customers.

QUESTIONS

1. Given two sets of requirements, one for the FIFA games and the other for after the games, what would be an appropriate way to define "quality"?
2. List the quality management activities mentioned in the case.
3. a. Comment on the reporting structures and responsibility for audits and reviews.
   b. Who should have provided quality guarantees?
   c. What planning processes and techniques would have been helpful regarding the roles of the various stakeholders?
4. Comment on the problem of people from different organizations working in the same space at the same time.

CASE 10.3 AIRBAG ADVERSITY

Insufficient quality management during product development, launch, and production can lead to subsequent costly projects and programs to rectify problems. This is especially true when safety-critical items are involved. The 2015 global recall of a large variety of automobile makes, which affected millions of owners, is such as case. The massive recall was related to potentially defective airbags used by auto manufacturers following reports that the airbags had inflators that could explode and expel metal and plastic shards into vehicle occupants. The airbags were supplied by Takata Corporation of Japan, the second largest global supplier of airbags and seatbelts. A *New York Times* report found a total of at least 139 reported injuries across all automakers; in Honda vehicles alone, at least two deaths and 30 injuries were reported.

When the fault was first announced in 2013, only six makes were involved, but by 2015, a large range of makes and 34 million vehicles in the United States alone were potentially affected. It was said that Takata was ramping up to produce replacements at the rate of 10 million per year.

Initially it was thought that propellant chemicals were mishandled and improperly stored during assembly, which might cause the metal inflators to explode due to extreme internal pressure. Later, humid weather was thought to have played a role as well. Takata cited other possible contributors, including rust, bad welds, and in at least one case chewing gum dropped into an inflator. Documents showed that in 2002 Takata's plant in Mexico allowed a defect rate that was "six to eight times above" the acceptable limit, or roughly 60 to 80 defective parts for every 1 million airbag inflators shipped.

QUESTIONS

1. Explain the role of classification of characteristics in reducing costs of ensuring quality.
2. Discuss why any pressure to rush or cut costs on the development of safety-critical items should be resisted. List specific costs incurred by recall programs to withdraw vehicles from use; include costs for (a) loss of automaker or Takata reputation and future sales, (b) litigation between automakers and Takata, and (c) lawsuits resulting from people killed and injured.
3. Discuss specific procedures and steps in the design and manufacturing processes for safety-critical components and systems and how they should differ from procedures and quality management steps for noncritical items.
4. What specific techniques and procedures would you recommend for the design and manufacture of such safety-critical items?
5. Specifications often state that a certain incident or event should not occur more than, say, once in 1 million or once in 10 million times. Explain why tests to ensure such a requirement are difficult and costly.

Notes

1. Carruthers M. *Principles of Management for Quality Projects*. London: International Thompson Press; 1999.
2. Ibid.
3. Yourdan E. *Rise and Resurrection of the American Programmer*. Upper Saddle River, NY: Yourdan Press/Prentice Hall; 1998, pp. 157–181.
4. Crosby P. *Quality Is Free*. New York: McGraw-Hill; 1979.
5. Bach J. The challenge of 'good enough' software. *American Programmer* 8(10); 1995: 2–11.
6. Nicholas J. *Lean Production for Competitive Advantage: A Comprehensive Guide to Lean Methodologies and Management Practices*, 2nd edn. Boca Raton, FL: CRC/Productivity Press; 2018.
7. International Systems Organization. *ISO 9001, Quality Management Systems—Requirements*. Geneva; 2015.
8. Crosby. *Quality Is Free*.
9. Kransdorff A. The role of the post-project analysis. *The Learning Organization* 3(1); 1996: 11–15.
10. The ISO/CD 10007 standard offers guidelines on configuration management systems: International Standards Organization. *ISO/CD 10007 Quality Management Systems—Guidelines for Configuration Management*. Geneva; 2003.

11. Gray M. *Angle of Attack: Harrison Storms and the Race to the Moon*. New York: W.W. Norton; 1997, pp. 170–171.
12. East E., Kirby J. and Perez G. Improved design review through web collaboration. *Journal of Management in Engineering*; April 2004: 51–55.
13. From Muirhead B. and Simon W. *High Velocity Leadership: The Mars Pathfinder Approach to Faster, Better, Cheaper*. New York: Harper Business; 1999, pp. 86–89, 178–179.
14. www.boeing.com/commercial/777family/pf/pf_computing.html, accessed August 2006.
15. Where multiple units of a system are produced, the first and second groups of tests are performed on a prototype. When the system is single copy, the second group of tests occurs during construction, and the design is verified afterward.
16. Information for this application provided by Elisa Denney and Jennifer Brown.
17. Ishikawa K. *What Is Quality Control?* Englewood Cliffs, NY: Prentice Hall; 1982.
18. Bamford D. and Greatbanks R. The use of quality management tools and techniques: A study of application in everyday situations. *International Journal of Quality and Reliability Management* 22(4); 2005.
19. Juran J. and Gryna F. *Juran's Quality Control Handbook,* 4th edn. New York: McGraw-Hill; 1988.
20. Belluck P. and Zezima K. Accident in Boston's Big Dig kills woman in car. *New York Times*; July 12, 2006.
21. Bradley M. Bolt failure at Big Dig: an anomaly? *The Christian Science Monitor*; July 21, 2006.
22. Murphy S. Memo warned of ceiling collapse: safety officer feared deaths in '99, now agonizes over tragedy. *Boston Globe*; July 26, 2006.
23. Allen S. and Murphy S. Big Dig job may have used wrong epoxy. *Boston Globe*; May 3, 2007.
24. Drake B. Investigators probe Boston Tunnel design. *CENews.com*; September 1, 2006, www.cenews.com/article.asp?id=1108, accessed May 15, 2007.
25. Waters P. *Physics forums*, www.physicsforums.com/showthread.php?t=126374, russ_waters, July 17, 2006, 9.30 pm, accessed May 20 2007.
26. Personal communication, Eugene van Vuuren. Member of LOC Technical Team. November 2010.

Chapter 11

Project risk management

Life "looks just a little more mathematical and regular than it is; its exactitude is obvious, but its inexactitude is hidden; its wildness lies in wait."

—G. K. Chesterton[1]

Every project is risky, meaning project outcomes won't necessarily turn out as planned. The project could significantly overrun cost or schedule targets, or the end-item may fall short of requirements. Project outcomes result from many things, including some that are unpredictable and uncontrollable. Risk level is associated with the certainty that outcomes will be as expected. High-certainty outcomes have low risk; low-certainty outcomes have high risk. Certainty derives from knowledge and experience gained in prior projects, as well as management's ability to mitigate anticipated risks and respond to newly emerging ones.[2]

11.1 Risk concepts

Risk is a function of the uniqueness of a project and the experience of the project team. When activities are routine or have been performed many times before, managers can anticipate the risks and manipulate the system design and project plan to achieve the desired outcomes. But when the work is unique or the team inexperienced, the outcomes are less certain, which makes it difficult to anticipate problems or know how to deal with them. Even routine projects can be risky due to factors that newly arise or are beyond anyone's control.

The notion of project risk involves two concepts:

1. The *likelihood* that some problematic event will occur.
2. The *impact* of the event if it does occur.

Risk is a joint function of the two,

$$\text{Risk} = f(\text{likelihood}, \text{impact})$$

A project will ordinarily be considered "risky" whenever at least one—the likelihood or the impact—is large. For example, it will be considered risky when the potential impact is human fatality

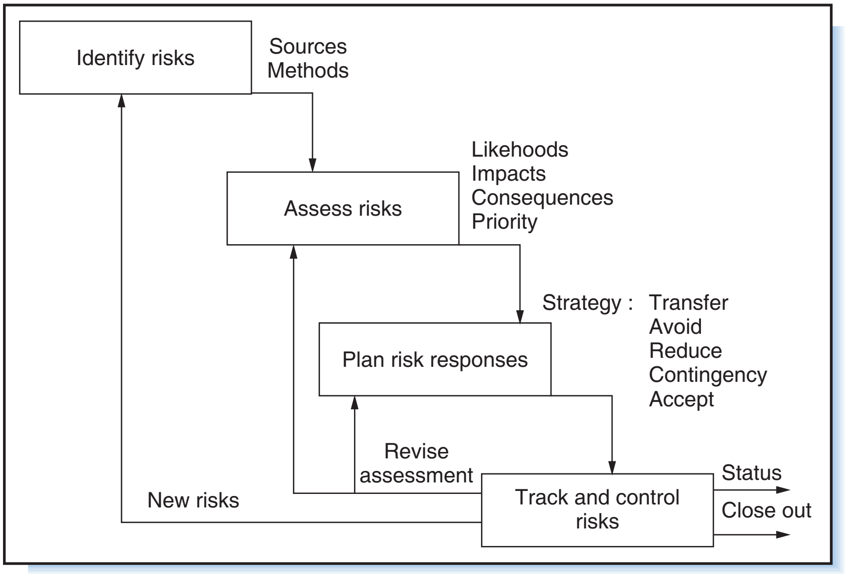


Figure 11.1
Risk management elements and process.

or massive financial loss, even if the likelihood is small. Risk can also mean *opportunities*, such as potential greater rewards, savings, or benefits. Typically, however, risk management focuses on negative consequences.

Many managers are accustomed to dealing with facts, figures, and hard numbers, so they find the concept of risk hard to deal with. Faced with uncertainty, they prefer to ignore problems, though, of course, that doesn't make the problems go away.

Although risk cannot be eliminated, it can be reduced and plans readied in case things go wrong; this is the purpose of the risk management process, shown in Figure 11.1.

11.2 Risk identification

You can only manage things you are aware of. Thus, risk management begins with identifying the risks and predicting their consequences.

Risk in projects is sometimes referred to as the *risk of failure*, which implies that a project might fall short of schedule, budget, or technical performance goals by a significant margin.

See Chapter 10

Among ways to identify project risks, one is to proceed according to project chronology—that is, to look at the phases and stages in the life cycle (feasibility, contract negotiation, system concept, definition, etc.) and identify the risks in each. Each phase presents unique hurdles and problems that could halt the project immediately or lead to later failure (as illustrated in Chapter 10, Table 10.2). In product development projects, the risk of failure is highest in the early stage of preliminary design and diminishes thereafter. Some risks remain throughout, such as potential loss of funding or management commitment.

Risk can also be identified by type of work or technical function, such as engineering risks associated with product reliability and maintainability or production risks associated with the manufacturability of a product or the availability of raw materials.

Risk identification starts in the conception phase and focuses on those risk factors that would make the project difficult or destined to fail. Factors that contribute to high risk include:

- Using an unusual approach.
- Attempting to both develop a new system and advance technology at the same time.
- Developing and testing new equipment, systems, or procedures.
- Operating in an unpredictable or variable environment.

High-risk factors must be studied and well understood before the project can be approved and funds can be committed. Risks identified in the conception phase are often broadly defined and subjectively assessed, though they might also be analyzed using methods discussed later. When multiple competing projects are under consideration, an assessment is performed to decide which of them, based upon tradeoffs of the relative risks, benefits, and available funding, is best.[3] Comparing and selecting projects based upon criteria such as risk is discussed in Chapter 19.

See Chapter 19

Risk sources

Any uncertain factor that can influence the outcome of a project is a *risk source* or *risk hazard*. Identifying risk sources involves learning as much as possible about potential things known to go wrong and the outcome for each, as well as trying to identify things not already known—the "unknown unknowns."

Risk sources in projects can be classified as internal risks and external risks.

Internal sources

These are sources of risk that originate inside the project and over which the project managers and stakeholders have some measure of control. They fall into three main categories: market risk, assumptions risk, and technical risk.

Market risk is the risk of not fulfilling market needs or the requirements of particular customers. Sources of market risk include:

- Failure to adequately define the market or customer needs and requirements.
- Failure to identify changing needs and requirements.
- Failure to identify products newly introduced by competitors.

Market risk stems from the developer misreading the market environment. It can be reduced by working closely with the customer; thoroughly defining needs and requirements early in the project; closely monitoring trends and developments among markets, customers, and competitors; and updating requirements as needed throughout the project.

Assumptions risk is risk associated with the numerous implicit or explicit assumptions made in feasibility studies and project plans during project conception and definition. Faulty, inaccurate, or invalid assumptions put the project in jeopardy of not meeting time, cost, or technical requirements or resulting in unanticipated and harmful side effects.

Technical risk is the risk of encountering technical problems in project work or with the end-item. (Sometimes these risks are listed in special categories—*schedule risks* being those that would cause delays, *cost risks* those that would lead to overruns, and so on.) Technical risk is high in projects that involve new and untried technical applications but low in projects that involve familiar activities and technologies.

One approach to expressing technical risk is to rate the project primary process or end-item as being high, medium, or low according to the following features:[4]

- *Maturity*. How experienced or knowledgeable is the project team in the project technology? An end-item or process that takes advantage of existing experience and knowledge is less risky than one that is innovative, untried, or cutting edge.
- *Complexity*. How many steps, elements, or components are in the product or process, and how tightly are they interrelated? *Ceteris paribus*, an end-item or process with numerous, interrelated steps or components is riskier than one with fewer steps and simpler relationships.
- *Quality*. How producible, reliable, and testable is the end-item or process? In general, an end-item or process that has been produced and is reliable and/or testable is less risky than one that has yet to be produced or has unknown reliability or testability.
- *Concurrency* or *dependency*. To what extent do multiple dependent activities in the project overlap? Activities performed in sequence with no overlap are less risky than activities that are overlapped (i.e. the discrete-staged approach is less risky than fast-tracking).

A subcategory of technical risks are health, safety, and environmental risks; these include hazards to project workers, the larger society, and the ecology as a consequence of the project. These risks stem from short-term hazards due to working conditions, procedures, and materials used in the project and from long-term hazards from the functioning, operation, or mere existence of the project end-item.

External sources

These are risk sources that originate from outside the project and over which project managers often have limited or no ability to control. They include:

- government regulations
- competitors' actions
- interest rates and exchange rates
- senior management or customer decisions regarding project, priority staffing, or budgets
- customer needs and behavior
- supplier/subcontractor relations and business failures
- local physical environment (weather, terrain, infrastructure)
- labor availability (strikes and walkouts)
- material or labor resources (shortages)
- customer or subcontractor control over project work and resources
- local culture
- adverse impacts of climate change.

In general, the risks associated with most of these categories tends to increase for international projects, the topic of Chapter 20.

Another source of risk is stakeholders. By definition, stakeholders are affected by the project, and many of them are able to influence project outcomes—both positively and negatively. Identifying and working with stakeholders is discussed in Chapters 16 and 18.

See Chapters 16, 18, and 20

Identification techniques

Project risk sources (hereafter just called "risks") are identified in many ways; principal among them are project analogy, checklists, WBS analysis, process flowcharts, project networks, cause-effect diagramming, brainstorming, and the Delphi technique.

Project analogy

The *project analogy* method involves scrutinizing the records, post-completion summary reports, and project team members' recollections of earlier analogous projects to identify risks in upcoming projects. The more complete, accurate, and well catalogued the documentation of past projects and the better people's memories, the more useful are these for identifying risks. Beyond just investigating past projects, the method requires identifying ones that are similar *in significant ways* to the project for which risks are being assessed. *Knowledge management* methods, described in Chapters 10 and 18, promote learning from past projects that can help anticipate risks in new ones.

See Chapters 10 and 18

Checklists

Documentation from prior projects is also used to create *checklists* of risk sources in projects. A checklist is initially based upon the experiences from past projects and is updated as new experience is gained from recent projects. Risk checklists can pertain to the project as a whole or to specific phases, work packages, or tasks within the project.

To illustrate, the checklist in Table 11.1 shows the risk severity associated with three categories of risk sources: (1) status of implementation plan, (2) number of module interfaces, and (3) percentage of components requiring testing. Suppose, for example, an upcoming project will use a standard plan, have eight module interfaces, and test 20 percent of the system components. Thus, the project will be rated as low, low, and medium, respectively, for the three risk sources.

As experience grows with completed projects, the checklists are expanded and updated. The more experience a manager or company gains with projects, the more they learn about the risks and the more comprehensive they can make the checklists. While a checklist cannot guarantee that all significant risk sources in a project will be identified, it does help ensure that the important known ones won't be overlooked.

Table 11.1 Risk checklist.

Risk Sources	Risk Severity
Status of implementation plan	
1. No plan required	None
2. Standard plan, existing, complete	Low
3. Plan being prepared	Medium
4. Plan not started	High
Number of interfaces between modules	
1. Less than 5	None
2. 5–10	Low
3. 11–20	Medium
4. More than 20	High
Percent of system components requiring tests	
1. 0–1	None
2. 2–10	Low
3. 11–30	Medium
4. Over 30	High

A disadvantage of risk checklists is that people might look at only the risks listed and not consider any not on the list. Checklists therefore need to be supplemented by other methods.

Work breakdown structure

Risks can be identified using the WBS. Each work package is scrutinized for potential technical hurdles or problems with managers, customers, suppliers, equipment, or resource availability. It is assessed for internal risks in terms of, for example, complexity, maturity, quality, and concurrency, and for external risks, for example, relying on a subcontractor to manage the work package. The risk of every work package is rated as, for example, high, medium, or low.

Process flowchart

Project risks can also be identified from process flowcharts that illustrate the steps, procedures, and flows between tasks and activities in a project or work package process. Examining the flowchart enables the pinpointing of potential trouble spots and risky areas.

Failure mode and effects analysis and hazard and operability study

See Chapter 10

The failure mode and effects analysis (FMEA) method (see Chapter 10) can be used to identify conditions leading to system failure and thus subjecting the project, people, and the environment to risk. A related method called HAZOP—hazard and operability study—is a rigorous investigation of a system to assess what happens when it starts up, shuts down, or encounters problems. The method focuses on the system design and possible errors, omissions, or inherent hazards. Both FMEA and HAZOP are widely used in technical projects—HAZOP most commonly in process industries and infrastructure projects.

Project networks and convergence points

See Chapters 7 and 8

Similarly, risks can be identified through scrutiny of the precedence relationships and concurrent or sequential scheduling of activities in *project networks* (Chapters 7 and 8). Risk sometimes increases at merge points in the network where work performed by different teams comes together and must be integrated; sometimes only then do problems become evident, such as subsystems produced by two teams not matching up or functioning correctly. The risk of project delay from this so-called "merge-point bias" is discussed in Chapter 8.

Brainstorming and cause-and-effect diagram

Risks can be identified from the collective experiences of project team members who participate in a *brainstorming* session to share opinions about possible risk sources and record them on a *cause-and-effect diagram*, as shown in Figure 11.2. Brainstorming and CE diagrams are used in two ways: (1) given an identified, potential outcome (*effect*), to identify the potential *causes* (sources); (2) given a risk source (*cause*), to identify the outcomes that might ensue (*effects*). Figure 11.2 illustrates the first use: it shows potential sources leading to the effect of "completion delay."

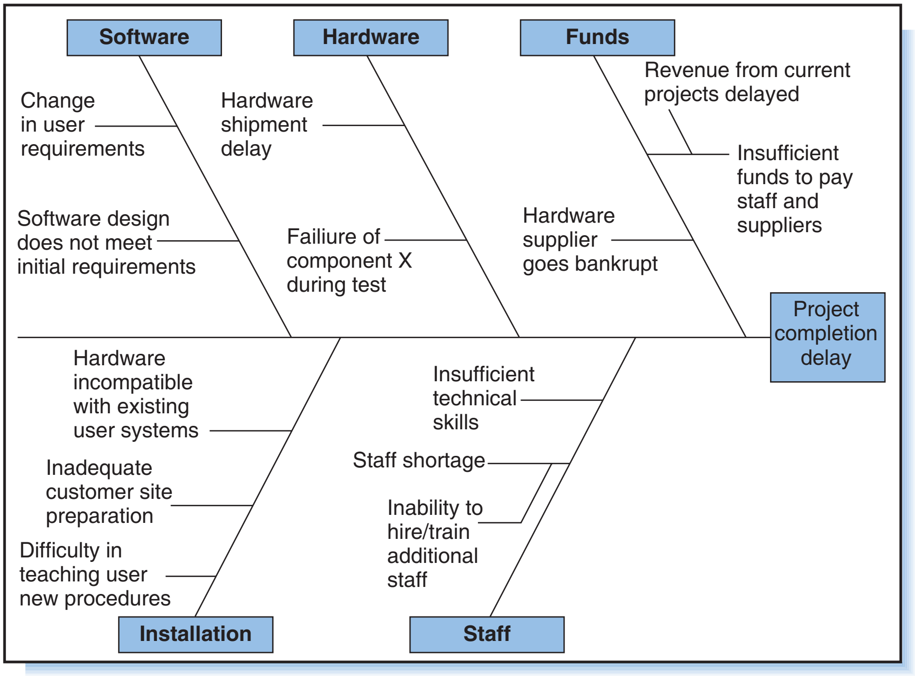


Figure 11.2
Cause-and-effect diagram.

The diagram in Figure 11.2 is divided into the generic risk categories of software, hardware, and so on (other categories are possible). Each category is subdivided into more fundamental sources of risk; for example, the category "staff" includes the risk of "staff shortage," which could be caused by "inability to hire and train additional staff." CE and related analysis techniques are further discussed in Chapter 10.

See Chapter 10

To encourage original thinking and a comprehensive list of possible risks, the risks should not be assessed during brainstorming. Any early mention that a risk is "unrealistic" or "impossible" might lead to some very important risks being discarded. Hence, no risks should be assessed until after the risk list has been compiled.

Risks related to the project end-item may also be discovered during formal design reviews, which are discussed in Chapter 10.

Delphi technique

The term *Delphi* refers to a group survey technique for combining the opinions of several people to develop a single judgment. The technique comprises a series of structured questions and feedback reports. Each respondent is given a series of questions (e.g. what are the five most significant risks in this project?), to which he responds giving his opinions and reasons. The responses of everyone surveyed are summarized in one report that is given to everyone. Seeing others' opinions, respondents then have the opportunity to modify their own opinions. Because the written responses are anonymous, no one feels pressured to conform to others' opinions. If people change their opinions, they must explain the reasons why; if they don't, they must also explain why. The process continues until the group reaches a collective opinion. Studies have proven the technique to be an effective way of reaching consensus.[5]

Risk symptoms and triggers

As the sources and outcomes of each risk are identified, so are its *symptoms*, which are visible *indicators* or warning signs that the risk is materializing; these serve as a *trigger* to initiate counteractions or contingencies to mitigate or combat the risk. For example, for the risk "failure to meet technical requirements," a symptom might be "failure of component X during test"; should that symptom be observed, it would trigger the action "move to design plan B."

11.3 Risk assessment

Risks are ubiquitous but only the notable or significant ones require attention. If a risk and its consequences are significant, ways must be found to avoid or reduce the risk to an acceptable level. What is considered "acceptable" depends on the *risk tolerance* of project stakeholders. Often, managers with experience avoid risks (are risk averse) because they understand the risks and their consequences, whereas managers with less experience take risks (are risk tolerant) because they are ignorant of the consequences of the risks.

What is considered "significant" depends on the risk likelihood, the risk impact, and the risk consequence.

Risk likelihood

See Chapter 13

Risk likelihood is the probability that a risk factor will actually materialize.[6] It can be expressed as a numerical value between 1.0 (certain to happen) and 0 (impossible) or as a qualitative, ordinal rating such as high, medium, or low. (Interestingly, if a risk has probability of 1.0—meaning it is certain to happen—it is considered not a risk but as an "issue" to be dealt with, as discussed in Chapter 13.) Numerical values and qualitative ratings are sometimes used interchangeably. Table 11.2 shows an example: when, for instance, someone says, "the likelihood of this risk is low," that means the probability of it happening, according to the table, is 20 percent or less.

But Table 11.2 is an illustration only, and the association between qualitative ratings and numerical values is subjective and depends on the experience of the project team and the risk tolerance of stakeholders. For example, Table 11.2 might have been created for a project with high economic stakes, in which case "high risk" equates to a numerical likelihood of greater than 50 percent. In a project with low economic stakes, "high risk" might equate to a numerical likelihood of 75 percent or more. People often have difficulty agreeing on the numerical likelihood value for a given qualitative rating and vice versa, even given the same information or experience; this is described later in Example 11.2.

Table 11.2 Risk likelihood: qualitative ratings for quantitative values.

Qualitative	Numerical
Low	0–0.20
Medium	0.21–0.50
High	0.51–1.00

Table 11.3 Likelihoods for different sources of failure.

Likelihood	M_H	M_S	C_H	C_S	D
0.1 (low)	Existing	Existing	Simple design	Simple design	Independent
0.3 (minor)	Minor redesign	Minor redesign	Minor complexity	Minor complexity	Schedule dependent on existing system
0.5 (moderate)	Major change feasible	Major change feasible	Moderate complexity	Moderate	Performance dependent on existing system
0.7 (significant)	Complex design; existing technology	New, but similar to existing software	Significant complexity	Significant complexity	Schedule dependent on new system
0.9 (high)	State of the art; little research done	State of the art; never done	Extreme complexity	Extreme complexity	Performance dependent on new system

*M_S, failure likelihood due to software immaturity; C_S, failure likelihood due to software complexity; M_H, failure likelihood due to hardware immaturity; C_H, failure likelihood due to hardware complexity; D, failure likelihood due to dependency on external factors.

Note: "failure" refers to not meeting technical goals.
Adapted from Roetzheim W. *Structured Computer Project Management*. Upper Saddle River, NJ: Prentice Hall; 1988, pp. 23–26.

Table 11.3 is a checklist for five potential sources of failure in computer systems projects and associated numerical likelihoods.[7] Looking at the M_S column, the likelihood of failure for existing software is low, but for state-of-the-art software, it is high. To repeat, the likelihood values are illustrative and would be tailored to each project depending on the experience and opinion of stakeholders. A likelihood estimate based on the opinions of several individuals (assuming all have relevant experience) is usually more valid than one based on only a few.

When a project has multiple independent risk sources (as is common), they can be combined into a single *composite likelihood factor*, or CLF. Using the sources in Table 11.3, the CLF can be computed as a weighted average,

$$\mathrm{CLF} = (W1)M_H + (W2)C_s + (W3)M_s + (W4)C_s + (W5)D \tag{11.1}$$

where $W1$, $W2$, $W3$, $W4$, and $W5$ each have values 0 through 1.0 and sum to 1.0. This is illustrated in Example 11.1.

Example 11.1: Computation of Composite Likelihood Factor

The ROSEBUD project involves development of hardware and software with characteristics as follows: the hardware is existing and of minor complexity; the software will be developed as a minor redesign of current software and is of moderate complexity; the performance of the overall system will depend on how well it can be integrated into another, larger system. Thus, from Table 11.3, $M_H = 0.1$, $C_H = 0.3$, $M_S = 0.5$, $C_S = 0.3$, and $D = 0.5$. If all sources are rated equally at 0.2, then

$$\text{CLF} = (W1)M_H + (W2)C_H + (W3)M_s + (W4)C_s + (W5)D$$

The application of this CLF will be discussed shortly.

Note that the computation in equation (11.1) assumes that the risk sources are *independent*. If they are not—if, for example, failure due to software complexity depends on failure due to hardware complexity—then the two likelihoods cannot be summed. The sources would have to be subjectively combined into one source (e.g., "failure due to a combination of software *and* hardware complexity") and a single likelihood value assigned based on judgment.

One way to show the interdependency of risk factors is with an *influence diagram*. An example is Figure 11.3.[8] To construct the diagram, start with a list of previously identified risks (e.g. from Figure 11.2). Then look at each risk and ask whether it is influenced by, or has influence on, any of the other risks. If so, draw them as in Figure 11.3, using arrows to show the direction of influence of

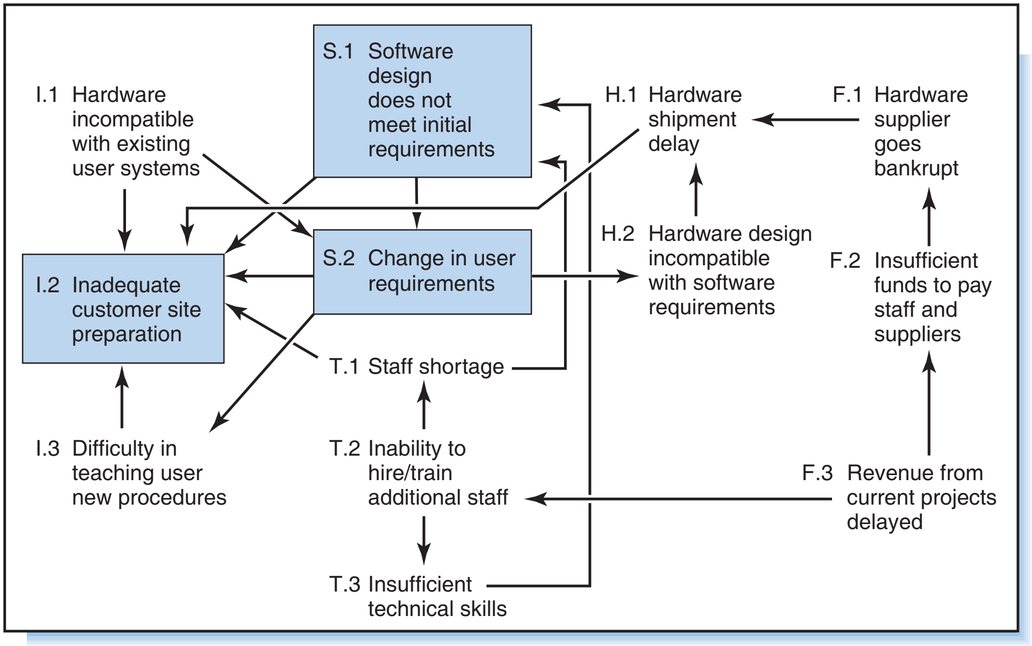


Figure 11.3
Influence diagram.

related risks to the direction of influence (e.g. S.1 influences S.2 and I.2). To minimize confusion, keep the number of risks on the diagram small, about 15 or fewer. Risks with the most connections are the most important; in Figure 11.3, these would be risks I.2, S.1, and S.2; each is influenced by other risks, which increases the failure likelihood.

Risk likelihood also is affected by the future: *ceteris paribus*, activities planned further in the future are more risky (have greater likelihood of failure) than those closer at hand.[9] This is because activities farther in the future have greater chances of being influenced by unknowns. The greater risks and more unknowns over phases later in the project are reasons for phased (rolling wave) project planning, discussed in Chapter 4. As a project enters the execution phase and moves toward completion, the unknowns diminish and so does likelihood of failure. But there is a tradeoff: as the project progresses and the risks diminish, the stakes in the project—the amount of human and financial capital sunk into it—increase. This means that losses from failure incurred later in the project far exceed losses if incurred earlier.

See Chapter 4

Risk impact

What would happen if a risk hazard materialized? The result would be a risk impact. A poorly marked highway intersection is a risk hazard; it poses the risk impact of a collision and personal injury. Risk impact in projects can be specified in terms of time, cost, performance, publicity, pollution, and so on. For example, the impact of insufficient resources might be failure to meet the target date.

Risk impact can be expressed as a qualitative rating such as high, medium, or low based upon a manager's judgment about the impact. For example, a risk leading to a schedule delay of 1 month might be considered "medium impact," whereas a 3-month delay would be deemed "high impact."

Risk impact also can be expressed as a numerical measure between 0 and 1.0, where 0 is "not serious" and 1.0 is "catastrophic." Again, the rating is subjective and depends upon judgment. Table 11.4, for example, represents judgments about the impacts associated with various technical, cost, and schedule situations, and suggested impact value ratings associated with each of them.[10] The assigned risk impact values are largely subjective—even when derived from empirical data.

Table 11.4 Impact values for different technical, cost, and time situations.

Impact value	Technical impact (TI)	Cost impact (CI)	Schedule impact (SI)
0.1 (low)	Minimal impact	No cost increase; within budget	Negligible schedule slip; compensated by slack time
0.3 (minor)	Small performance reduction	<10% increase	Minor (< 1 month)
0.5 (moderate)	Moderate performance reduction	10–25% increase	Moderate (1–3 months)
0.7 (significant)	Significant performance reduction	25–50% increase	Significant (>3 months)
0.9 (high)	Technical goals possibly not achievable	>50% increase	Large (unacceptable)

Adapted from Roetzheim W. *Structured Computer Project Management*. Upper Saddle River, NJ: Prentice Hall; 1988, pp. 23–26.

Example 11.2: Estimating Risk Likelihood and Risk Impact in New Technologies

Risk assessment in new technologies is, well, difficult. The risk of a serious problem can stem from a chain of events (e.g. a machine malfunctions, a sensor does not detect it, an operator takes the wrong action), and to assign the probability of the risk requires identifying all the events in the chain, estimating the probability of each, and combining the probabilities together. Managers and designers can try to think of every event, but they can never be sure they haven't missed some. When a project involves new technologies, the estimates are largely guesses. In 1974, MIT released a report stating that the likelihood of a nuclear reactor core meltdown is one every 17,000 years. The report said a meltdown in a particular plant would occur only after *many hundreds of years* of operation, yet less than 5 years later, a reactor at Three Mile Island suffered a partial meltdown and released radioactivity into the atmosphere.[11]

The space shuttle is another case: NASA originally put the risk of a catastrophic accident at 1 in 100,000, but after the Challenger disaster revised it to 1 in 200. With the additional loss of Columbia (the second loss in 113 missions) the actual risk became 1 in 56. The shuttles originally were design-rated for 100 missions, yet Columbia broke up during its 26th.[12] Few data points (five operational shuttles and 113 missions over 20 years) in combination with incredible complexity made it impossible to accurately predict the risks for the shuttle system, yet for many projects, the data available for estimating probabilities are even sparser.

Estimating impacts is equally difficult, and experts from different fields given identical facts often reach different conclusions. In one survey that rated the hazards of nuclear waste using a 17-point scale, biologists rated it 10.1, geologists 8.3, and physicists 7.3.[13] Risk assessment depends on culture and training and is never completely rational; because of this, it should be based upon the opinions of many experts representing a range of disciplines.

Just as the likelihoods for multiple risks can be combined, so can the impacts from multiple risk sources. A composite impact factor (CIF) can be computed using weighted average,

$$\text{CIF} = (W1)\text{TI} + (W2)\text{CI} + (W3)\text{SI} \tag{11.2}$$

where W1, W2, and W3 have values 0 through 1.0 and together sum to 1.0. CIF will range from 0.0 to 1.0, where 0 means "no impact" and 1.0 means "the most severe impact." co Example 11.3 illustrates.

Example 11.3: Computation of Composite Impact Factor

A particular failure to meet certain technical goals is expected to have minimal impact on technical performance and be corrected within 2 months at a cost of 20 percent. Therefore, from Table 11.4:

$$\text{TI} = 0.1,\quad \text{S1}=0.5,\quad \text{CI}=0.5$$

Suppose the most important criteria are technical performance, followed by the schedule, then cost, and the weights assigned to the criteria are 0.5, 0.3, and 0.2, respectively. Therefore, from equation (11.2):

$$\text{CIF}= (0.5)(0.1)+(0.3)(0.5)+(0.2)(0.5)=0.22$$

Equation (11.2) assumes that the risk impacts are independent. If they are not, the equation does not apply, and the single value impacts must be treated jointly, an example being "the impact of both a 20 percent increase in cost and a 3-month schedule slip is rated as 0.6." Application of this CLF is discussed in the next section.

Another way to express risk impact is in terms of what it would take to *recover* from, or compensate for, an undesirable impact. For example, suppose that use of a new technology poses a risk of not meeting performance requirements. The plan is to test the technology, but then, if the tests reveal poor performance, to abandon it and instead use a proven approach. The risk impact would be the impact of switching technologies in terms of schedule delay and additional cost, for example, 4 months and $300,000.

Risk impact should be assessed for the entire project and articulated with the assumption that no response or preventive measures are taken. In the previous instance, $300,000 is the anticipated expense under the assumption that nothing will be done to avoid or prevent the failure of the new technology. This assessed impact will be used as a measure to evaluate the effectiveness of possible ways to reduce or prevent risk hazards, as discussed later.[14]

Risk consequence

Earlier, the notion of risk was defined as being a function of risk likelihood *and* risk impact; the combined consideration of both likelihood and impact is referred to as the *risk consequence* or *risk exposure*.

The most common way, mathematically, to express risk consequence is,

$$\text{Risk consequence} = (\text{Likelihood}) \times (\text{Impact}) \tag{11.3}$$

Using the previously computed likelihood (CLF) of 0.34 (Example 11.1) and impact (CIF) of 0.22 (Example 11.3), the risk consequence rating, RCR, is

$$\text{RCR} = (\text{CLF}) \times (\text{CIF}) = (0.34) \times (0.22) = 0.078$$

RCR ranges in value from 0 to 1.0, and a very small RCR such as 0.078 might be judged "inconsequential." Assessing values of RCR as being high, medium, or low is subjective, and the principal use of RCR is to compare and prioritize risks—to separate those that can likely be ignored (small RCR, low consequence) from those that must be heeded (large RCR, high consequence).

Risk consequence can be expressed in other ways, too. For example, suppose the likelihood associated with a risk is 0.40, and, should the risk materialize, its estimated impact would be delaying the project by 4 months and increasing the cost by $300,000. The risk consequences for time and cost are thus

$$\text{Risk consequence time}(\text{RT}) = (4 \text{ months})(0.40) = 1.6 \text{ months} = 6.4 \text{ weeks}$$

$$\text{Risk consequence cost}(\text{RC}) = (\$300{,}000)(0.40) = \$12{,}000$$

These are "expected value" risk consequences, or what the average outcomes would be if the situation were repeated a large number of times. The concept of expected value is further discussed in the Appendix to this chapter.

A disadvantage of using expected value is that it assumes people are "risk neutral," which they are not. For example, you might be willing to play a game with a 50 percent chance of losing $10 (i.e. RC = $5), but would you still play it with a 10^{-6} percent chance of losing $5,000,000 (RC = $5 also)?

See Chapter 19

The magnitude of the consequences—whether high, medium, or low—as a function of the specified likelihood and impact values can be determined by plotting the values on a diagram such as Figure 11.4. Just as the likelihood and impact values are subjective, so is the positioning of the isobars demarcating regions of high, medium, and low risk consequence. Interesting to note is that this method is analogous to those used to assess projects, discussed in Chapter 19; a quick comparison of Figure 11.4 and Figure 19.5 reveals the similarity.

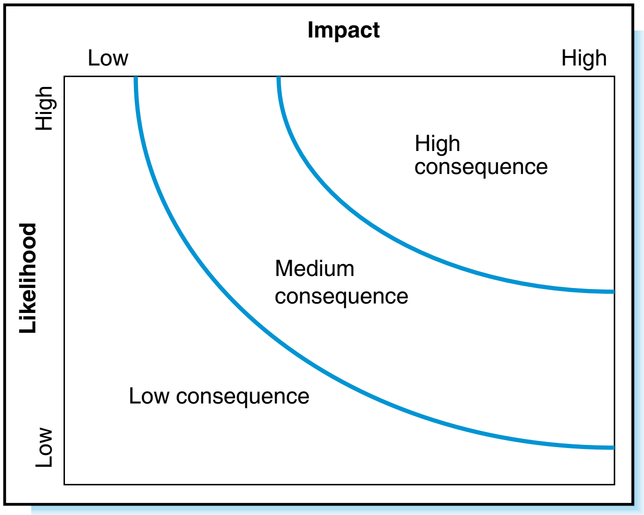


Figure 11.4
Risk consequence as a function of likelihood and impact.

See Chapter 10

The method is also similar to the failure mode and effect analysis technique discussed in Chapter 10. Both methods identify the consequences of risk, although FMEA is directed specifically at risks in technical systems.

PERT

See Chapter 8

The PERT and Monte-Carlo simulation methods discussed in Chapter 8 can be used to account for risk in project scheduling and to estimate additional time needed to compensate for risks in meeting project deadlines.

The PERT method accounts for risk by using three time estimates for each project activity: a, m, and b (optimistic, most likely, and pessimistic times, respectively). Greater risk in an activity is reflected by a greater spread between a and b and especially between m and b. For an activity with no perceived risk, a, m, and b would be identical; any risk hazards identified are accounted for by raising the values of b and m or by moving b farther from m.

With PERT, recall it is the expected time, not m, that is the basis for scheduled times, where the expected time is the mean of the beta distribution,

$$t_e = \frac{a + 4m + b}{6}$$

Thus, for a particular activity with given optimistic and most-likely values (a and m), using a larger value of b will result in a larger value of t_e. This logically allows more time to complete the activity and compensate for risks. In addition, however, the larger value of b also results in a larger time variance for the activity because

$$V = \left(\frac{b - a}{6}\right)^2$$

This larger V will result in a larger variance for the *project* completion time, which would spur the cautious project manager to add a time buffer (schedule reserve) to the project schedule.

Risk priority

Based upon the computed risk consequences, the risk sources can be listed on a *risk register* or *risk log* and those with medium-to-high consequences given a careful look. Project team members, managers, subcontractors, and customers review the list and prepare appropriate responses to them. Table 11.5 is an example risk register showing rank-ordered risk sources and mitigation responses.

One drawback with using expected value consequences to prioritize risks is that very low likelihood risks might be ignored even when they have severe or catastrophic impact. Suppose, for example, the impact of a project failure is 1,000 fatalities. If the risk likelihood is infinitesimal, then the expected consequence will be very small (tiny likelihood of many fatalities) and hence the risk relegated a low priority.[15]

In a complex system with a large number of relationships where joint failures in several of them would lead to system failure, it is common to ignore such failures in the hope they will not occur. Usually the likelihood of joint failure is very low. Very low, however, is not the same as impossible, and a failure with terrible impact should never be ignored, regardless of how small the expected value. For example, the chemical plant accident at Bhopal, India, has been attributed to over 30 separate causes, their joint probability being so small as to be beyond comprehension. Yet they *all* did happen, causing an accident that resulted in between 1,800 to 10,000 deaths and 100,000 to 200,000 injuries.[16] Similarly, the nuclear accident at Chernobyl was the result of *six errors* in human action, any one of which, if absent, would have precluded the accident. But despite the minuscule likelihood, all six did happen, resulting in an accident that immediately caused several dozen deaths, several hundred hospitalizations, and 135,000 evacuations, *plus* later an estimated 5,000 to 24,000 deaths from cancer in the former Soviet Union and many more countries throughout Europe and Asia.[17] The lesson: any risk with a severe impact should never be ignored, no matter how small the likelihood.

Among risks threatening projects everywhere are those associated with climate change. Although both the likelihood and impacts of such risks are difficult to assess, most scientists and planners agree that for many projects, the likelihoods, impacts, and hence consequences of such risks will only increase.

Example 11.4: Assessing Vulnerability to Climate Change

Among the risks imposed by anticipated adverse impacts of climate change (CC) are rise in sea level, frequency and ferocity of storms, average sea and atmospheric temperatures and urban heat islands, droughts, flooding, coastal erosion, wild fires, and landslides. Such impacts threaten the viability of projects and the life cycles of the end-item systems they create. Researchers and planners are grappling with ways to address these impacts. One example is the European Commission's guidelines for managing projects.[18] The guidelines call for (1) assessment of a project's vulnerability and risk due to hazards posed by CC and (2) adapting the project to increase its "resilience" to the hazards of CC.

Table 11.5 Risk registry.

Risk ID Number	Risk Source or Condition (Highest Consequence Ranked First)	Functional Area Impacted	Risk Impact (1–5)	Risk Likelihood	Consequence Rating	Effect on Project if Risk Source Materializes	Action to Mitigate or Eliminate Risk
19	Creative Robotics software does not perform to customer requirements.	Application Development	5	75%	375	Schedule delays. Cost of hiring a replacement vendor.	Test drone software at IBC site; incorporate lessons learned from Godzilla and Mothra projects. Apply K-P standards to all CRC tasks.
6	Unknown site factors encountered during installation of storage racks and computer systems.	Site Operations	4	90%	360	Scheduling delays and possible system reengineering. Increased system/project costs.	Use tracking mechanism to identify issues as they occur. Be ready to shift schedule and resources as necessary.
29	Customer is unable to move operations on time to alternative site during installation.	Customer Relations, Site Operations	5	70%	350	Entire installation delayed.	Assist customer in developing plan/schedule to move to alternative site. Rehearse move 1 week in advance.
12	Robotic drones perform poorly due to multiuser code employed on a single-user code system.	Application Development	4	75%	300	Increased retrieval/placement times. Inability to meet contract requirement.	Perform multiuser code testing at IBC site. Ridgeway team on call for tech support.
4	Hyper-Drive system won't meet installation schedule, which requires uploading SKU data to new system.	Application Development	4	75%	300	Difficulty in handling some SKUs. Could require a change in upload strategy.	Utilize lessons learned from Godzilla project for Hyper-Drive. Have second Hyper-Drive available on standby.
32	Excessive manual changes during post-allocation process.	Site Operations	4	70%	280	System startup delay.	After initial system test, determine extent of excess work and readjust resources.
3	Conversion of Wildnight to DBA and redesigned application.	Application Development	4	65%	260	If not handled properly, potential error in bucket placement.	Extensive quality assurance of process. Dedicate proper staffing. Training early in project.

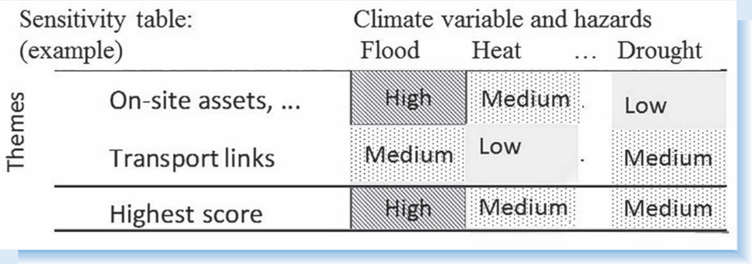
Not every project is affected by CC. When there is reason to suspect a project or the life cycle of its end-product might be affected, the project's *vulnerability* to CC hazards should be assessed, where

Vulnerability = Sensitivity × Exposure

Sensitivity means "how sensitive to CC hazards is this specific *type of project*?" irrespective of project location. For example, *any* tunneling, subway, or water-spanning bridge project is threatened by floods, regardless of project location. The analysis of sensitivity should address the various themes or aspects of the project, such as on-site assets, resources needed, outputs (products and services), and transport links.

For example, Table 11.6 represents a river-spanning bridge project.[19] Since, in general, aspects of such projects (e.g. elevation of the bridge and roads leading to it) depend on water levels, the CC hazard of flooding might be considered a serious threat. Other CC hazards such as temperature rise and drought would pose less serious threats.

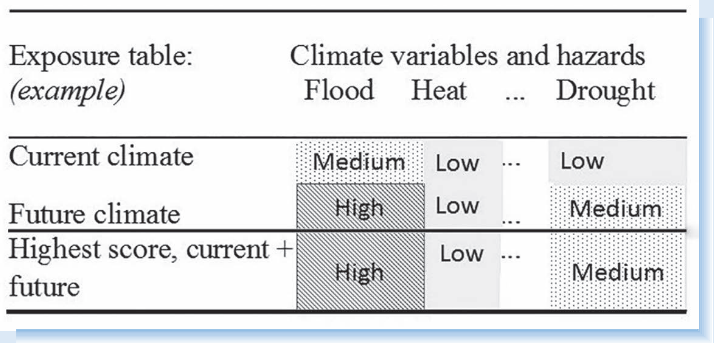
Table 11.6 Sensitivity of features of river-spanning project to climate hazards.



Sensitivity table: (example)		Climate variable and hazards			
		Flood	Heat	…	Drought
Themes	On-site assets, …	High	Medium		Low
	Transport links	Medium	Low		Medium
	Highest score	High	Medium		Medium

Exposure means "how exposed to CC hazards is the *location* of this particular project?" irrespective of the project type. For example, *any* project located by a river or in a coastal low-lying plain might be threatened by floods but less threatened by temperature rise or drought (e.g. coastal cities like London, Miami, Tokyo, Mumbai, Guangzhou, Dhaka, Jakarta, Lagos). Exposure has two parts: exposure in the *current climate* and exposure in the *future climate* (as predicted by, say, climate models). In many cases, exposure to CC hazards can be expected to worsen over time. Table 11.7 reflects worsening threats to low-lying coastal areas from the hazards of floods, heat rise, and drought.

Table 11.7 Exposure of low-lying coastal area locations to climate hazards.



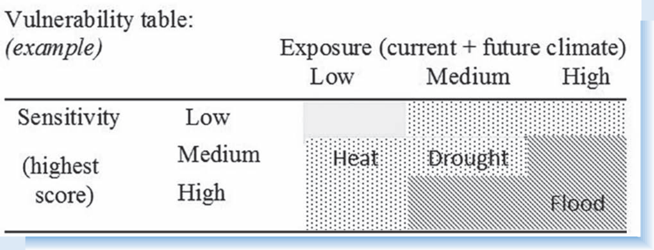
Exposure table: *(example)*	Climate variables and hazards			
	Flood	Heat	...	Drought
Current climate	Medium	Low	...	Low
Future climate	High	Low	...	Medium
Highest score, current + future	High	Low	...	Medium

Summarizing the threats in Tables 11.6 and 11.7:

- Flood: highest sensitivity score is High; highest exposure score is High
- Heat: highest sensitivity score is Medium; highest exposure score is Low
- Drought: highest sensitivity score is Medium; highest exposure score is Medium.

Vulnerability to specific CC hazards, which is a function of both sensitivity and exposure, can be expressed in a table that combines the two. For example, Table 11.8 shows the vulnerability to CC threats for a river-spanning bridge project located in a low-lying coastal area: the project has high vulnerability to floods and medium vulnerability to heat rise and drought.

Table 11.8 Vulnerability of project to climate hazards.



Vulnerability table:
(example)

		Exposure (current + future climate)		
		Low	Medium	High
Sensitivity	Low		░	░
(highest score)	Medium	░ Heat	░ Drought	▨
	High	░	▨	▨ Flood

Important to note is that with climate change, many things can be expected to change. For example, a project that is assessed today to have low exposure to a hazard might in 20 years have medium exposure and in 100 years high exposure. Therefore, with appropriate forethought, project planners might take action today for a current low-risk situation that prevents it from becoming high risk in the future.

The purpose of the vulnerability assessment is to raise awareness about the potential climate change impacts on a project. In response to situations rated as high or medium vulnerability, project planners would instigate a more thorough risk assessment and adopt measures to reduce the project's vulnerability to or increase its resilience against CC threats.

11.4 Risk response planning

Risk response planning addresses the matter of how to *deal* with risk. In general, the ways of dealing with a risk are to transfer, avoid, reduce, accept, or contingency plan for it.

Transfer risk

Risk can be transferred between customers, contractors, and other parties using insurance, contracting, and contractual incentives.

Insurance

The customer or contractor purchases insurance to protect against a wide range of risks, including those associated with:

- Property damage or personal injury suffered as a consequence of the project.
- Damage to materials while in transit or in storage.
- Breakdown or damage of equipment.
- Theft of equipment and materials.
- Sickness or injury of workers, managers, and staff.
- Fluctuations in exchange rates on imported items, or "forward cover."

Subcontract work

Risk can arise from uncertainty about how to approach a problem or situation. One way to avoid such risk is to hire contractors that specialize in those specific problems or situations. For example, to minimize the financial risk associated with the capital cost of tooling and equipment for production of a large, complex system, a manufacturer might subcontract the production of the system's major components to suppliers familiar with them. This relieves the manufacturer of the financial risk associated with the production tooling and equipment. But, as mentioned, transferring of one kind of risk often means inheriting another. For example, in subcontracting work for the components, the manufacturer now must rely on outsiders, which increases the risks associated with quality control and scheduling. But such risks often can be reduced through the contract agreement and careful management of the subcontractors.

Choice of contract

Risk and contracts are inextricably linked since risk can be transferred or allocated to other parties through the use of the appropriate kind of contract. This is addressed in depth in Chapter 12, but briefly, it works like this. In a *fixed-price* contract, the contractor assumes most of the risk of a cost overrun; in a *cost-plus* contract, the customer assumes most of the risk. When the statement of work is clear and well-defined, a contractor will readily accept a fixed-price contract because the work is certain and unlikely to change. When, however, the scope of the work is unclear and the potential for change is great, the contractor prefers a cost-plus contract, which will cover all expenses incurred in the event of changes. Sometimes the two parties negotiate to reach an agreement that neither finds too risky.

See Chapter 12

But not all risks can be transferred. Even with a fixed-price contract, where ostensibly the contractor assumes the risk of overruns, the customer will nonetheless incur damages and hardship should the project fall behind schedule or the contractor declare bankruptcy. The project still must be completed, and someone has to pay for it. To avoid losses, a contractor might feel pressured to cut corners, which increases the customer's risk of receiving a subpar-quality end-item.

Risk responsibility

Risk may be transferred, but never is it completely "offloaded." Usually, a warranty or guarantee in the contract specifies the time or place at which the risk is transferred from one party to another. For instance, when an item is procured and shipped from abroad, the risk of damage usually remains with the seller while the item is being shipped, but as soon as it is hoisted over the rail of the ship, risk is transferred to the buyer.

A party willing to accept high responsibility for risk in a project will usually demand a high level of *authority* over the project. For example, a customer willing to risk poor quality or a cost overrun will almost certainly insist on a large measure of control over aspects of the project that influence quality and cost. Parties bearing high risk will also usually insist on *compensation* to cover the risks. In cost-plus contracts, for example, the contractor's risk is covered by compensation for all expenses, but the customer's risk is covered by his management oversight of the contractor to prevent expense abuses.

Avoid risk

Risk can be avoided by such measures as increasing supervision, eliminating risky activities, minimizing system complexity, altering end-item quality requirements, changing contractors, and incorporating redundancies. But attempts to avoid risk often entail the addition of innumerable management controls and monitoring systems, which tend to increase system complexity and, perversely, introduce *new sources* of risk. Risk avoidance measures can also diminish payoff opportunities. Many risk factors can be avoided, but not all, especially in complex or leading-edge projects. Research and new product development projects are inherently risky but offer potential for huge benefits later on. Because the size of the risk is often proportionate to the potential payoff, rather than avoiding risk, it is better to try to reduce risk to an acceptable level.

Reduce risk

Among the ways to reduce technical risk (its likelihood, impact, or both) are to:[20]

- Employ the best technical team.
- Base decisions on models and simulations of key technical parameters.
- Use mature, computer-aided system engineering tools.
- Use parallel development on high-risk tasks.
- Provide the technical team with incentives for success.
- Hire outside specialists for critical review and assessment of work.
- Perform extensive tests and evaluations.
- Minimize system complexity.
- Use design margins.

The latter two points deserve further explanation. In general, risk and uncertainty increase with system complexity: the more elements in a system and the more they are interconnected, the more likely an element or interconnection will go wrong and impact other elements. Thus, minimizing complexity through reorganizing and modifying elements in product design and project tasks reduces the risk. For example, *decoupling of activities* and subsystems, that is, making them independent of one another, prevents a failure in one activity or subsystem from spreading to others.

Incorporating *design margins* into design goals is another way to reduce risk associated with meeting technical requirements.[21] A design margin is a quantified value that serves as a safety buffer held in reserve and allocated by management. In general, a design margin is incorporated into a requirement by setting the target design value to be *stiffer* or more rigorous than the design requirement. In particular:

$$\text{Target Value} = \text{Requirement} + \text{Design Margin}$$

By striving to meet a target value that is stiffer than the requirement, the risk of not meeting the requirement is reduced.

Example 11.5: Design Margin Application for the Spaceship

The weight requirement for a spaceship navigation system is 90 lbs maximum. To allow for the difficulty of reaching the requirement (and reduce the risk of not meeting it), the design margin is set at 10 percent or 9 lbs. Thus, the *target weight* for the navigation system becomes 81 lbs.

A design margin is also applied to each subsystem or component within the system. If the navigation system is entirely composed of three major subsystems, A, B, and C, then the three together must weigh 81 pounds. Suppose C is an OTS item with a weight of 1 lb that is fixed and cannot be reduced. But A and B are being newly developed, and their design requirements have been set at 50 lbs for A and 30 lbs for B. Suppose a 12 percent design margin is imposed on both subsystems; thus, the *target weights* for A and B are 50 (1.0 – 0.12) = 44 lbs and 30 (1.0 –0.12) = 26.4 lbs, respectively.

Design margins provide managers and engineers a way to address problems in an evolving design. Should the target value for one subsystem prove impossible to meet, then portions of the margins from other subsystems or the overall system can be reallocated to the subsystem. Suppose subsystem B cannot possibly be designed to meet its 26.4-lb target, but subsystem A *can* be designed to meet *its* target; thus, the target for B can be increased by as much as 3.6 lbs (its margin value) to 30 lbs; if that value also proves impossible to meet, the target can be increased by another 6 lbs (subsystem A's original margin value) to 36 lbs. Even if that value cannot be met, the target can be increased again by as much as another 9 lbs (the margin value for the entire system) to 45 lbs. Even with these incremental additions to B's initial target value, the overall system would still meet the 90-lb weight requirement.

While design margins help reduce the risk of not meeting requirements, they encourage designers to exceed requirements—for example, to design systems that weigh less than required but that cost more. Thus, the margins must be carefully set so as to reduce the risks while not increasing the costs.

Design margins focus on risks associated with meeting technical requirements. Among ways to reduce risks associated with meeting *schedules* are:[22]

- Create a master project schedule and strive to adhere to it.
- Schedule the most risky tasks as early as possible to allow time for failure recovery.
- Maintain close focus on critical and near-critical activities.
- Put the best workers on time-critical tasks.
- Provide incentives for overtime work.
- Shift high-risk activities in the project network from series to parallel.
- Organize the project early, and staff it adequately.
- Insert project and feeding buffers (contingency reserves) into the schedule, as discussed in Chapter 8.

See Chapter 8

To reduce the risk associated with meeting *budget* or cost targets:[23]

- Identify and monitor the key cost drivers.
- Use low-cost design alternatives.
- Verify system design and performance through modeling reviews and assessment.
- Maximize usage of proven technology and commercial off-the-shelf equipment.
- Provide contingency reserves in project budgets.
- Perform early breadboarding, prototyping, and testing on risky components, as discussed in Chapter 10.

See Chapter 10

The last way is especially powerful. *Breadboards* and *prototypes*, that is, test mockups and models, enable ideas to be tested experimentally so designs can be corrected early in the project.[24] This greatly reduces the need for later design changes, which can be costly. The following illustrates other ways to reduce risk.

Example 11.6: Managing Schedule and Cost Risk at Vancouver Airport[25]

The expansion project at Vancouver International Airport involved constructing a new international terminal building (ITB) and a parallel runway. The schedule for the $355-million project called for full operation of the ITB less than 3.5 years after the project was approved and opening of the new runway 5 months after that. The project team identified the following as major risks in meeting the tight budget and schedule constraints:

1. *Risk in structural steel delivery and erection*. Long procurement lead times from steel mills and difficulties in scheduling design, fabrication, and erection make big steel projects risky. Recognizing this, the project team awarded the structural steel contract very early in the project to allow ample time to design, procure, fabricate, and erect the 10,000 tons of steel required for the ITB. As a result, the ITB was completed on time.
2. *Material handling risk*. Millions of cubic meters (cum) of earth had to be moved, and over 4 million cum of sand were required for concrete runways and taxiways. The project team developed an advance plan to enable coordinated movement of earth from one locale to another and used local sand in the concrete. This saved substantial time and money, enabling the runway to be completed a year ahead of schedule.
3. *Environmental risk*. Excavations and transport of earth and sand by barges threatened the ecology of the Fraser River estuary. These risks were mitigated by advance planning and constantly identifying and handling problems as they arose through cooperative efforts of all stakeholders.
4. *Functionality risk*. Because new technologies pose risk, the project team adopted a policy of using only proven (OTS) components and technology whenever possible. Consequently, all ITB systems were installed with few problems and were operational according to schedule.

One additional way to reduce the risk of not meeting budgets, schedules, and technical performance is to do whatever necessary to achieve the requirements, *but nothing more.*[26] The project team might be aware of many things that could be done beyond the stated requirements; however, in most cases, these will consume additional resources and add time and cost. Unless the customer approves the added time and cost, all extras should be avoided.

Contingency planning

Contingency planning implies anticipating risks that might arise and then preparing a course of action to cope with them. The initial project plan is followed, and throughout execution the risks are closely monitored. Should a risk materialize as indicated by a trigger symptom, the contingency plan is adopted. The contingency plan can be a post-hoc remedial action to compensate for a risk impact, an action undertaken in parallel with the original plan, or a preventive action initiated by a trigger symptom to mitigate the risk impact. Multiple contingency plans can be developed based upon “what-if” scenarios for multiple risks.

Accept risk (do nothing)

Not all impacts are severe. If the cost of avoiding, reducing, or transferring the risk is estimated to exceed the benefits, then “do nothing” might be the best alternative. In Figure 11.4, the do-nothing strategy would be chosen for risks falling in the “low consequence” region (except when the impact is potentially catastrophic, which is off the chart). Besides, sometimes nothing *can* be done to avoid, reduce, or transfer a risk, in which case the risk must be accepted, regardless of the consequence. Fortunately such situations are rare.

Responding to a risk sometimes creates a new, *secondary risk* (see Example 5.1 in Chapter 5). When preparing a risk response plan, the project management team should check for these before implementing the plan.

See Chapter 5

11.5 Risk monitoring and response

Identified risks are documented in a *risk log* or *risk register* and ordered by rank, greatest risk consequence first. For risks with serious consequences, mitigation plans are prepared and strategies adopted (transfer, reduce, avoid, or contingency); for those of little or no consequence, nothing is done (accept).

Thereafter, the project should be *continuously monitored* for symptoms of previously identified risks as well as for newly emerging risks (not previously identified). Known risks may take a long time before they start to produce problems. Should a symptom reach the trigger point, a decision is made as to the course of action, which might be to institute a prepared plan or to convene a meeting to find a solution. Sometimes the response is to do nothing; however, everything should be a conscious choice, not an oversight, and be tracked afterward to ensure it was the right choice.

All risks deemed critical or important are tracked throughout the project or the phases to which they apply; to guarantee this, someone should be *assigned responsibility* to track and monitor the symptoms of every important risk.

Altogether, the risk log, mitigation strategies, monitoring methods, people responsible, contingency plans, and schedule and budget reserves constitute the *project risk management plan*. The plan is continuously updated to account for changes in risk status (old risks avoided, downgraded, or upgraded; existing risks reassessed; new risks added). The project manager (and sometimes other managers and the customer) is alerted about emerging problems; ideally, the project culture embodies candor and honesty, and people readily notify the project manager whenever they detect a known risk materializing or a new one emerging.

11.6 Project management *is* risk management

Risk management supplements and is a part of other project management practices such as requirements definition, scheduling, budgeting, change control, and performance tracking and control. Managers use all of these to identify and assess risks so they can proactively reduce risks or plan for the consequences. If, for example, a project must finish in 9 months but is estimated to take 12, management can take a multitude of steps to increase its likelihood of finishing in 9.

Ideally, risk identification, assessment, and response planning is treated as a formal aspect of project planning, and the resulting risk management plan is integrated into the execution plan alongside the schedule, budget, quality plan, change control plan, communication plan, and so on. During project execution, risk tracking is incorporated as a measure within the tracking and control process. Ideally, many project team members and other stakeholders are involved in risk identification, response planning, and risk tracking. Whenever someone detects a risk, she contacts the project manager or risk officer (described later); then, depending on the severity of the risk, messages (pop-ups) are sent to others in the project informing them of the risk.

Of course, not all projects *need* comprehensive risk management. On small projects, a small, well-paid, and motivated staff can usually overcome difficulties associated with the risks and, if not, the consequences are usually small anyway. In larger projects, however, where the stakes and risks of failure are high, risk management is important. Such projects require awareness and respect for all the significant risks—safety, legal, social, political, technical, and financial.

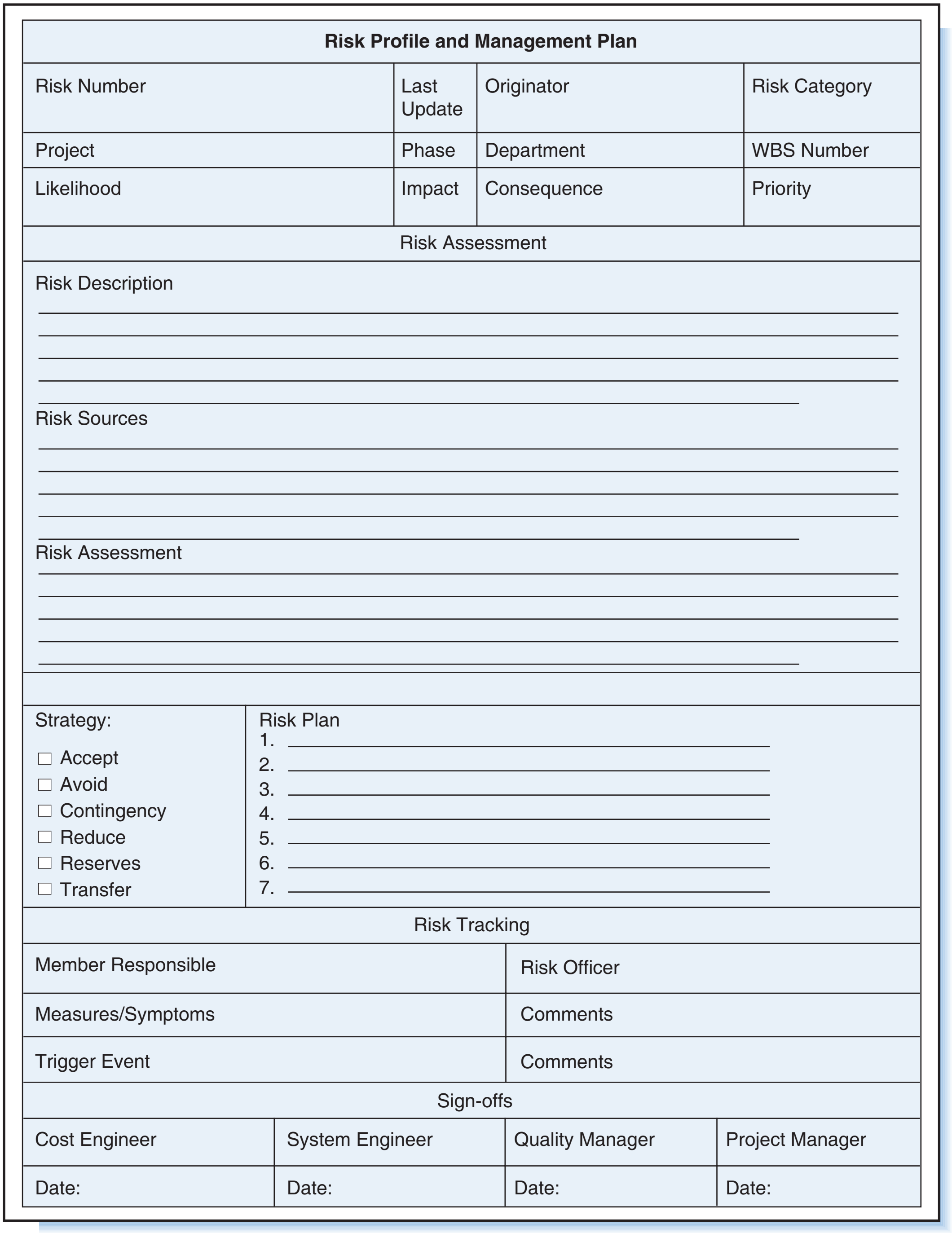
Risk management principles

Every project for which non-trivial risks are known or suspected should have a risk management plan. The plan should specify- for a particular project- the procedures for identifying and assessing risks, person(s) involved in the risk management process and their specific responsibilities, methods for assessing and prioritizing risks, guidelines for risk mitigation and contingency planning, and methods for tracking and reporting risks and addressing emergent, unforeseen risks. The plan should address general principles for managing risks, including the following:[27]

- Create a *risk profile* for each risk source; this includes the risk likelihood, cost and schedule impact, and contingencies to be invoked. The profile should also specify the earliest visible symptoms (trigger events) that would indicate when the risk is materializing. In general, high-risk sources should have lots of eyes watching, and contingency plans should be updated to reflect project progress and emerging risks. Figure 11.5 illustrates a risk profile template, which would include a summary of everything known about a risk. This document would be retained in a binder or library, updated as necessary until the risk is believed to no longer exist and is "closed out."
- Appoint a *risk officer* to the project, someone whose principal responsibility is the project's risk management. This should not be the same person as the project manager; he should *not* be a can-do person but instead a devil's advocate, identifying all the reasons something might not work—even when everyone else believes it will.
- Include in the budget and schedule a calculated risk *reserve*—a buffer of money, time, and other resources to deal with risks should they materialize. The reserve is used at the project manager's discretion to cover risks not specified by each risk's profile. It may include the RT or RC values (see the Appendix to the chapter) or other amounts. It is usually not associated with a contingency plan, and its use might be constrained to particular applications or areas of risk. The project manager keeps the exact amounts held in the reserves strictly confidential (else a project will tend to consume whatever the amount held), although others should know *there is a reserve available* (otherwise they will build in their own *secret* reserves).
- Establish *communication channels* (sometimes anonymous) within the project team to ensure any bad news gets to the project manager quickly, risks are continually monitored, and risk status is continuously assessed and communicated.
- Specify procedures to ensure accurate and comprehensive documentation of proposals, project plans, change requests, progress reports, and the post-completion summary report. In general, the better the documentation of past projects, the more information available for planning future similar projects and identifying possible risks.

Expect the unexpected

Having identified myriad risk hazards and consequences and prepared all kinds of specialized controls and safeguards, people can be led to believe that everything that possibly could go wrong has been anticipated and accounted for; thus, when something still goes wrong, it catches them *completely off guard*. Although it is true that risk planning can cover many or most risks, it can never cover all of them. Thus, risk planning should be tempered with the concept of "non-planning" or Napoleon's approach, which is *to expect that something surely will go wrong* and to be ready to find ways to deal with it *as it emerges*. This is as important to coping with risk as is extensive planning and believing that all risks have been covered.[28]



Risk Profile and Management Plan

Risk Number	Last Update	Originator	Risk Category
Project	Phase	Department	WBS Number
Likelihood	Impact	Consequence	Priority

Risk Assessment

Risk Description

Risk Sources

Risk Assessment

Strategy: ☐ Accept ☐ Avoid ☐ Contingency ☐ Reduce ☐ Reserves ☐ Transfer	Risk Plan 1. 2. 3. 4. 5. 6. 7.

Risk Tracking

Member Responsible	Risk Officer
Measures/Symptoms	Comments
Trigger Event	Comments

Sign-offs

Cost Engineer	System Engineer	Quality Manager	Project Manager
Date:	Date:	Date:	Date:

Figure 11.5
Document for risk profile and management of an identified risk.

Example 11.7: Managing Risks as They Arise—Development of the F117 Stealth Fighter[29]

An example of how to manage risk in R&D projects is the F117 Stealth Fighter program, aimed at developing a revolutionary new "low observable" (difficult to detect with radar) aircraft capable of high-precision attacks on enemy targets. The F117 involved high risk because many lessons had to be learned during the program and significant challenges had to be overcome. But managers *expected* challenges would occur throughout the program, from early design and testing, through to evaluation and final deployment. To handle the risks, numerous decisions were made on the spot between program managers for Lockheed (contractor) and the Air Force (customer). The program was set up for rapid deployment of resources to solve problems *as they arose*. Managers from the customer and the contractor worked closely to minimize bureaucratic delays. Schedules were optimistic and based on assumptions that everything would work; however, everyone throughout the management chain *knew the risks* and the challenges to overcome, so problems never came as a surprise or threatened program support—a good example of *managing* risk as opposed to *avoiding* risk.

Risk management caveats

For all the good it can provide, risk management can *create* risks. Most every philosophy, procedure, or prescription has caveats, and that is true of risk management as well. Misunderstanding or misapplication of risk management concepts can stymie a project by fooling people into thinking they have nothing to worry about, which can actually leave them worse prepared for dealing with *emerging* problems they didn't anticipate.

Having created a risk management plan, managers might be emboldened to take risks they otherwise might not take. Much of the input to risk analysis is subjective; it addresses what might happen—not what will happen. Data analysis and planning gives people a sense of having power over events, even when the events are chancy. Underestimating the risk likelihood or impact can make consequences seem insignificant, leading some people to venture into dangerous territory that common sense would disallow. For example, the security of seat belts and air bags encourages some drivers to take risks such as driving too close behind the next car or accelerating through yellow lights. The result is an *increased* likelihood of an accident.

Repeated experience and good documentation are vital ways to identify risks, but they cannot guarantee that all important risks will be identified. Same and similar outcomes that have occurred repeatedly in past projects eventually deplete people's capacity to imagine anything else happening. As a result, some risks become unthinkable. Even sophisticated computer models are worthless when it comes to dealing with the unthinkable because a computer cannot be instructed to analyze situations that are beyond the imagination of the humans that created them. Experience provides but a sample of possibilities, not the entire population.

Managing risk does not mean eliminating it, although some managers don't know that. The prime symptom of "trying to eliminate risk" is micromanagement: excessive controls and documentation requirements and trivial demands for the authorization of everything. Projects inherently entail uncertainty and risk. Micromanagement is seldom appropriate, and for some projects, it can be disastrous, particularly when the projects involve the new, untried, and untested. When management tries to eliminate risk, it stifles innovation and, say Aronstein and Piccirillo, "forces a company into a plodding, brute force approach to technology, which can be far more costly in the long run than a more adventurous approach where some programs fail but others make significant leaps forward."[30] The appropriate risk management strategy for most projects is to try to accommodate and mitigate risk, not to avoid or eliminate it.

11.7 Summary

Project risk management involves identifying the risks, assessing them, and planning appropriate responses. Identifying project risks starts in the project conception phase. Project risks stem from many sources, such as failure to define and satisfy customer needs and market requirements; technical problems arising in the work; weather, labor, and supplier problems; competitors' actions; and changes imposed by outsiders. Such risk hazards are identified using a variety of methods that draw from experience with past projects and scrutiny of future projects.

Of innumerable risks in projects, only the important ones need be addressed. Importance depends on the likelihood, impact, and overall consequence of the risk. Likelihood is the probability a risk will occur, impact is the effect of the risk, and risk consequence is the combination of the two. In general, measures of risk consequence are used to decide which risks should receive attention and which can be ignored. As a precaution, however, every risk with severe impact should be carefully considered, even when the likelihood is very small.

Risk response planning addresses ways the identified risks will be handled. Some risks can be transferred to other parties or spread among many stakeholders or subcontractors. Some can be avoided; some can be eliminated. Sometimes, however, high risk is associated with high benefits, and trying to eliminate the risk can also reduce the payoff. Thus, better than trying to eliminate risk is to try to reduce it to a manageable level. For areas of high risk, alternative contingency plans should be developed.

The principles for risk management include creating a risk management plan that specifies the risks, their symptoms, and backup plans; a risk officer who is responsible for identifying and tracking the risks; and a budget and schedule reserve. The plan must specify the ways to monitor risks and emerging problems and to communicate them to the project manager. Proper documentation from past projects furnishes lessons learned and forewarns managers about potential risks in upcoming projects. No amount of preparation can anticipate all risks; managers should expect the unexpected and be ready to deal with risks as they arise.

The following Appendix discusses common analytical methods for assessing risk consequences and deciding between alternative risk responses. Similar methods are employed in project selection—the topic of Chapter 19.

See Chapter 19

APPENDIX: RISK ANALYSIS METHODS

Four common methods for risk analysis are expected value, decision trees, payoff tables, and simulation.

Expected value

Selection of the appropriate risk response sometimes depends on the risk consequences expressed in terms of the expected value of costs or schedules.

An expected value is the average outcome of numerous repeated events. For risk assessment, expected value represents the average outcome of a project if it were repeated many times, accounting for the possible occurrence of risk. Mathematically, it is the weighted average of all the possible outcomes, where the weights are the likelihoods of the possible outcomes, that is

$$\text{Expected Value} = \sum[(\text{Outcomes}) \times (\text{Likelihoods})]$$

The consequence of risk on project duration, called the *risk time*, RT, is the expected value of the estimated time to correct for risk, computed as

$$\mathrm{RT} = (\text{Corrective time}) \times (\text{Likelihood}) \tag{11.6}$$

The consequence of risk on project cost, called the *risk cost*, RC, is the expected value of the estimated cost to correct for the risk, computed as

$$\mathrm{RC} = (\text{Corrective time}) \times (\text{Likelihood}) \tag{11.7}$$

For example, suppose the baseline time estimate (BTE) for project completion is 26 weeks, and the baseline cost estimate (BCE) is \$71,000. Assume that the risk likelihood for the project as a whole is 0.3, and, if the risk materializes, the project would be delayed by 5 weeks and cost \$10,000 more. Because the probability of the risk materializing is 0.3, the probability of it *not* materializing is 0.7. If the risk does not materialize, no corrective measures will be necessary, and the corrective time and cost will be nil. Hence

$$\mathrm{RT} = (5)(0.3) + (0)(0.7) = 1.5 \text{ Weeks}$$

and

$$\mathrm{RC} = (\$10{,}000)(0.3) + (0)(0.7) = \$3{,}000$$

See Chapters 8 and 9

These figures, RT and RC, are the schedule *reserve* and *project contingency* (budget reserve), respectively, mentioned in Chapters 8 and 9. Accounting for the risk time, the expected project completion time, ET, is

$$\mathrm{ET} = \mathrm{BTE} + \mathrm{RT} = 26 + 1.5 = 27.5 \text{Weeks}$$

Accounting for the risk time, the *expected project completion time*, ET, is

$$\mathrm{EC} = \mathrm{BCE} + \mathrm{RC} = 71{,}000 + 3{,}000 = \$74{,}000$$

Accounting for the risk cost, the *expected project completion cost*, EC, is

$$\mathrm{ET} = \mathrm{BTE}(1 + \text{Likelihood}) = 26.(1.3) = 33.8 \text{ Weeks} \tag{11.8}$$

When the corrective time and cost cannot be estimated, then ET and EC are computed as

$$\mathrm{EC} = \mathrm{BCE}(1 + \text{likelihood}) = \$71{,}000(1.3) = \$92{,}300 \tag{11.9}$$

These examples account for risk factors that affect the project as a *whole*. Another way to determine risk consequence is to first disaggregate the project into work packages or phases and then to estimate *for each* the risk likelihood and corrective time and cost. These individual estimates are then aggregated to determine ET and EC for the entire project. This approach tends to give more credible RT and RC estimates than do equations (11.6) through (11.9) because risks pinpointed to individual tasks or phases can be more accurately assessed and the necessary corrective actions and associated time and costs for particular tasks more easily identified.

Say a project has eight work packages; Table 11.9 lists cost information and EC for each, where EC is computed as

$$EC = BCE + [(\text{Corrective cost}) \times (\text{Likelihood})]$$

As shown in Table 11.9, the EC for the *project* is $84,850.

Now, for the same eight projects, Table 11.10 gives time information, where ET is computed as

$$ET = BTE + [(\text{Corrective time}) \times (\text{Likelihood})]$$

Suppose the project network is as shown in Figure 11.6. Ignoring the risk time, the critical path would be J–M–V–Y–W–X and the project BTE 26 weeks. Accounting for risk consequences, the critical path would be the same, but the duration (the project ET) would increase to 27.9 weeks.[31]

Although activities on critical and near-critical paths should be carefully monitored, in general, *every* activity with high-risk consequences (high likelihood and/or high impact) should be carefully monitored, even when not on the critical path.

Increasing the project schedule and budget to account for the expected risk time or risk cost is no guarantee of adequate protection against risk. The expected risk time and cost are the equivalent to the long-run averages, which result from repeating something many times; this is questionable in projects, since seldom are project activities identically repeated.

Table 11.9 EC computation.

WBS Element	BCE	Corrective Cost	Likelihood	EC
J	$10,000	$ 2,000	.2	$10,400
M	8,000	1,000	.3	8,300
V	16,000	4,000	.1	16,400
Y	10,000	6,000	.2	11,200
L	8,000	2,000	.3	8,600
Q	9,000	2,000	.1	9,200
W	5,000	1,000	.3	5,450
X	5,000	1,500	.3	5,750
Total		$71,000		$84,850

Table 11.10 ET computation.

WBS Element	BTE	Corrective Time	Likelihood	ET
J	6	1	.2	6.2
M	4	1	.3	4.3
V	6	2	.1	6.2
Y	8	3	.2	8.6
L	2	1	.3	2.3
Q	8	1	.1	8.1
W	1	1	.3	1.3
X	1	1	.3	1.3

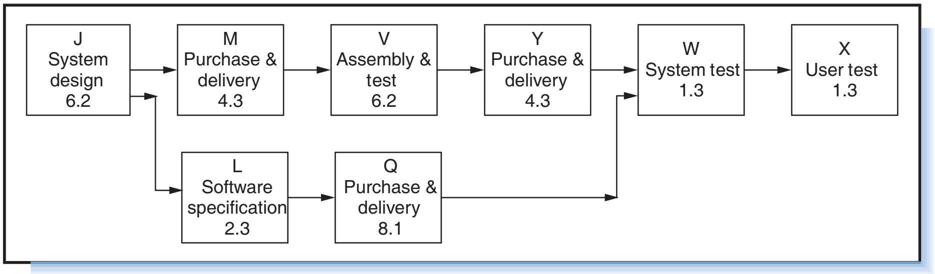


Figure 11.6
Project network, accounting for risk time.

Decision Trees[32]

A decision tree is a diagram wherein the tree "branches" represent different chance outcomes. It is used to assess which risk response among alternatives yields the best expected consequence.

One application of decision trees is to weigh the cost of project failure against the benefit of project success. Assume a project has a BCE of \$200,000 and a failure likelihood of 0.25 and, if successful, will yield a net profit of \$1,000,000.

The expected value concept can be used to compute the average value of the project. Assuming the project could be repeated many times, then it would lose \$200,000 (BCE) 25 percent of the time and generate \$1,000,000 profit the other 75 percent. Thus, the expected outcome would be

$$\begin{aligned}\text{Expected Outcome} &= (-\$200{,}000)(0.25)+(\$1{,}000{,}000)(0.75)\\ &= \$700{,}000\end{aligned}$$

This suggests that although there is potential to net \$1,000,000, it is more reasonable to use \$700,000 for the BCE. It also suggests that all project costs plus actions taken to reduce or eliminate the failure risk should not exceed \$700,000.

Another application of decision trees is in deciding between alternative risk responses. Suppose a project has a BCE of \$10 million, risk failure likelihood of 0.6, and a risk impact of \$5 million. Two strategies are being considered to reduce the risk likelihood (but not the risk impact):

Strategy 1 will cost \$2 million and will reduce the failure likelihood to 0.1.

Strategy 2 will cost \$1 million and will reduce the failure likelihood to 0.4.

The decision tree and resultant expected project costs are shown in Figure 11.7. The analysis suggests Strategy 1 should be adopted because it has the lowest expected cost.

Another application of decision tree analysis is the expected commercial value method used in project selection, discussed in Chapter 19.

Uncertainty and payoff tables

When there is no prior experience or historical data upon which to estimate the likelihood, then the expected-value risk consequence cannot be computed, and other criteria must be used to assess courses of action in the face of risk. This situation is referred to as *uncertainty*, which implies no information is available about what might occur. To determine the best strategy under uncertainty, begin by identifying possible alternative paths the project could take in response to factors over which management has no

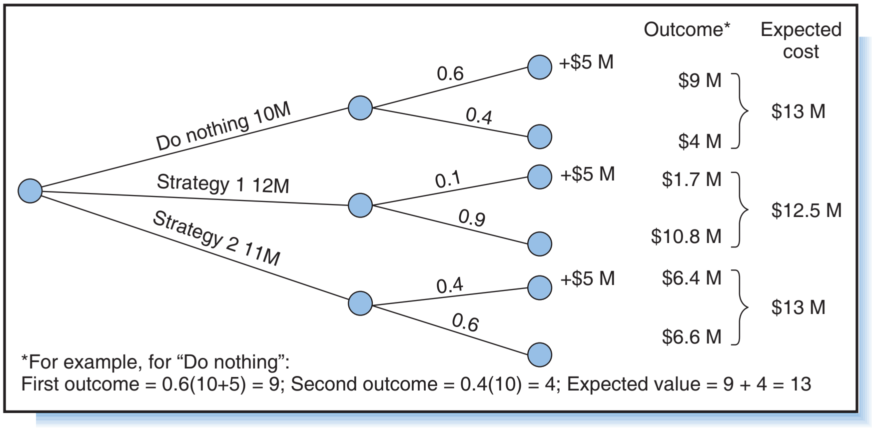


Figure 11.7
Decision tree.

control. These different paths are called *states of nature*. Consider different possible strategies or actions, and then indicate the likely outcome for each state of nature. The outcomes for different combinations of strategies and states of nature are represented in a *payoff table*.

For example, suppose the success of a project to develop Product X depends on market demand, which is known to be a function of particular performance features of the product. The development effort can be directed in any of three possible directions, referred to as strategies A, B, and C, each of which will provide the product with different performance features. Assume also that a competing firm is developing a product that will have performance features similar to those under Strategy A. When the product development effort ends, one of three future states of nature will exist: N1—no competing product enters the market for at least 6 months; N2—the competing product enters the market within 6 months of Product X; N3—the competing product is introduced before Product X. Suppose the likely profits in millions of dollars for the different combinations of strategies and states of nature are computed (shown in Table 11.11).

The question: Which strategy should be adopted? The answer: It all depends! If project sponsors are optimistic, they will choose the strategy that maximizes the potential payoff. The maximum potential payoff in the table is $90 million, which happens for Strategy C and State of Nature N1. Thus, optimistic project sponsors will adopt Strategy C. In general, the strategy choice that has the potential to yield the largest payoff is called the *maximax* decision criterion.

Now, if project sponsors are pessimistic, they will instead be interested in minimizing their potential losses, in which case they will adopt the strategy that gives the best outcome under the worst possible conditions. For the three strategies A, B, and C, the worst-case payoff scenarios are -$20 million, $50 million, and $40 million, respectively. The best (least bad) of the three is $50 million, or Strategy B. In general, the strategy that gives the best outcome out of multiple worst-case scenarios is called the *maximin* decision criterion.

Any choice of strategy other than the best one will cause the decision-maker to experience an opportunity loss or *regret*. This way of thinking suggests another criterion for choosing between strategies, the *minimax* decision criteria, which is the strategy that minimizes the *regret* of not having chosen the best strategy. Regret for a given state of nature is the difference in the outcomes between the best strategy and any other strategy. This is illustrated in a *regret table*, shown in Table 11.12. For example, given the payoffs in Table 11.11, for State of Nature N1, the highest payoff is $90 million. Had Strategy C, the optimal strategy, been selected, the regret would have been zero, but had strategies A or B been selected instead, the regrets would have been $30 million each (the difference between their outcomes, $60 million,

Table 11.11 Payoff table.

	States of Nature		
Strategy	**N1**	**N2**	**N3**
A	60	30	−20
B	60	50	60
C	90	70	40

Table 11.12 Regret table.

	States of Nature		
Strategy	**N1**	**N2**	**N3**
A	30	40	80
B	30	20	0
C	0	0	20

and the optimum, $90 million). The regret amounts for States of Nature N2 and N3 are determined in similar fashion.

To understand how to minimize regret, first look in the regret table at the largest regret for each strategy. The largest regrets are $80 million, $30 million, and $20 million for strategies A, B, and C, respectively. Next, pick the smallest of these, $20 million, which occurs for Strategy C. Thus, Strategy C is the best choice in terms of minimizing regret.

Another strategy selection approach is to assume that every state of nature has the same likelihood of occurring. This is called the *maximum expected payoff* decision criterion. Referring back to the payoff table, Table 11.11, assume the likelihood of each state of nature is one-third; thus, the expected payoff for Strategy A given outcomes from the payoff table is

$$1/3(60)+1/3(30)+1/3(-20)=23.33, \text{or } \$23.33 \text{ million}$$

The expected payoffs for strategies B and C, computed similarly, are $56.66 million and $66.66 million, respectively. Thus, Strategy C would be chosen as giving the maximum expected payoff. Notice in the previous examples that three of the four selection criteria point to Strategy C. This in itself might convince decision-makers that Strategy C is most appropriate.

Simulation

See Chapter 8

Application of simulation to project scheduling, illustrated in Chapter 8, gives the probability distribution of outcomes, which can be used to determine the probability (or likelihood) of a particular outcome such as completion cost or time. In turn, this can be used to establish an appropriate target budget or completion date or to prepare contingency plans. For instance, although the critical path in Chapter 8, Example 8.2, indicated the project would be completed in 147 days, the simulated completion time distribution in Figure 8.14 indicated that it would be 155 days, *on average*. Thus, at the *earliest*, the target completion should be set at 155 days, although the likelihood of *not meeting* that date would be 50 percent. Using the simulated probability distribution, a target completion date can be set such that the likelihood of not meeting it is more acceptable. Alternatively, given a pre-specified project target completion date, simulation can be used to estimate the likelihood of not meeting it and hence to decide whether to prepare contingency plans or change the project requirements, activities, or network.

Review Questions and Problems

1. Should risks that have low likelihood be ignored? Explain.
2. How does a person's risk tolerance affect whether he rates a risk high, medium, or low?
3. What is meant by risk of failure?
4. What factors make a project high risk?
5. Discuss the difference between internal risk and external risk. List sources of risk in each of these categories.
6. Describe each of the following sources of technical risk: maturity, complexity, quality, and concurrency or dependency.
7. Briefly describe the following risk identification techniques: analogy, checklists, WBS analysis, process flowcharts, and brainstorming.
8. Describe a cause-and-effect diagram. Pick a problem (effect) of your own choice and use a cause-and-effect diagram to illustrate it.
9. A project involves developing a system with state-of-the-art hardware and software, both complex, and where system performance depends on another, external system that is being developed concurrently. Based on Table 11.3, and assuming all risk factors are independent and equally weighted, what is the CLF for the project?
10. What is an influence diagram? How is it used to identify and analyze risk sources and to assign priorities to those sources?
11. Tables 11.3 and 11.4 are for illustration purposes. Discuss the general applicability of these tables to rating risks in projects. Would *you* use these tables to assess the risk likelihood and impact in a project of your choice? Why or why not?
12. Are equations (11.1), (11.2), and (11.3) good ways for rating the overall likelihood, impact, and consequences of risk? Discuss pros and cons of using these equations.
13. Discuss briefly each of the following ways to handle risk: transfer risk, avoid risk, reduce risk, contingency plan, and accept risk.
14. Think of a project you are familiar with and problems it encountered. List some ways the problems could have been avoided, and explain each of them.
15. What is a design margin? How does its application reduce risk?
16. One requirement of a power-generating system states that it must provide 500 kWh (kilowatt hours) minimum output. The system has three power-generating subsystems, X, Y, and Z. Constraints on physical size indicate that the output capacity of the overall system will be split among the three subsystems in the approximate ratio of 5:3:2. A 3 percent design margin is applied to the system and the subsystems. Note, because the power requirement is stated as *minimum* output, the target output will be 3 percent *above* the requirement.
    a. What is the target requirement output for the overall system?
    b. What are the target requirement outputs for each of the subsystems? (Remember, subsystem margins are in addition to the system margin.)
    c. Suppose that, at best, Subsystem X can be designed to meet only 47 percent of the power output requirement for the overall system. Assuming that Subsystems Y and Z can be designed to meet their respective design targets, can the output requirement for the overall system also be met?
17. List and review the principles of risk management.
18. How does risk planning serve to increase risk-taking behavior?
19. Risk management includes being prepared for the unexpected. Explain.
20. Can risk be eliminated from projects? *Should* management try to eliminate it?
21. How and where are risk time and risk cost considerations used in project planning?
22. Where would the maximax, maximin, and minimax regret criteria be used during the project life cycle to manage project risk?

23. Figure 11.8 is the network for the Largesse Hydro Project:

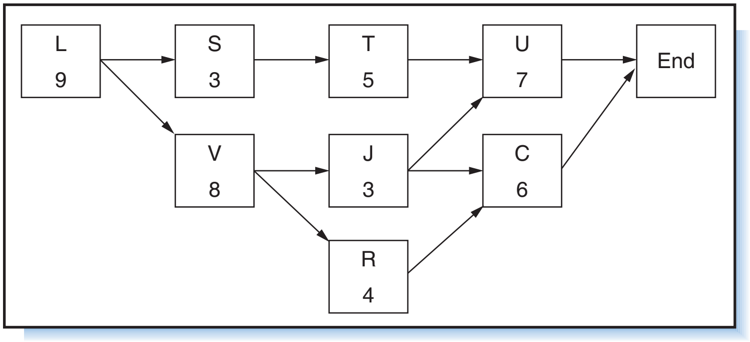


Figure 11.8
Largesse Hydro Project.

The following table gives the baseline cost and time estimates (BCE and BTE), the cost and time estimates to correct for failure, and the likelihood of failure for each work package.

			Corrective		
WBS Element	**BCE**	**BTE (wk)**	**Cost**	**Time**	**Likelihood**
L	$20,000	9	$4,000	2	.2
V	$16,000	8	$4,000	2	.3
T	$32,000	5	$8,000	2	.1
U	$20,000	7	$12,000	3	.2
S	$16,000	3	$4,000	1	.3
J	$18,000	3	$4,000	1	.1
R	$10,000	4	$4,000	3	.3
C	$15,000	6	$5,000	2	.3

a. Determine the risk time and risk cost for all the WBS elements of the project.
b. Consider the risk times on noncritical paths. Which activities and paths should be watched carefully as posing the highest risks?
c. What is the project expected cost (EC) and expected time (ET)?

24. The geographical location of the Largesse Hydro Project threatens it with weather-associated delays and costs. The bad weather likelihood is estimated at 0.30, with a potential impact of delaying work by 10 weeks and increasing the cost by $20,000.

a. Ignoring the time and cost risks in Problem 23, what are the expected project completion time and completion cost considering the weather risk?
b. What is the estimated expected project completion time and cost considering the weather risk and the risks listed in Problem 23?

25. Softside Systems has a $100,000 fixed-price contract for installation of a new application system. The project is expected to take 5 weeks and cost $50,000. Experience with similar

projects suggests a 0.30 likelihood that the project will encounter problems that could delay it by as much as 3 weeks and increase the cost by $30,000. By increasing the project staff 20 percent for an additional cost of $10,000, the likelihood of problems would be reduced to 0.10 and the delay and cost to 1 week and $8,000, respectively. Set up a decision tree to show whether Softside should increase the size of the project staff.

26. Corecast Contractors has been requested by a municipality to submit a proposal bid for a parking garage contract. In the past, the cost of preparing bids has been about 2 percent of the cost of the job. Corecast project manager Bradford Pitts is considering three possible bids: cost plus 10 percent, cost plus 20 percent, and cost plus 30 percent. Of course, increasing the "plus percent" increases the project price and decreases the likelihood of winning the job. Bradford estimates the likelihood of winning the job as follows:

	Bid price	P(win)	P(lose)
P1	C + 0.1C = 1.1C	0.6	0.4
P2	C + 0.2C = 1.2C	0.4	0.6
P3	C + 0.3C = 1.3C	0.2	0.8

In all cases, the profit (if the bid is won) will be the bid price minus the proposal preparation cost, or 0.02C; the loss (bid is not won) will be the proposal preparation cost. Prepare a decision tree for the three options. If Bradford uses the maximum expected profit as the criterion, which bid proposal would he select?

27. Iron Butterfly, Inc., submits proposals in response to RFPs and faces three possible outcomes: N1, Iron Butterfly gets a full contract; N2, it gets a partial contract (job is shared with other contractors); N3, it gets no contract. The company is currently assessing three RFPs, coded P1, P2, and P3. For P3, the customer will pay a fixed amount for proposal preparation; for P1 and P2, Iron Butterfly must absorb the proposal-preparation costs, which are expected to be high. Based upon project revenues and proposal-preparation costs, the expected profits ($ thousands) are as shown:

	N1	N2	N3
P1	500	200	−300
P2	300	100	−100
P3	100	50	25

To which RFPs would Iron Butterfly respond using the three decision criteria?

28. Frank Wesley, project manager for the LOGON project, is concerned about the development time for the robotic drone transporter. Although the subcontractor, Creative Robotics, has promised a delivery time of 6 weeks, Frank knows that the actual delivery time will be a function of the number of other projects Creative Robotics is working on. As incentive to speed up delivery of the transporter, Frank has three options:

S1: Do nothing.
S2: Promise Creative Robotics a future contract with Iron Butterfly.
S3: Threaten never to contract with Creative Robotics again.

He estimates the impact of these actions on delivery time would be as follows:

Payoffs:	Creative Robotics Workload		
Strategy	Slow	Average	Busy
S1	4	6	8
S2	3	4	7
S3	3	6	6

What strategy should Frank adopt based upon uncertainty criteria? Use criteria similar to the maximax, maximin, minimax, and maximum expected payoff, except note that the criteria must be adapted because here the goal is to *minimize* the payoff (time); this is in contrast to the usual case, which is to maximize the payoff.

Questions About the Study Project

1. What did managers and stakeholders believe were the major risks in the project?
2. In your own judgment, was this a risky project? Why or why not?
3. Was formal risk analysis performed? When was it done (in initiation, feasibility, etc.)?
4. Was a formal risk management plan created? Discuss the plan.
5. Was there a risk officer? Discuss her duties and role in the project.
6. How were risks identified?
7. How were risks dealt with (through risk transfer, acceptance, avoidance, reduction, etc.)?
8. Was a risk register used? Was it ever updated? If so, how often?
9. Discuss the use of contingency plans and budget and schedule reserves to cover risks.
10. What risks materialized during the project, and how were they handled?

CASE 11.1 THE SYDNEY OPERA HOUSE[33]

The Sydney Opera House (SOH) is a top tourist attraction and landmark for Sydney and all of Australia. It is a major arts center, although owing to its design, it is not necessarily the best place to hear opera. The SOH is visually spectacular and a magnificent structure (Figure 11.9), but it was a nightmare to design and build.

The original concept for the SOH was a sketch submitted by Danish architect Jorn Utzon. Judges selected it from an open competition that ended with 233 entries from 11 countries. Though happy to win, Utzon was mildly shocked. The concept that had caught the judges' attention consisted only of simple sketches, with no plans or even perspective drawings. Utzon faced the challenge of converting the sketches into a design from which a structure could be built, but he had no prior experience in designing and constructing such a large building. Because there were no plans, detailed drawings, or estimates of needed materials, there was little from which to base cost estimates. No one knew how it would be built; some experts questioned that it could be built at all. Interestingly, because the design was so unique, some people thought it would also be inexpensive to build. The initial cost was estimated at $7 million, to be paid by the government through profits from a series of state-run lotteries.

Figure 11.9
Sydney Opera House.
Source: iStock.

Engineers reviewing the concept noted that the roof shells were much larger and wider than any shells ever built. Further, because they stuck up so high, they would act like sails in the strong winds blowing up the harbor. Thus, they would have to be carefully designed and constructed to prevent the building from blowing away!

Government managers worried that people scrutinizing the design might raise questions about potential problems and stall the project. They thus quickly moved ahead and divided the work into three main contracts: the foundation and building except the roof, the roof, and the interior and equipment.

As experts had warned, the SOH project became an engineering and financial debacle, lasting 15 years and costing $107 million ($100 million over the initial estimate). Hindsight is 20/20, yet from the beginning, this should have been viewed as a risky project. Nonetheless, risks were downplayed or ignored, and little was done to mitigate or control them.

QUESTIONS

1. Identify the obvious risks.
2. What early actions should have been taken to reduce the risks?
3. Discuss some principles of risk management that were ignored.

CASE 11.2 INFINITY & BEYOND

Infinity & Beyond, Inc., produces high-tech fashion merchandise. The company's marketing department has identified a new product "concept" through discussions with three customer focus groups. The department is excited about the new concept and presents it to top management, who approves it for further study. Lisa Denney, senior director of new product development, is asked to create a plan and cost breakdown for the development, manufacture, and distribution of the product. Despite the enthusiasm of the marketing department, Lisa is unsure about the product's market potential and the company's ability to develop it at a reasonable cost. To her way of thinking, the market seems ill defined, the product goals unclear, and the product and its production technology uncertain. Lisa asks her chief designer to create some product requirements and a rough design that would meet the requirements and to propose how the product might be manufactured.

After a few weeks, the designer reports back with requirements that seem to satisfy the marketing concept. She tells Lisa that because of the newness of the technology and the complexity of the product design, the company does not have the experience to develop or even manufacture the product on its own. Lisa checks out several design/development firms, asking one, Margo-Spinner Works Company, MSW, to review the product concept. MSW assures Lisa that although the technology is new to them, it is well within their capability. Lisa reports this to top management, who tells her to go ahead with the development project.

Lisa sets a fixed-price contract with MSW and gives them primary responsibility for the development effort. MSW management had argued for a cost-plus contract, but when Lisa stipulated that the agreement had to be fixed-price, MSW said okay, only under the condition that it be given complete control of the development work. Lisa feels uncomfortable with the proposition, but knows of no other design company qualified to do the work, so she agrees.

QUESTIONS

1. Discuss the major sources of risk in this project.
2. What do you think about Lisa's handling of the project so far? Would you have done anything differently?
3. Discuss what Lisa and other parties did that served to increase or decrease the risks.

CASE 11.3 THE NELSON MANDELA BRIDGE[34]

Newtown, South Africa, is a suburb of Johannesburg that boasts a rich cultural heritage. As part of an attempt to help rejuvenate Newtown, the Nelson Mandela Bridge was constructed to link it to important roads and centers of commerce in Johannesburg. Spanning 42 electrified railway lines, the bridge (Figure 11.10) has been acclaimed for its functionality and beauty.

Lack of space for the support pylons (towers) between the railway lines dictated that the bridge design would have a long span. This resulted in a structure with the bridge deck supported by stay cables from pylons of unequal height. The pylons on the northern side are 48 meters high, and those on the southern side are 35 meters high.

The pylons are composite columns consisting of steel tubes that had to be filled with concrete after being hoisted into the vertical position. The decision was made to pump the concrete into the tubes through a port at the bottom of each tube. This had to be done in a single operation. Although

Figure 11.10
Nelson Mandela Bridge, Johannesburg.
Source: iStock.

the technology for casting concrete this way was not new, the columns were the highest in South Africa, and filling them would set a world record for bottom-up pumping of self-curing concrete.

The pump for the concrete was placed at ground level between the electrified railway lines, which exposed workers to the risks of being near continuous rail operations. The pumping method posed the risk of the stone aggregate and cement in the concrete mixture segregating in the pylon tubes before the concrete solidified, which would compromise the strength of the concrete. Another risk was that the pump might fail and result in the concrete solidifying in an uncompleted pylon, rendering further pumping of concrete from the bottom impossible. Two contingencies were considered: an additional pump on standby and completing the process by pouring concrete from the top of the pylon.

The concrete had to be transported by trucks to the site, which risked interrupting the concrete supply owing to traffic congestion in the city.

Despite working over a busy yard with trains running back and forth, no serious accident occurred at any time in the 420,000 labor-hours project. The pump never failed, and construction finished on time. The stay cables—totaling 81,000 meters in length—were installed and the bridge deck lifted off temporary supports, all while the electrified railway lines beneath remained alive. Upon completion of the bridge, some felt that the costs incurred to reduce the risks had been excessive; others held that the risks were too high and not enough had been done to reduce them.

QUESTIONS

1. How would you have identified the risks? (Refer also to methods in Chapter 10.)
2. Using the following table, discuss how the risks were addressed or how they could have been addressed. Include any additional risks you can think of.

Possible Risk Event	Plans to Address Risk				
	Accept	Avoid	Reduce	Transfer	Contingency (Plans and/ or Reserves)
Failure to make an acceptable profit					
Not finishing the construction by Nelson Mandela's 85th birthday					
Interference with rail activities					
Geological structures necessitating expensive foundations					
The concrete mixture segregating when pumped into the columns					
A pump failure while concrete is being pumped					
Interrupted supply of concrete due to trucks transporting concrete delayed in traffic					

3. State whether the risks listed in the table previously are internal or external.
4. Describe how you would determine the expected values of the risks listed in the table.
5. Compile a complete list of information that you would require in order to make an assessment of the risk of a pump failure.
6. What information do you think would have been available early in the project, and from where would you obtain it?
7. Draw a CE diagram showing different factors that could contribute to delaying the project.
8. Describe how risks are reduced over the lifespan of a project such as this one.
9. With reference to the concerns expressed upon completion of the construction, discuss the statement: "Risks always relate to the future. There is no such thing as a past risk."
10. Discuss the difference between good decisions and good luck.
11. How could a manager protect himself against the risk of making a decision that might later have negative implications?

CASE 11.4 SUNRISE BEACH DEVELOPMENT

A developer purchased a plot of land located in a prime real-estate district near the downtown of a large Florida city. The developer thinks the site, currently occupied by a long-closed factory, is ideal for two 10- to 20-story buildings to contain hotels, retailers, and condominiums. Located by the Atlantic Ocean, the site, to be called Sunrise Beach, enjoys a large stretch of beach that, the developer speculates, would draw numerous tourists and affluent professionals who work in the nearby city. A quarter of the land is marshy area occupied mostly by wildlife, and the developer is considering filling this in and constructing a third high-rise building. To lure tourists, the developer is also considering mounting a small roller-coaster atop one of the buildings, similar to an attraction in Las Vegas. Automobile parking would be provided under the buildings to maximize street-level retail space.

The site is located on a low-lying sliver of land separated from the mainland by a river, which is spanned by a small two-lane bridge, built 70 years earlier to accommodate factory workers. The developer plans to widen the bridge structure to handle increased traffic.

In the last 5 years, the region was hit by three hurricanes, and the city suffered considerable storm-surge flooding. Lately, some streets flood at high tide, even on sunny days.

QUESTIONS

Consider the following threats posed by climate change: rise in sea level, frequency and ferocity of storms, average atmospheric temperatures and urban heat islands, droughts, flooding, and coastal erosion. Given characteristics of the *project itself* (building size and use, parking, beach, roller coaster, bridge), to which threats is the project most sensitive? Next, consider aspects of the *project location* (coastal, low-lying, southeastern United States). To which threats is the project most exposed? Consider both current and future climates, and assume threats will worsen. Use tables similar to Tables 11.6, 11.7, and 11.8 to rate the project's sensitivity, exposure, and vulnerability to the threats.

Based on this assessment, would you recommend going forward with the project as currently planned? If not, what changes would you suggest to increase the project's resilience to the threats posed by climate change?

Notes

1. Quoted in Bernstein P. *Against the Gods: The Remarkable Story of Risk*. New York: John Wiley & Sons; 1996, p. 331.
2. Asked once to define certainty, John Von Neumann, the principal theorist of mathematical models of uncertainty, answered with an example: to design a house so it is *certain* the living room floor never gives way, "calculate the weight of a grand piano with six men huddling over it to sing, triple the weight," then design the floor to hold it. That will guarantee certainty! Source: Bernstein. *Against the Gods*, p. 233.
3. See Argus R. and Gunderson N. *Planning, Performing, and Controlling Projects*. Upper Saddle River, NJ: Prentice Hall; 1997, pp. 22–23.
4. Adapted from Michaels J. *Technical Risk Management*. Upper Saddle River, NJ: Prentice Hall; 1996, pp. 208–250.
5. Turoff M. and Linstone H. (eds). *The Delphi Method: Techniques and Applications*; 2002, http://is.njit.edu/pubs/delphibook/

6. The term "likelihood" is sometimes distinguished from "probability." The latter refers to values based on frequency measures from historical data, the former to subjective estimates or gut feel. If two of three previous attempts met with success the first time, then *ceteris paribus*, the probability of success on the next try is 2/3 or 0.67. Even without numerical data, however, a person with experience can, upon reflection, come up with a similar estimate that "odds are two to one that it will succeed the first time." Although one estimate is objective and the other subjective, that does not imply one is better than the other. Objective frequency data will not necessarily give a reliable estimate because a multitude of factors can influence outcomes; a subjective estimate, in contrast, might be reliable because humans often can do a pretty good job of assimilating lots of factors.
7. Roetzheim W. *Structured Computer Project Management*. Upper Saddle River, NJ: Prentice Hall; 1988, pp. 23–26; further examples of risk factors and methods of likelihood quantification are given in Michaels. *Technical Risk Management*.
8. See Dingle J. *Project Management: Orientation for Decision Makers*. London: Arnold; 1997.
9. See Gilbreath R. *Winning at Project Management: What Works, What Fails, and Why*. New York: John Wiley & Sons; 1986.
10. Roetzheim. *Structured Computer Project Management*, pp. 23–26.
11. Pool R. *Beyond Engineering: How Society Shapes Technology*. New York: Oxford University Press; 1997, pp. 197–202
12. Kotulak R. Key differences seen in Columbia, Challenger disasters. *Chicago Tribune*; February 2, 2003, Section 1, p. 5.
13. Pool. *Beyond Engineering*, pp. 207–214.
14. Michaels. *Technical Risk Management*, p. 40.
15. Statistics make it easy to depersonalize the consequences. For example, it is less distressing to state that there is a 0.005 likelihood of someone being killed than to say that 5 people out of 1,000 will be killed.
16. Mitroff I. and Linstone H. *The Unbounded Mind*. New York: Oxford; 1993, pp. 111–135.
17. Ibid.
18. European Commission. Planning for Adaptation to Climate Change: Guidelines for Municipalities. Life Project No LIFE08 ENV/IT/000436. N.d, circa 2013, https://base-adaptation.eu/sites/default/files/306-guidelinesversionefinale20.pdf, accessed May 1, 2019.
19. Tables 11.6–11.8 adapted from European Commission on Climate Action. Climate Change and Major Projects. European Union Publications Office; 2016, p. 7, https://ec.europa.eu/clima/sites/clima/files/docs/major_projects_en.pdf, accessed March 30, 2019.
20. Eisner H. *Computer-Aided Systems Engineering*. Upper Saddle River, NJ: Prentice Hall; 1988, p. 335.
21. See Grady J. *System Requirements Analysis*. New York: McGraw-Hill; 1993, pp. 106–111.
22. Eisner. *Computer-Aided Systems Engineering*, p. 336.
23. Ibid.
24. A breadboard is a working assembly of components. A prototype is an early working model of a complete system. Both are used to demonstrate, validate, or prove feasibility of a design concept. Breadboards, prototypes, and modeling are discussed in Chapters 2 and 10.
25. Wakabayashi H. and Cowan B. Vancouver International Airport expansion. *PM Network*; September 1998: 39–44.
26. Whitten N. Meet minimum requirements: Anything more is too much. *PM Network*; September 1998: 19.
27. DeMarco T. *The Deadline*. New York: Dorset House; 1997, p. 83; Yourdan E. *Rise and Resurrection of the American Programmer*. Upper Saddle River, NJ: Prentice Hall; 1998, pp. 133–136.
28. Dorner D. *The Logic of Failure*. Reading, MA: Addison-Wesley; 1997, p. 163.
29. Aronstein D. and Piccirillo A. *Have Blue and the F117A: Evolution of the Stealth Fighter*. Reston, VA: American Institute of Aeronautics and Astronautics; 1997, pp. 79–80.
30. Ibid., pp. 186–190.
31. For other approaches to risk time analysis, see Michaels. *Technical Risk Management*.
32. This section and the next address the more general topic of decision analysis, a broad topic that receives only cursory coverage here. A classic book on the subject is Luce R.D. and Raiffa H. *Games and Decisions*. New York: John Wiley & Sons; 1957.
33. Adapted from Kharbanda O. and Pinto J. *What Made Gertie Gallop: Learning from Project Failures*. New York: Van Nostrand Reinhold; 1996, pp. 177–191.
34. *Source:* Kromhout F. Divisional Director, Bridges, BKS (Pty) Ltd, Pretoria

Chapter 12

Project procurement management and contracting

Projects require resources—materials, supplies, equipment, and appropriately skilled labor, some or much of which is purchased or contracted. Indeed, in many projects, almost everything is purchased or contracted, and virtually nothing is done or produced internally. Procurement management addresses everything associated with procuring, both purchasing and contracting, although its main focus is on contracting and contracted work. It is a specialized function that can require legal and contract administration skills. In some projects, procurement management is overseen by the project manager, in others, by a specialized procurement division or department.

Contracted work involves, simply, hiring someone with the appropriate capability to do the work for you; in projects, it is widespread and common. Certainly, such work is every bit as important to project costs and profitability as work that is not contracted (i.e. done internally). Procurement management is a major aspect of project planning and control. Early in the project, procurement planning takes place to ensure that everything to be procured as necessary to meet budget, schedule, and requirements targets is identified and acquired. Once the project is underway, procurement control takes over to ensure that everything procured is monitored and steered to meet contracted requirements. All of this happens within the context of company procurement policies, procedures, and standards.

12.1 Procurement and procurement management

Terminology

Procurement represents activities related to bought or contracted resources, and it always involves two parties—a buyer and a seller. In the context of project management, the buyer is the project customer; and the seller is the contractor, developer, or system development organization (SDO). Two substitute terms for procurement are acquisition and purchase, although, strictly speaking, they are not the same. **Acquisition** refers to buying an *entire complex system* that is not well defined—including its design, development, ramp-up, and production; **purchase** refers to buying a standardized (off-the-shelf) product or part. The term "procurement" is typically reserved for buying a component or subsystem (more than a part but less than an entire complex system) according to the customer's specifications. Hence, it would be appropriate to say "acquisition of a nuclear power plant," "procurement of an automatic shut-down safety system," and "purchasing a batch of standard 1-inch nails." Hereafter, though, we will tend to ignore the distinctions and use the terms somewhat interchangeably.

Procured resources for projects generally fall into the following categories:[1]

1. **Products**—parts, components, subsystems, systems.
2. **Materials**—bulk (cement, lumber, wire, stone, etc.) and consumable (nails, rivets, fuel).
3. **Equipment—**refers to equipment the project team does not already own (shop tools, cranes and scaffolding, welding and testing equipment, computers and office facilities).
4. **Work**—contract labor as provided by trade workers (steel workers) and professionals (engineers, programmers).
5. **Services**—maintenance, operation, and repair (MOR) work for equipment and systems; work of an intellectual nature such as advising, management, consultation, and development of specialized products or technology.

To simplify, the previous categories are hereafter referred to as *procured goods, work, services—GWS*. Procured GWS can further be categorized as off-the-shelf (OTS) and custom-designed and built. *Off-the-shelf* represents familiar, in-stock, or readily available GWS that are not produced specifically for the project. So-called *custom-designed and built* GWS are *not OTS*; they must be developed, sometimes from scratch, just for the project. Custom-designed GWS in projects range from simple components and tasks in a work package to major portions of the project. The latter is called "turnkey" work or a turnkey project, meaning that a contractor fully designs, builds, and installs major components, equipment, or even the complete end-item system. The customer just "turns the key."

Referring to the source of procured GWS (the seller), the terms *supplier* and *contractor* are often used interchangeably, although distinctions apply:

1. **Supplier:** an individual or company that produces and sells GWS to the project. In this chapter, it refers to producers or providers of *mostly-OTS* products, materials, and equipment.
2. **Contractor**: an individual or company that provides the project with skilled labor (e.g. a union steelworker or freelance engineer); consultation; or custom-designed and built equipment, components, or systems.

Another term, not used in this chapter, is *vendor*, an individual or company that *sells* GWS but does not produce or provide it. A vendor is the go-between a customer and a supplier/contractor.

Important to note is that procurement also occurs *within* an organization; that is, one party in the organization does work or provides materials to another part—the customer and contractor are in the same organization. In such cases, there is no contract, per se, although there is a formal "understanding" between the parties about the work/materials to be provided. This chapter addresses procurement in the context of GWS acquired from outside the organization—that is, from outside suppliers and contractors.

Procurement process

Procurement management is a process with four phases that roughly correspond to the three phases of the project life cycle:[2]

1. *Define and Plan the Procurement*. During the conception and definition phases, the necessary resources (GWS) for the project are defined; those that can be acquired internally are distinguished from those that must be procured (the "make or buy decision").
2. *Conduct the Procurement*. In the definition phase, qualified sources for procured GWS are identified and solicited; those interested are evaluated, and the best are selected for the project; contract agreements are signed with these parties.

3. *Control the Procurement*. During the execution phase, the GWS provided by suppliers and contractors are monitored, assessed, and controlled.
4. *Close out the Procurement*. At the end of the execution phase, the contracts and work orders are formally closed out.

Although, as noted, the procurement management process roughly corresponds to the project life cycle, in fact, all aspects of procurement management might be happening throughout a project. Large projects involve many suppliers and contractors, some whose work is identified, started, and finished early in the project, others whose work is only identified and then started and finished much later.

Procurement and methods overlap with those in project planning (Chapter 6), quality management (Chapter 10), risk management (Chapter 11), project monitoring and control (Chapter 13), and project selection (Chapter 19). This chapter will elaborate on these activities, plus topics specific to just contracts and the contracting process.

See Chapters 6, 10, 11, 13, and 19

12.2 Define and plan the procurement

The procurement process initiates during the conception and definition phases, while requirements and project work are being defined, as discussed in Chapters 3, 4, and 5. As objectives, requirements, work packages, and the resources needed for them are being defined, options about ways to meet the requirements, do work, and procure resources are assessed. What equipment is needed and should it be rented, leased, or purchased; what materials are needed and from where should they be acquired; what work is needed, and can it be done "in-house" by the project team, or should it be done by a hired contractor? These are the types of questions project and procurement managers should begin asking during this phase.

See Chapters 3, 4, and 5

Requirements and work definition

Decisions about which work can be done internally and which externally apply to most everything in the project at all levels of the WBS. A role of project management is to make the distinction and decide. Every end-item and work package in the project will have procured GWS requirements, some of which will be shared among different elements of the end-item and among work packages. Items to be procured are identified during the WBS process, either while planning the work and resources needed for particular work packages or from realizing that entire work packages must be outsourced. In the former case, work package managers identify GWS within the package that must be procured (e.g. the work package "build wing" will require procuring carbon-fiber, aluminum, and other materials from suppliers); in the latter case, project managers recognize that certain (sometimes significant) portions of the project (*entire* work packages) will have to be outsourced (e.g. the work package "develop rocket motor" will require development, fabrication, and testing of a rocket—*all* to be provided by contractor).

When many contractors are hired or appointed by a customer to do the project work, the customer usually appoints one contractor to oversee and/or hire the other contractors; the former is called the **prime contractor**, the others are called **subcontractors**. In effect, the prime contractor is the customer to the contractors it manages and/or hires. More will be said about this later.

Make or buy

The actual decision about whether to do work internally or externally is called make or buy. It applies to a variety of situations (for example, whether to lease or rent, rent or buy, make or lease, etc.). The decision involves analysis of many factors; cost is often the major one and the decision is based upon break-even analysis. Commonly, however, the decision involves many considerations beyond cost, such as: should work be retained in-house to keep employees working; what is company policy about *how much* work should be contracted; are there qualified contractors available to do the work; can the work be done faster, better, or at lower risk by a contractor?

12.3 Conduct the procurement

Soliciting and evaluating bids

Once the decision is made about which GWS should be procured, the process moves to soliciting potential supplier/contractors. This is referred to as the *solicitation* or *conduct-procurement process*, which initiates by addressing all matters related to soliciting bids and proposals from potential suppliers/contractors. It includes preparing a "solicitation package," which includes:[3]

- Solicitation document(s) to be used (RFP, RFQ, RFT, as discussed later). These documents contain everything a bidder (supplier, contractor) would need to know to participate, for example:
    - A description of the work (SOW) requested by the customer
    - Instructions informing potential suppliers about how they should respond to the solicitation (e.g. proposal contents)
    - Documentation requirements to submit with the response (e.g. project plans)
    - A schedule for completing the solicitation process
    - Procedures for addressing questions and contacts
    - Plan of payment.
- List of qualified bidders
- Evaluation process and criteria to be used for evaluating proposals
- Bidders or pre-proposal conferences
- Methods to handle changes in proposals.

In many cases, much or all of the contents of this solicitation package is sent to each potential supplier/contractor.

The parties appearing on the list of bidders depend on the number of bidders available and qualified and on customer policy or preference. *Multiple sourcing* means that multiple qualified bidders are available and will be invited to bid on a competitive basis. *Single sourcing* means that among several available and qualified sources, one is preferred and just that one will be invited to bid; a variation of this is *sole sourcing*, which happens when there is one (and only one) bidder qualified and available to do the work (i.e. a monopolistic, non-competitive situation). What makes a bidder "qualified" is determined by customer screenings of potential bidders, sometimes based upon previous work completed for the customer or elsewhere, sometimes using information received from potential bidders in response to requests for information (RFIs) or requests for qualifications sent by the customer. A customer that has established a valuable long-term or prior relationship with a contractor, especially one with unique skills or capabilities, will often approach only that contractor, which is single sourcing. Some companies consider identifying qualified bidders an aspect of "strategic sourcing," which seeks to optimize a company's overall base of suppliers in terms of costs, delivery, and quality.

Two main methods are used for soliciting and selecting contractors, depending on the nature of the items or work to be procured: advertising/bidding (or tendering) and proposal/negotiation.

Advertising/bidding

When the scope of the project is somewhat simple, requirements are well defined, and bidders are pre-qualified to do the work, the customer advertises for bids online and through other media using an RFQ, RFB, RFT, or IFB (request for quotation, bid, or tender or invitation for bid—which are, in all cases, a request for a simple price quote). Sometimes "bidder's conferences" are convened to explain to bidders the work to be done and answer their questions. Each interested bidder then submits its quote or tender—its price to do the work via, usually, a "sealed bid," that is, a bid document enclosed in a sealed envelope. Selection of the supplier/contractor is based almost wholly on the lowest-price bid. There is no negotiation; in fact, when the bidding is competitive, negotiation is prohibited and even considered unethical. For OTS-type GWS, advertising/bidding is the appropriate solicitation method. Customers soliciting bids via this process must be careful to scrutinize the basis for a bidder's price estimates and question whether the bidder can realistically do the work for the bid price. In a practice called "buy-in," a supplier intentionally sets the price low enough to get the job (but not necessarily to cover project costs). The bidder hopes that cost overruns will be covered by the customer requesting changes to the contract that will be compensated at high prices, or by lucrative follow-up contracts with the customer. Buy-in can happen during either the bidding or negotiation but is more likely in (and somewhat encouraged by) the former.

Proposal/negotiation[4]

For large and somewhat undefined systems that require design, development, research, artistic work, or other intellectual input, the proposal/negotiation method is more appropriate than advertising/bidding. The customer sends an RFP, discussed in Chapter 3, to a short list of qualified bidders. The RFP might be preceded by an RFI or request for qualifications to determine whether the contractor is qualified and should be sent an RFP. Sometimes as part of the solicitation process, a so-called *pre-proposal* or *contractor conference* is held to explain to contractors the scope of the project, what the customer expects from them, and contractual requirements. (The contents and preparation of proposals are discussed in Chapter 3.)

See Chapter 3

Selection of the winning contractor is based on a combination of proposal scores and negotiation. Proposals submitted by the contractors are scored using a set of evaluation criteria that goes beyond price, for example, completion date, ability of proposed deliverables to meet requirements, contractor's reputation, customer–supplier work relationship, and so on. In some projects, the score determines the winning contractor; in others, it reduces the bidders qualifying to a select few, a process called *screening*. Those proposers that pass screening are invited to enter into negotiation. Methods for scoring and screening are discussed in Chapters 3 and 19.

See Chapters 3
and 19

Sometimes the selection process is quite secretive. Although the evaluation criteria might be published, details of the evaluation process and criteria weights might not be. The process and the members of the evaluation committee are held in strict confidentiality. All of this is to preclude bidders from influencing the evaluators and the evaluation process and assure all parties of a "level playing field." During the negotiation, the customer and individual pre-selected contractors meet to hammer out specific technical details or terms of the proposal and to reach a contractual agreement on time, schedule, and performance requirements. Throughout negotiation, the project manager pushes the merits of his proposal; his goal is to obtain the best possible agreement for his company. In countering any customer objections to the proposal, the project manager's best defense is a well-thought-out project plan that shows what can or must be done to achieve the desired results. The project manager must be intimately familiar with the technical details of the proposed system's design and related costs. Sometimes the contract will include incentive or penalty clauses as inducements to complete the project before a certain date or below a certain cost. To competently negotiate such clauses, the project manager must be familiar with the project plan, especially those parts of the schedule, work, or price that are relatively "fixed" and those that are flexible and can be negotiated. Among the flexible parts, the project manager needs to know the maximums and minimums (in terms of schedule, price, and performance) that her company, the contractor, is willing to accept.

To be able to negotiate from a competitive position, the project manager must try to learn as much as possible about the customer. She should determine if the customer is under pressure to make a particular decision, faces an impending fiscal deadline, or historically has shown preference for one particular approach or contractor over others. She needs to know the customer's min-max positions regarding price, performance, delivery, and so on. The project manager also needs to know about competitor proposal bidders—their likely approach to the problem, costs, and competitive advantages and disadvantages. She learns this from historical information, published material, or employees who once worked for the competitors. (Relying on the last source is ethically questionable and, of course, works against the contractor whenever competitors hire its employees.) Negotiation is the last activity before a contract agreement is reached; however, the negotiation *process* often begins earlier during proposal preparation, because terms in the proposal must be mutually consistent and acceptable to both customer and contractor. During negotiation, terms in the proposal related to performance, schedules, and price are reviewed and converted into a legal agreement that is acceptable to both parties. In highly competitive situations, the customer will try to play contractors against one another, seeking to raise performance specifications while shortening the schedule and decreasing the price.

Although in theory, negotiation is the last formal opportunity to correct misunderstandings in the RFP/proposal process and reach a final contract agreement, the fact is, some customers are *always* negotiating—informally—to get a better deal, even after the project is long underway. Contractors must be wary of saying and writing anything that might be construed as a promise to deliver beyond what is specified in the contract.

In some cases, following selection of the winning bidder, the unselected bidders can request an explanation from the customer about why they lost. This is to aid the bidders in preparing future proposals or assure them that the selection process was fair.

It should be obvious that proposal/negotiation is more time consuming and expensive than advertising/bidding, since it involves considerable effort in preparing and evaluating proposals and negotiating contract terms. (This is not to say that advertising/bidding, per se, is inexpensive, since it too can involve considerable effort to estimate and administer the cost—even for a well-defined job.) Nonetheless, while unnecessary for standardized projects wherein project work and costs are fairly well known, in situations where the need, problem, requirements or outcomes are ill defined or unknown; the work is uncertain; and the customer must rely on a contractor to provide the solution, proposal/negotiation is the appropriate (and necessary) approach for soliciting and selecting bidders.

Contract award

The solicitation or *conduct-procurement* process ends with the selection of (or "award" to) a contractor and signing a contractual agreement. This agreement contains a SOW, perhaps similar to the SOW in the original proposal or RFP, modified to reflect negotiated and mutually agreed-to adjustments. This so-called *contract statement of work* (CSOW, also called *procurement statement of work*) specifies the contractor's expected performance in terms of work scope, requirements, end results, schedules, costs, and so on and also conditions under which deliverables or end results will be accepted by the customer. Failure to state these conditions clearly can lead to later disputes and project delays.

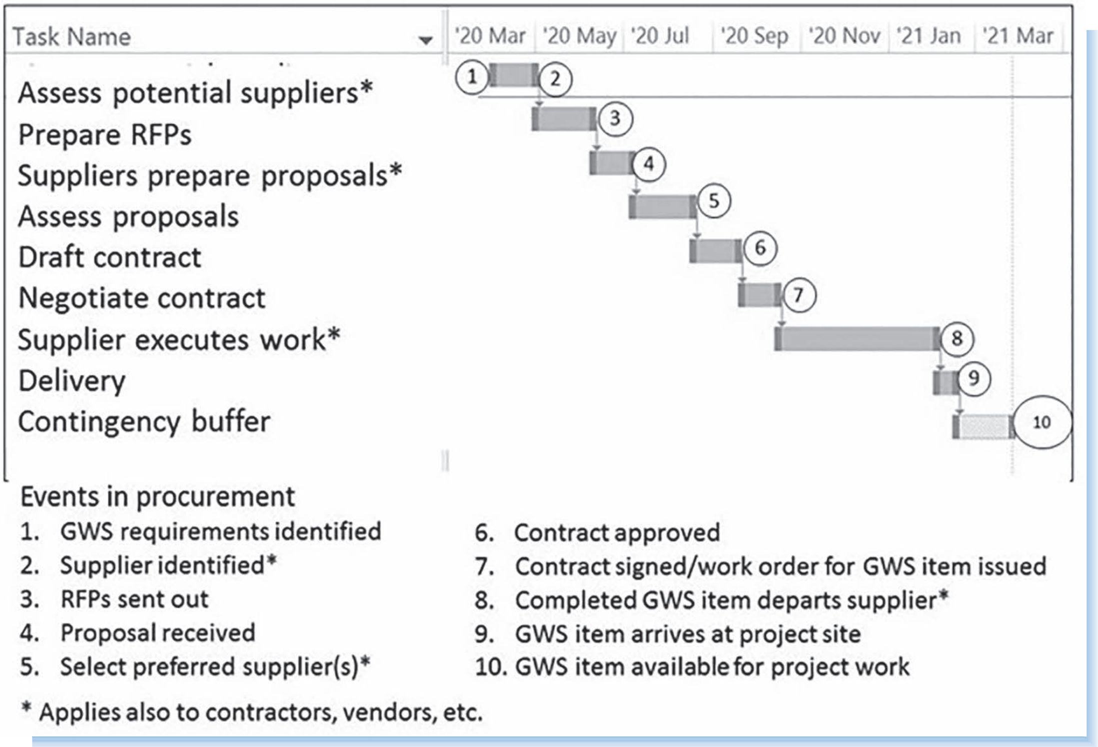
Before work can actually begin, however, requirements as specified in the CSOW must be translated into terminology that everyone in all the involved departments and subcontractors understands; these translations appear as the CSOW in contracts with every supplier and subcontractor. These CSOWs must be identical interpretations of the requirements and work as specified in the CSOW for the entire project. Broken down further, these CSOWs appear on *work requisitions* or *work orders* to inform every party about the work they are expected and authorized to do.

Changes to any contractual agreements thereafter must follow formal change procedures—change requests, reviews, approvals, and, sometimes, contract renegotiation.

Procurement schedule

Associated with each procured GWS is a schedule specifying when the item is needed and when procurement activities must begin. All procured GWS must be scheduled to allow enough time to conduct the solicitation process and for the items to be delivered (and/or designed and built) and installed as needed in the project. Figure 12.1 shows the schedule for a procured GWS item. It is prepared by working backward, starting with the date when the GWS item must be completed and/or available in the project (Event 10). This scheduling procedure is repeated for every procured GWS item. The schedules are integrated with the project schedule to ensure that all procurement-related activities happen far enough in advance that GWS items will be available when needed in the project.

Of course, preparing such a schedule requires knowing the lead times for each of the procured activities—the time needed for, for example, suppliers and subcontractors to prepare proposals, the project team to evaluate proposals and negotiate and issue contracts, and suppliers/contractors to fulfill work orders (which, for special design-build items, could be substantial). It is not uncommon, especially in international projects, for these times to be grossly underestimated and subsequently the project delayed. The schedule in Figure 12.1 starts at the point where GWS requirements have already been identified, which happens early in the project definition phase when project work and resources are being identified. Procured GWS require the same consideration of responsibility, budget, quality, and risk as internal aspects of the project; hence, all these matters must also be addressed in the project plan.



Events in procurement

1. GWS requirements identified
2. Supplier identified*
3. RFPs sent out
4. Proposal received
5. Select preferred supplier(s)*
6. Contract approved
7. Contract signed/work order for GWS item issued
8. Completed GWS item departs supplier*
9. GWS item arrives at project site
10. GWS item available for project work

* Applies also to contractors, vendors, etc.

Figure 12.1
Procurement activities schedule.

Logistics plan

Logistics relates to the transport and storage of materials. In projects that are materials intensive, the loading, unloading, transportation, inspection, clearance and approval, and storage of materials can be major issues. For example, consider a large building project and the importance of timing the arrival of materials (steel, pipes, concrete slabs) to coincide with when those materials will be needed for the building. Obviously, the materials cannot arrive late, because that will delay the project. But equally serious is when the materials arrive early. Where do you *put* them? And where do you put the truck that brings them? In congested urban areas, there simply is no space, and if there is, materials delivered early are subject to damage, deterioration, and theft. In urban areas with high traffic and narrow roadways, clogged streets might constrict the number of deliveries received per day and, *de facto*, the work to be scheduled throughout the project. Whenever GWS items cannot be scheduled to arrive *just in time*, provision must made to store and protect them, which on large projects can be costly.

12.4 Control and close out the procurement

Contract administration

From the time when the contract is signed until the project is closed out or terminated, the contractual agreement must be *managed*, which means updating the contract with respect to ongoing changes in the project, customer needs, and contractor capability and checking that all work conforms with the agreement. This process, called *contract administration*,[5] enables the customer to retain a measure of control over contracted work. To exercise that control, however, the contract must clearly specify the project areas over which the customer is authorized to monitor progress and, perhaps, to supervise work.

In many projects, this aspect of procurement management is overseen by a *contract administrator*. The customer might have a contract administrator to oversee contract-related matters with all individuals and companies it hires; in turn, these contractors might have their own contract administrators to oversee contract-related matters with their customers and their own contractors, that is, subcontractors.

The role of contract administration is to ensure that commitments made by the developer/contractor and the customer as specified in the contract are met. It is an aspect of procurement management that pertains exclusively to contracted work and relations between the customer and contractors. It can include any and all of the following: authorizing work to begin; monitoring work with respect to budgets, schedules, and technical performance; ensuring quality; insuring compliance to warranties (contractors' responsibilities); managing waivers and changes; checking for default or breach of contract (failure to meet commitments); resolving disputes; and closing out or terminating the project.

Contract administration is also responsible for ensuring that the customer is invoiced for deliverables specified in the contract throughout the project and that contractors and suppliers are paid for GWS received. For simple projects, billing and payment tracking is done through the contractor's accounts receivable system; for large, complex projects, it is handled through a dedicated billing and payments tracking system.

Managing changes

Among the reasons for changes in contracted work are:[6]

- Scope or other changes requested by the customer
- Impossible-to-meet requirements
- Misinterpreted contract terms

- Accelerated work
- Late or unsuitable information or resources provided by the customer
- Poor cooperation.

All requests for changes in contracted work, whether customer or contractor initiated, are assessed against conditions as stated in the contract. Requested changes that deviate from the contract are implemented only after the customer approves and the contract is modified. (Procedures for change control are described in Chapter 13.) Sometimes changes result in adjustments to contractual compensation or payments. If not properly handled, such changes can lead to litigation.

See Chapter 13

Inspection, acceptance, and close-out/termination

Contract administration is responsible for determining whether project end-items meet requirements as specified in the contract and whether all, some, or none of the deliverables should be accepted. It also decides situations where the project or certain contract work should be prematurely terminated, such as a contractor's failure to meet schedule, cost, performance, progress, or other contract obligations. Sometimes the customer requires additional specific procedures for testing, monitoring, and reporting, in which case these must be incorporated into the contractor's project tracking and control system.

At close-out, the product or deliverable is formally handed over to the customer. Most of the responsibilities for close-out as described in Chapter 5 fall under contract administration, but specifics vary, depending the project and the contract. For example, the customer might have to pay for work underway but not completed/accepted, or the contractor might have to repay the customer for any advances received.

See Chapter 5

The way this happens can depend on conditions as stated in the contract. Some contracts specify a *first handover at completion* and then a *second handover after a defects liability period* (a.k.a. retention period, guarantee period, and maintenance period). At first handover, the customer must seek to identify and report all *patent defects,* which are deviations from specifications that someone qualified could readily detect, and that the contractor must remedy. Thereafter, the contractor is liable only for rectifying *latent defects*, which are defects that could not be detected through a reasonable inspection at first handover. If, for instance, it wasn't raining at the time of the first handover, a roof that leaks later *when it does rain* would be considered a latent defect.

The second handover affords the customer more time to identify deviations from specifications or substandard workmanship. After second handover, the contractor is no longer liable for defects; any *retention fees* withheld by the customer to ensure compliance to the contract are paid to the contractor.

12.5 Contracting

Contracting environment[7]

Contracting is ubiquitous in projects. Most projects, even internal ones, involve some degree of external contracting, since so often the customer must hire someone external to perform at least some of the work. As mentioned, in many projects, most *everything* is provided by contractors. As Figure 12.2 illustrates, the project involves many organizations interlinked by contractual agreements. The customer might contract with a principal party (a "prime contractor" or SDO) to oversee the project; in turn, this party contracts with other parties—subcontractors (including consultants, material suppliers, and contract labor)—for portions of the project. These subcontractors might then contract with still others. In very large ("mega") projects where no one company is willing to assume the risks of the entire project, multiple companies will team up and form a "joint venture" to share the risk associated with managing

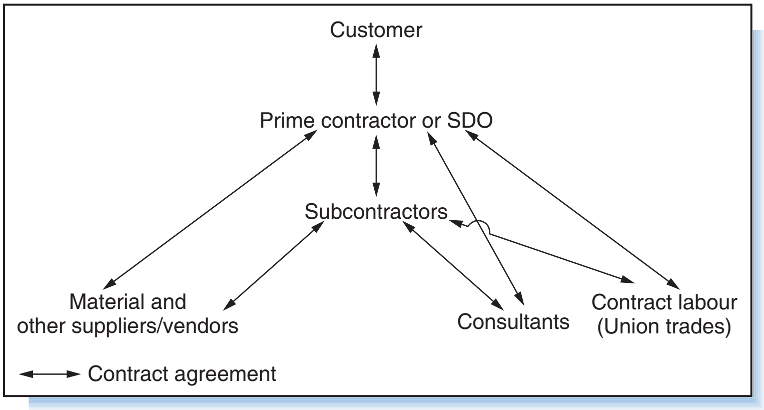


Figure 12.2
Contracting parties in a project.

See Chapter 16

the project and overseeing numerous subcontractors. This was the case of Boston's Big Dig (see example 16.5 in Chapter 16).

The solicitation process described earlier happens everywhere throughout the project, addressing the question of who will do the work. Whether it is the customer, prime contractor, or subcontractors down the line, any party that contracts work or acquires material or services from other parties follows such a similar process to identify, choose, and work with those most qualified.

Subcontracting[8]

Every party in Figure 12.2 must decide what portions of the project it will do itself and what it will contract others to do. For example, typically in a construction project, the general or prime contractor will assemble the building structure but then hire others to do specialized work such as wiring, plumbing, ventilation, and interior details.

How much of and what kind of work the prime contractor should do is the customer's choice. A customer that wants the contractor to do all the work it proposes (and not give it to subcontractors) specifies that in the RFP or RFQ. Other possibilities include allowing the contractor to freely select its own subcontractors, to select subcontractors only with the customer's approval, or to select subcontractors from a customer-provided list. In the most extreme case, the customer *nominates a supplier*, which is a particular subcontractor the contractor must hire. In general, the more the customer intervenes in subcontracted work, the less accountable is the prime contractor for that work. A contractor that is wholly free to select its own subcontractors is wholly accountable for the subcontractors' work; accountability shifts wholly to the customer when it specifies the subcontractors the contractor must hire. RFPs usually address this, stipulating that contractors' proposals indicate which project work they intend to do versus which they will give to subcontractors and names of the subcontractors. As a rule of thumb, it is generally a good idea to let the prime contractor select subcontractors; this allows the contractor to build the best "contractor team" based upon experience, especially since the prime contractor will have to manage and be responsible for the subcontractors once the project begins.

Example 12.1: Project Contracts in Construction

Large construction projects are often in the news—sometimes because of problems owing to cost overruns or schedule slippages. Although many factors are cited (materials shortages, labor union problems, weather, inflation), the cause is frequently poor procurement management and lack of control. Often, the project manager is either the designer/architect or the builder. This works on small construction jobs but not on big jobs because designers and builders each represent separate interests. When things go wrong, both tend to argue their own self-interests, and there is no one impartial who can reconcile differences in the best interests of the customer (owner or developer).

A better arrangement is when the customer appoints an independent project manager who will represent her interests during the entire project—including both design and construction. Figure 12.3 shows two possible ways to arrange this: engineering, procurement and construction management (EPCM) and engineering, procurement, and construction (EPC). In the figure, EPCM and EPC represent the independent project manager. In the EPCM case, the customer contracts directly with the designer contractor and building contractor (general contractor); in the EPC case, the independent project manager does the contracting. In either case, the central position of the project manager enables her to monitor and coordinate all design and building tasks in accordance with the best interests of the customer.

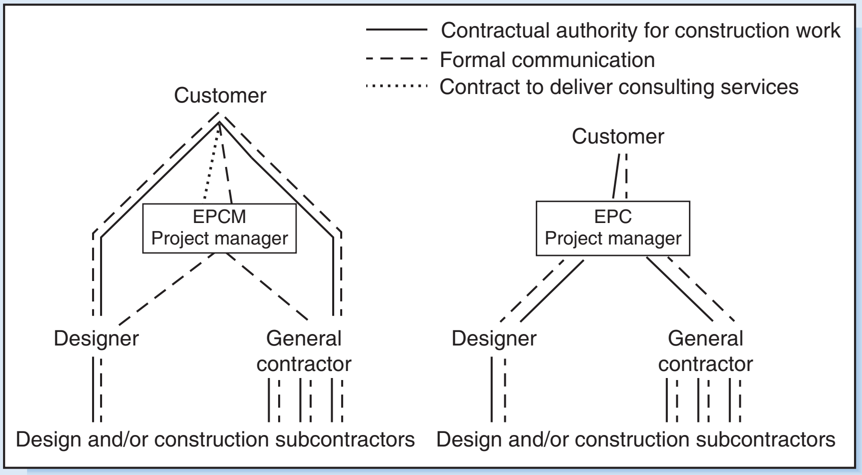


Figure 12.3
Alternative types of project manager in a construction project.

The main role of the EPCM project manager is to ensure that the design meets the customer's cost and building requirements and the general contractor's work is executed in accordance with contract specifications and at a fair price. The project manager is involved in everything—overseeing preliminary design, subcontracting, and site work according to the design specifications, schedule, budget, and safety rules. Although the customer signs contracts with the designer and the builder, the project manager acts as the customer's agent to facilitate relationships among the parties.

A project manager in EPC acts in a similar way as the EPCM; however, since the EPC project manager directly contracted with the designer and the general contractor, she has *full authority and accountability* for all elements of both the design and the building; typically this is a "turnkey" project; the customer has little involvement in the project and certainly less than in the EPCM case. Because the customer is less involved with contractors and the project manager has greater authority, the EPC arrangement is less risky to the customer than EPCM. Although common in construction, EPC and EPCM agreements are used in other kinds of projects as well.

Even though a contractor might be capable of doing all the work itself, it may choose to subcontract because it has limited capacity or believes a subcontractor could do the work for lower cost or less risk. In development projects of large-scale systems, the prime contractor will usually design the overall system and major subsystems and perhaps produce some elements of the system itself, but it will subcontract production of all others. In projects where significant portions of project work are to be subcontracted, the customer often mandates the scope of the subcontracted work and the criteria for selection of suitable contractors or suppliers.

Usually, obligations in subcontracts exist solely between a contractor and subcontractor. That means, for example, that the contractor (not the customer) is responsible for ensuring that a subcontractor performs work according to the requirements, and the contractor (not the customer) is obligated to pay for the subcontracted work. The contractor is also responsible for the quality of delivered materials, equipment, or components and inspection at any subcontractor offsite facilities. Similarly, any communication about customer changes to requirements is channeled through the contractor to the subcontractor. (If, however, you, as a subcontractor are having trouble getting paid by the contractor, you might appeal directly to the customer to pressure the contractor into paying you.)

In preparing a proposal, the contractor must determine which work specified in the RFP it can do internally and which it will contract out. Then, of course, it must be certain there are subcontractors and suppliers who are qualified and will be available to do work and provide materials when needed for the project. In other words, the contractor must follow the procurement management process in defining work and in soliciting and hiring contractors—ideally before it submits a proposal that includes the subcontracted work.

12.6 Kinds of contracts

A contract is an agreement between two parties wherein one party (the seller—project contractor) promises to provide a product or service to another (the buyer—project customer), typically in return for payment. The project or service is specified in either of two ways:

- The seller is to provide a deliverable or end-item: the contract is fulfilled upon its acceptance by the customer.
- The seller is to provide a "level-of-effort" or period of work; that is, provide specific labor, skills, or facilities for a specified number of labor-hours/days or time period.

Most contracts stipulate the following:

- Scope of work to be done or items to be sold, including support and side items such as manuals, documentation, and training. Any requirements, specifications, and standards referenced are considered as part of the contract.

- Contractor responsibilities in providing the work or items.
- Time schedule allowed.
- Customer duties regarding payments (including a schedule for milestone payments).
- Ways to handle changes to the contract and disputes.
- Ways to handle risks, including warranties, penalties, or bonuses/incentives.

Contracts may also specify the following variables:

C_{ex}	Target (expected) cost under normal circumstances. "Cost" represents monies expended by the contractor in performing the work.
C_{ac}	Actual, reimbursable cost of the project at completion.
Fee	Amount paid to the contractor in excess of reimbursable costs.
Price	Price the customer pays for the project. Price includes reimbursable costs incurred by the contractor plus the contractor's fee.

For complex work, "customized" contracts are drafted by project teams in collaboration with company lawyers. For less complex, more standard work, however, "standard" contract formats or templates are more common. An advantage of standard formats is that they use familiar terminology and in the event of litigation are somewhat straightforward to interpret. Standard-format contracts have been developed by professional societies, large companies ("boilerplate" contracts), and some countries and states.[9]

Within the standard contract format are several kinds of contracts; the two fundamental ones are *fixed price* and *cost reimbursable* (or *cost plus*). In the fixed-price contract, the price is agreed upon and remains fixed as long as there are no changes to the project scope or provisions in the agreement. In the cost-reimbursable contract, the contractor is reimbursed for all or some expenses incurred during the project and, as a result, the final price is unknown until the project is completed. Within these two types are variations, including some with incentives for the contractor to meet cost, time, or performance targets. Most projects involve multiple contractors and hence multiple contracts and contract types, for example, cost plus for engineering and design work and fixed price for construction work. The basic forms of contracts are described next. It must be noted that certain industries require specific contract forms beyond the ones described here.[10]

12.7 Fixed-price contracts

Under a fixed-price (FP) or "lump-sum" agreement, the contractor agrees to perform all work at a fixed price. The contractor must be careful in estimating the target cost because, once agreed upon, the price will not be adjusted. If the contractor in the bidding stage estimates the target cost too low, he might win the job but make no profit or suffer a loss. Types of fixed-price agreements include firm fixed price, fixed-price incentive fee, and fixed price with economic pries adjustment. These are illustrated next.

Firm fixed price contract

With a firm fixed price (FFP) contract, no matter what the project actually ends up costing (C_{ac}), the price to the customer remains the same. Suppose in the contract agreement: Cost estimate, $C_{ex} = \$100,000$, Fee = \$10,000, and Price = \$110,000. Under an FFP, the price to the customer will remain \$110,000, no matter what.

When project work is straightforward and can be specified in detail, everyone prefers this kind of contract. Customers like FFPs because they are less concerned about project costs. Contractors like it because customers tend to request fewer changes to the contract.

The disadvantage of an FFP contract is that it can be difficult and costly to prepare. The contractor risks underestimating the cost and losing money on the project, which might motivate him to cut corners (use cheaper-quality materials, perform marginal workmanship, or extend the completion date) to reduce costs. To counteract this, the customer can specify in the contract rigid end-item specifications and completion dates and closely supervise the work. If, however, the project gets into serious trouble, bankrupts the contractor, and leaves the project incomplete, the customer may be subject to litigation from other stakeholders.

FFP contracts do not work well in large, high-risk projects. Project sponsors might want to impose an FFP contract, thinking it transfers the risk of overruns to the contractor. Sometimes it does, but when a large project gets into trouble and the contractor cannot absorb the overrun, the sponsor will have to keep paying if it wants the project to finish.

FFP contracts can be short sighted. A project's success often depends on the performance of the end-item long after the project is completed, yet the "fixed price" may force contractors to jettison things (cut corners) in the end-item that diminish that performance.

Fixed price incentive fee contract

When a contractor is unwilling to enter into a fixed-price agreement and the customer does not want a cost-reimbursable contract (discussed later), an alternative is an *incentive* contract. The purpose of the incentive is to maximize contractor performance: good performance is rewarded with higher profits, poor performance with lower profits or losses.

In some cases, the incentive is determined by the *cost sharing ratio* (CSR). A CSR of m/n (where $m + n = 100$) means that for any difference (savings or overrun) between target and actual cost, the customer gets n percent of any savings and pays m percent of any overrun. Project price is computed as

Under target cost: Price = $C_{ac} + (C_{ex} – C_{ac}) \times n$ + Fee
Over target cost: Price = $C_{ex} + (C_{ex} – C_{ac}) \times m$ + Fee

A CSR of 80/20, for example, means that the customer and the contractor split the costs 80/20. This encourages the contractor to keep costs low because he *pays* 20 cents on every dollar spent above C_{ex} but *earns* 20 cents more on every dollar saved below C_{ex}. As a further inducement to keep costs low, the ratio might be changed for costs above C_{ex} so that the contractor must pay a higher percentage. Such contracts appeal to the contractor, who can earn a greater profit, and the customer, who pays a lower price. (Sometimes two CSRs are used, one for costs under target, the other for costs over target. See end-of-chapter review Question 22.)

The efficacy of incentive contracts is open to debate; some studies say they work, others say they don't or work only marginally at best.[11] Incentive contracts with penalties can lead a contractor to *overstate* the estimated cost so as to ensure it will complete the project *below* that cost and earn a bonus. The customer will then believe the incentive worked, when really it only served to elevate the target cost!

Incentives also pose an issue of trust between customer and contractor. What they implicitly say is that I, the customer, "don't trust that the fee alone is enough to get you, the contractor, to hit the target (cost, price, date, performance, etc.) and that I need to bribe you to do so."[12]

Different kinds of incentive contracts place the incentive emphasis on different targets: cost, price, schedule, end-item performance, or some combination. A *fixed price incentive fee* (FPIF) contract (Example 12.2) places a ceiling on both project price and sometimes profit. The contractor negotiates to perform the work for a target price based upon a target cost (C_{ex}) plus a fee, but the customer negotiates the caps on price and profit. If the project ends up costing less than the target cost, the contractor can earn a higher profit, but only up to the maximum. If there is a cost overrun, the contractor will have to absorb some or much of it.

Example 12.2: Fixed-Price Incentive Fee Contract

Contract agreement:

Cost estimate, C_{ex} = \$100,000
Fee = \$10,000
Target Price = \$110,000
Maximum price = \$125,000 (fee + reimbursement) Customer will pay no more than this.
Maximum profit = \$15,000 Contractor will profit no more than this.
Cost sharing: CSR = 50/50

If C_{ac} < \$100,000, customer will reimburse C_{ac} plus an additional 50 percent of amount below \$100,000, as long as the additional amount does not exceed \$5,000 (and the amount plus fee does not exceed \$15,000). If C_{ac} > \$100,000, customer will reimburse \$100,000 plus an additional 50 percent of amount above \$100,000, but the price cannot exceed \$125,000. Again, the incentive is for the contractor to keep costs low and not exceed \$100,000. However, because the contractor cannot earn a profit of more than \$15,000, there is little incentive for the contractor to cut corners to increase profit.

Suppose C_{ac} is \$80,000 (\$20,000 under C_{ex}). The contractor gets paid \$80,000 plus the \$10,000 fee, plus an additional \$5,000 for the cost savings (50 percent of the \$20,000 savings is \$10,000, of which only \$5,000 is allowed because the maximum allowable profit is \$15,000). Total price to customer: \$95,000, a \$15,000 savings from the target price.

Suppose C_{ac} is \$200,000 (\$100,000 over C_{ex}). Fifty percent of the overrun is \$50,000; that plus the fee plus \$100,000 is \$160,000. But the specified maximum price is \$125,000, which is all the customer pays. The contractor suffers a \$200,000 – \$125,000 = \$75,000 loss.

FPIF contracts are not true fixed-price contracts. They invite a contractor to negotiate an unrealistically high C_{ex} so that extra profits can be made through the incentive features. But unlike CPFF contracts (discussed later), they provide some assurance of a maximum price and some protection against the contractor cutting corners to gain a hefty profit. FPIF contracts apply to long-duration or large-production projects but not to development or other projects where the target cost is difficult or impossible to estimate.

Fixed price with economic price adjustment[13]

Projects with long lead times such as construction or production have contract *escalation provisions* that protect the contractor against increases in materials, labor, or overhead costs. For example, the contract price may be tied to an inflation index and be adjusted in the advent of inflation, or it may be *re-determined* as actual costs become known. In the latter case, the initial price is negotiated with the stipulation that it will be re-determined later to reflect actual cost data. There are a variety of *fixed price with economic price adjustment* (FP-EPA), also called *fixed price with redetermination*, contracts: some establish a ceiling price for the contract and permit only downward adjustments; others permit upward and downward adjustments as demanded by either party; some establish one readjustment at the end of the project, and others allow periodic readjustments at specified times. Each price redetermination is formalized by modification to the contract. FP-EPA contracts are appropriate wherever design work is difficult to specify or the final price cannot be estimated for lack of accurate cost data.

Because the only requirement to renegotiate the price is substantiating cost data, FP-EPA contracts tend to induce inefficiencies. After negotiating a low initial price, the contractor may produce a few items and then "discover" that the costs are much higher than expected. The contract thus becomes a "cost-reimbursable" kind of contract and is subject to abuse.

Any contract wherein approved costs are reimbursed is called a "cost-reimbursable" contract; these include the cost-plus and incentive contracts discussed next.

12.8 Cost-reimbursable contracts

In complex, uncertain, or risky projects where it is difficult to estimate project costs accurately, a cost-reimbursable (or *cost-plus*) type contract allows the project to begin before the costs are fully determined.

Cost plus fixed fee

Under a cost plus fixed fee (CPFF) contract, the contractor is reimbursed for all allowable costs plus an additional, fixed amount to cover profit. This contract is justified when costs cannot be accurately estimated or rise due to changes in the project scope or factors beyond anyone's control. Regardless of the actual cost, the contractor's fee remains the same, usually computed as a percentage of the initial estimated cost, C_{ex}.

Example 12.3: Cost Plus Fixed Fee Contract

Contract agreement:

Cost estimate, C_{ex} = \$100,000
Fee = \$10,000
Target Price = \$110,000

In addition to the fee, the customer will pay for all allowable costs (perhaps "all" costs, C_{ac}). Thus, if the project ends up costing C_{ac} = \$200,000, the price to the customer is \$210,000.

In contrast to FFP contracts, CPFF agreements put the burden of risk on the customer. The customer does not know the project price until the end of the project, and the contractor has little incentive to control costs or do anything beyond minimum requirements, since he gets paid the same fee regardless. A major factor motivating the contractor to control costs and schedules is the negative effect of overruns on his reputation. Another is that as long as the contractor's workforce and facilities are tied up, he cannot work on other projects.

The contractor's "profit" is ostensibly the fee above the cost, although, in reality, that might just be the tip of the iceberg, since the contractor can profit from just about anything—materials, services, travel, and so on. A contractor might specify a "fee" of \$10M but then profit another \$100M from fees added to materials and services. The customer will learn about these added costs only through auditing the project. Contractors sometimes argue that the costs in a CPFF agreement are proprietary; usually, however, that is nonsense, and the customer needs a good auditor to check on every cost during the project and before the contractor is paid. The customer may also specify who is to be project manager or assign her own project manager to work alongside the contractor's project manager.

Despite the risks, the customer might have to resort to a CPFF contract just to attract contractors. CPFF is the contract of choice whenever the project involves high risk or the costs are difficult to estimate. Although CPFF would seem to pose little financial risk to contractors, in fact, it does unless they are able to fully justify all costs. The contractor cannot just spend willy-nilly and expect to be automatically reimbursed! CPFF contracts typically permit customers to carefully scrutinize contractor costs and financial records and to negotiate settlements of or not reimburse any costs they find questionable or unjustified.

Cost plus percent of cost

A variation of the CPFF contract is the cost plus percentage of cost (CPPC) contract, wherein the customer agrees to pay all justified costs plus a percentage of those costs as the contractor's fee. In other words, the final price of the project is C_{ac} (1 + percentage fee), where the percentage is specified in the contract. Customers dislike this kind of contract even more than CPFF because the contractor's profit increases with the costs—providing it little incentive to control costs (and rewarding it for increasing costs!). The customer must keep close track of all costs incurred and pay only for "justified" costs.

Cost plus incentive fee

The cost plus incentive fee (CPIF) contract emphasizes hitting a *cost target*, and the contractor can earn a larger profit by reducing costs. The contract specifies the target cost, C_{ex}, and the CSR. The project price is then based on a percentage of the actual cost as set by the CSR, plus the contractor's fee. It is identical to the FPIF contract, but without limits on profit and price.

Example 12.4: Cost Plus Incentive Fee Contract

Contract agreement:

Cost estimate = Target cost = C_{ex} = $100,000
Fee = $10,000
Estimated Price = $110,000
Cost sharing: CSR = 50/50

The contractor's incentive is to keep costs below $100,000.

Suppose C_{ac} is $80,000 ($20,000 under C_{ex}).
Price = $80,000 + ($20,000) 0.50 + 10,000 = $100,000

The customer saves $10,000 on price, and the contractor earns $10,000 bonus. The customer must be vigilant to ensure that the incentive hasn't led the contractor to "cut corners" on work and materials.

Now suppose C_{ac} is $200,000 ($100,000 over C_{ex}).

Price = $100,000 + ($100,000) 0.50 + $10,000 = $160,000

The contractor is paid $200,000 — $160,000 = $40,000 in the red.

Beyond cost and price, incentives can be applied to schedules and performance—to target completion dates and target performance parameters for the end-item. Called *schedule incentive* and *performance incentive* contracts, respectively, they "reward" for exceeding performance targets or completing the project early and "penalize" for the underperforming or finishing late.

Example 12.5: Schedule Incentive Contract: Hoover Dam

The project to construct Hoover Dam, one of the America's largest and most historically significant dams, began in 1931. Before the dam could be constructed, however, engineers had to divert the Colorado River away from the site, which they did by channeling it through four 50-ft.-diameter, ¾-mile-long tunnels cut through rock adjacent to the river. Eventually, some 11.5 million cubic yards of rock would be removed. So as to not delay construction of the dam, the US government set a completion date for the tunnels of October 31, 1933. The contract agreement included a penalty of $3,000 for each day the tunnels were completed late, and a bonus of $3,000 for each day they were completed early.

Tunnel work started in May 1931 and was completed in November 1932 when the Colorado River was diverted through them. This was 11 months ahead of target, so the contractors received a bonus of *$990,000* (30 days × 11 months × $3000), a stupendous amount in Depression-era 1932.

No doubt the bonus provided an incentive for contractors to beat the deadline, although, unfortunately, at the time, there were few safety inspectors on site to enforce the even fewer safety regulations in place, so the contractor's handsome profit came at the expense of several tunnelers who lost their lives from heat prostration, carbon monoxide poisoning, and electrocution. Working in the tunnels was a hell-hole, with temperatures frequently hitting 140°F, carbon monoxide from gasoline-fueled vehicles clouding the air, and dangerous cabling strung across the wet ground to power electrical equipment. True of most incentive contracts, the bonus/penalty system *drove* performance to meet one criterion (e.g. date), though at the expense of others (e.g. safety).

Cost plus award fee

Cost plus award fee (CPAF) is another form of cost-reimbursement incentive contract whereby the contractor is reimbursed for all justified expenses plus a fee. The fee includes a base amount that is negotiated before work begins plus an amount determined after the project, based upon the customer's judgment of the contractor's performance (in terms of cost, schedule, and/or technical requirements). The base fee can be small or even zero, which means the bulk of the fee depends on the customer's satisfaction with the work as measured by criteria specified in the contract.

Guaranteed maximum price

With a cost plus fixed fee (CPFF) agreement, the final price is unknown until the project is completed and the costs tallied: the sky is the limit. A more appealing agreement to customers is the guaranteed maximum price contract, which is a CPFF contract with a price cap. The GMP includes the contractor's fee, which can be fixed or a percentage of costs. The customer agrees to pay actual project costs until the project price reaches the GMP; for costs beyond that, the contractor is responsible.

Suppose the fee is set at $10,000 and the GMP at $110,000. If C_{ac} ends up at $80,000, the customer pays the contractor $80,000 + $10,000 = $90,000. If C_{ac} is $200,000, the customer pays the GMP, $110,000, and the contractor incurs a $90,000 loss.

Time and materials

The time and materials (T&M) contract is a variation of cost-reimbursement contract since the final price is not known until after the work is completed and the costs are tallied. It is called "time and materials" because the contractor is reimbursed for labor and material costs incurred in the project. It provides for payment of direct labor hours at a specified per-person hourly rate that includes direct and indirect labor costs and a mark-up. The material fee includes the contractor's material cost, handling fee, and a mark-up. Sometimes a ceiling price is established that may be exceeded, depending on the agreement. Charges for private consultants and the services of electricians, carpenters, plumbers, mechanics, and so on are usually based on T&M. The T&M contract places all cost risk onto the customer and is least preferred if other contract types are available.

12.9 Contract-related matters

Risk

One reason for the prevalence of contracting and subcontracting is risk transfer; by contracting the work, one party can transfer the risk to another. The degree of risk transfer depends on the type of contract, as shown in Figure 12.4. For example, with an FFP agreement, the contractor assumes most of the risk of a cost overrun. Contractors find this acceptable whenever the statement of work is clear and involves little uncertainty but unacceptable when the scope of the work is unclear, the work likely will require many changes, and they will have to absorb cost overruns. In the latter case, they would obviously prefer a CPFF contract whereby all costs incurred will be covered by the customer. Between FFP and CPFF, the contractor and customer share the risks to varying degrees. In an FPIF contract, the contractor accepts roughly 60 percent of the risk and the customer 40 percent. In a CPIF contract, the contractor assumes about 40 percent and the customer 60 percent.

But rarely is risk transfer as simple or complete as Figure 12.4 might suggest. Even with an FFP contract whereby the contractor assumes the risk of paying for a overrun, a large enough overrun can overwhelm and bankrupt a contractor—even a big contractor, in which case the customer must pay the overrun if the project is to be completed. Alternatively, to avoid the losses from an overrun, a contractor might feel pressured to cut corners, which increases the customer's risk of receiving a subpar-quality end-item. To lessen such risks, the contract must stipulate strict quality inspections and penalties.

In large projects, a variety of contracts are used depending on the risk associated with individual work packages or deliverables. In the Chunnel project, the most uncertain part was tunneling under the English Channel; thus, that part of the work was contracted on a CPFF basis. The electrical and mechanical works for the tunnels and terminals were perceived as low risk and were thus done on a fixed-price basis. Procurement of the rolling stock, perceived as slightly riskier, used a CPPC contract.[14]

The party at risk depends not only on the contract type but also on whoever estimated and set targets in the contract. A customer who estimates and sets the target cost inherits the risk of a too-low estimate; when the project cost exceeds the estimate due to the customer's estimating errors or omissions, the customer must pay the excess, even in an FP contract. Had the price agreement been based on the contractor's estimate, the contractor would pay the overrun.

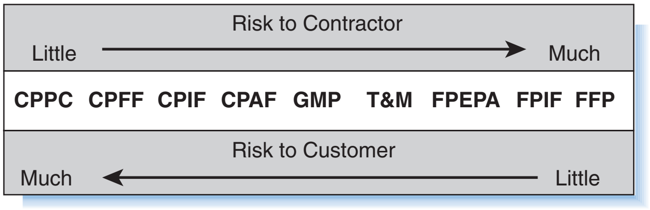


Figure 12.4
Contract type and degree of risk assumed by contractor and customer.

Customer recourse

A standard clause found in contracting is *force majeure*, which exempts parties from fulfilling their contractual obligations for causes that could not be anticipated and/or are beyond their control. These include so-called acts of God (floods, earthquakes, and other natural disasters), acts of man (war, riots, etc.), and other events or occurrences that are unforeseeable and unpreventable.

When a contractor or supplier fails to meet contractual obligations for reasons other than *force majeure*, customer recourse falls into three increasingly severe categories.

1. Sue for breach of contract
2. Claim penalties for breach of contract
3. Demand a surety bond.

Breach of contract means, simply, failure to satisfy conditions or requirements as specified in the contract. Under breach, the customer can either cancel the contract (if the contract includes a cancellation clause) or sue for "damages"—where damages are determined either as harm caused by the breach itself or whatever degree of effort is needed to recover and fulfill the conditions of the contract. The downside of suing for breach is a sometimes expensive and lengthy litigation with no certainty of the outcome.

A *penalty clause* is a statement in the contract that specifies a sum of money to be paid or other action to be taken in the event of a breach; for example, $10,000 per calendar-day for failure to meet the target completion date. The penalty amount, so-called *liquidated damages* (liquidate means to convert to cash), is calculated to represent how much the customer stands to lose if the contract is breached or performance not delivered. It is intended to represent a fair and genuine pre-estimate of the damages negotiated before the start of the contract and not as punishment to the contractor. The customer need not prove damage for the penalty to come into operation, only that the breach has occurred.

Another measure is a *surety bond*, which is a contract between the customer, contractor, and a guarantor or third party—usually a bank or insurance company. Surety bonds protect the customer in a variety of ways. One, called a performance bond, guarantees the contractor's work; if the contractor is unable to complete the specified work, the guarantor may provide the contractor with needed credit or else appoint another contractor to do the work.

Subcontract contracts

As discussed, the choice of contract depends on many considerations, such as risk and relative advantages and disadvantages to the customer and the contractor. However, when the contract is between a prime contractor and other contractors (subcontractors), the type of contract also depends on the type of agreement between the prime contractor and the customer. If the "prime contract" (between the prime contractor and the customer) is fixed price, then all subcontract agreements should also be FP; otherwise, the prime contractor is in jeopardy of being charged more by its subcontractors than it can recoup from the customer in the FP agreement. If the prime contract is cost-plus or incentive, there is more latitude in the subcontracts, since any or most costs charged by subcontractors might then be recovered by costs charged to the customer. Beyond simply covering its costs, however, the prime contractor can gain better overall control of project costs by setting FP or incentive agreements with its subcontractors, even if its agreement with the customer is CR.

12.10 Summary

Procurement management pertains to the acquisition and oversight of everything purchased or contracted for the project—all procured goods, work, and services. It represents the management of agreements between all parties in the project—the customer, the prime contractor, subcontractors, and suppliers. It is a four-phase process that roughly corresponds to the three phases of the project life cycle:

Define and plan procurement happens during the conception and definition phases to determine the necessary resources (good, work, and services—GWS) for the project and distinguish those that can be acquired internally (make) from those that must be procured (buy). Steps of the procurement process as well as consideration of all procured items and the delivery/receipt logistics of those items must all be included in elements of the project plan—WBS, schedule, budget, responsibility matrix, and so on.

Conduct procurement happens in the definition phase to identify and solicit qualified sources (suppliers and contractors) of GWS via RFPs, RFQs, or RFBs; to evaluate proposals/bids from those sources interested; and to select and contract with the best of them, sometimes through a process of negotiation.

Control procurement occurs throughout the execution phase. The procured GWS and relationships with suppliers and contractors are monitored and controlled to ensure conformance to schedule and quality requirements and to manage changes to contracted project work.

Close-out procurement happens at the end of the project and focuses on the orderly review, acceptance, and handover of contract end-items and the formal closeout of all contracts and work orders.

Most projects involve some degree of external contracting, since often the customer must hire someone to perform at least some of the work. Sometimes the customer hires a party to oversee the project (“prime contractor” or SDO), and this party contracts with other parties—subcontractors—to do portions of the project.

Even when a contractor is capable of doing all the work itself, it may choose to subcontract because it has limited capacity or believes a subcontractor could do the work for lower cost or less risk. In large-scale development projects, the prime contractor might design the overall system and major subsystems but then subcontract production of the subsystems or even the overall system to others.

The fundamental kinds of contacts are *fixed price* and *cost reimbursement*. In the FP contract, the price is agreed upon and remains fixed as long as there are no changes to the project scope or contract provisions. In the CR contract, the contractor is reimbursed for *all or most* expenses incurred during the project; as a result, the final price is unknown until the project is completed. A variation exists with both FP and CR contracts called *incentive contracts*, which provide incentives for the contractor to meet cost, time, or performance targets. The choice of contract depends on the project and project environment, as each type of contract has relative advantages and disadvantages to the customer and the contractor. Most projects involve multiple contractors and hence multiple contracts and contract types.

Review Questions

1. When does the procurement process begin?
2. Describe what procurement means. How is it different from/similar to acquisition and purchases?
3. What types of project resources can be procured?
4. How do the steps of procurement align with the project development cycle? Describe the steps of procurement.
5. Describe five components of a solicitation package.
6. What is the process for solicitation through bidding? For what type of projects is this method used and why?
7. In bidding solicitation, why should customers be careful to scrutinize a bidder’s price?
8. When does the negotiation process end?
9. How does the negotiation process work? For what type of projects is this method of solicitation and why?
10. Why is the CSOW important?

11. Why does the procurement schedule often end up being grossly underestimated?
12. What is logistics? Describe the importance of logistics planning in a project.
13. Describe the role of contract administration. List three control measures it includes.
14. What happens at first handover at completion? At second handover?
15. In contracting work, does the customer relinquish all control over the project to the contractor? Explain.
16. How can a contractor be both the sender and receiver of RFPs and proposals; that is, how can it both prepare and submit proposals and receive and review proposals?
17. When a contractor hires a subcontractor, to whom is the subcontractor obligated—the end-user customer or the contractor?
18. What must the project manager know to be able to effectively negotiate a contract? Consider aspects of the customer, competition, and technical content of the proposal.
19. Discuss the difference between the SOW, CSOW, and work requisition or work order.
20. Describe the different kinds of contracts. What are the relative advantages and disadvantages of each to the customer and the contractor?
21. A customer accuses a project manager of cost overruns and a delay in delivery. Why is it relevant whether the relationship between the customer and the project manager is governed by an EPC or EPCM contract?
22. Refer to the CPIF and FPIF example problems in Examples 12.2 and 12.4.
    a. In both the CPIF and FPIF cases, what is the price if $C_{ac} = \$90,000$? What is the contractor's profit?
    b. In both cases, what is the price if $C_{ac} = \$160,000$. What is the contractor's profit?
    c. Sometimes two CSRs are used, a different one each for underruns and overruns. What are the answers to a. and b. if the CSR is 70/30 for underruns and 80/20 for overruns?

Questions About the Study Project

1. What are the procured GWS in the project? Were these items managed differently than in-house aspects of the project? How were they first identified and then integrated into the project plan? Did procured items pose any difficulties to the project?
2. How were contracts negotiated, and who was involved in the negotiation?
3. What kinds of contracts were used in the project?
4. Did the project have a procurement manager? Does the company have a procurement team or department? If yes, how were they involved in the project, and what else do they work on?
5. How was it determined what would be purchased or contracted and what would be done internally?
6. What kind of auditing occurred on procured items (quality checkpoints and testing)?
7. Were there any delays in the project due to procured GWS? Why or why not—good controls vs. poor controls? How were the logistics planned? Did logistics create any issues in terms of timing or resource availability?

CASE 12.1 CONTRACT MESS-UP AT POLANSKI DEVELOPERS

LaPage Power Company needed to upgrade the fire extinguishing system for the control room of a nuclear power plant. It selected Polanski Developers Company because Polanski was the only contractor willing to do the work for a fixed-price contract. Polanski's $11 million price was based on its $9.5 million estimated cost for work and materials and a fee of $1.5 million. Polanski managers felt the fee was large enough to provide ample profit and absorb any unforeseen work difficulties. The upgrade would require interfacing with many plant safety systems, some dating back to when the plant opened in 1985 and others that had been upgraded many times since.

The interfaces with other systems would make the upgrade complex and challenging. Polanski anticipated this and, to reduce the risk of a cost overrun, contracted with Moreland Systems, a company with substantial experience in nuclear power plants. Moreland would be responsible for virtually all of the actual system design and installation. Said Billy Chester, Moreland's project manager, "You never know what you'll find in these kinds of projects." He told Polanski that Moreland would take on the job, but on a cost-plus basis only. The CPFF contract specified a target price of $10 million using Polanski's $9.5 million cost estimate and a fee of $500,000. Polanski agreed.

When the project was completed—having encountered several unanticipated problems—Moreland's bill was $14.5 million. The CPFF contract had specified periodic audits of Moreland's costs, but none were ever done.

Discuss the financial consequences to Polanski, Moreland, and LaPage. What should Polanski have done that could have altered the consequences? How does the choice of contract type depend on risks involved?

CASE 12.2 CONSOLIDATED ENERGY COMPANY

Consolidated Energy (CE) is a public utility that generates and distributes electricity throughout the United States. The company is involved in many kinds of projects, including construction of electrical generating and transmission equipment and facilities, upgrade and repair of equipment and facilities, information technology for customer service, and energy research. Much of this project work is contracted out, although about half of it is done by CE itself. The company has construction units and equipment specialists in five regions, information technology specialists in three regions, and research units in two. The research units work on projects initiated by the corporate office, but the construction, equipment upgrade and maintenance, and IT units work on projects initiated by the five regional offices. Each of the units is assigned to one or two regions; any project identified by a regional office is automatically handed to the construction, IT, or equipment unit assigned to that region.

Decisions about projects are made at regional and corporate levels: projects costing more than $20M are handled at the corporate level; otherwise, they are handled regionally. Whenever a regional office funds a project, it first decides if the IT, equipment, or construction unit for its region can handle the job; if so, it assigns the job to them; otherwise, it contracts the work using the RFP/proposal process. A corporate PRB (project review board) makes decisions for projects that exceed $20M. When the PRB approves a project, it awards the job to either the internal unit assigned to the region that requested the project or to a contractor via the RFP/proposal process.

Recently a member of the PRB had a clever idea: why not use the RFP/proposal process for all projects, including ones that might be done internally? When a regional office identifies a potential project, instead of giving the project automatically to the pre-assigned internal unit, it would send an RFP to all of the company's IT, construction, or equipment units. The unit with the best proposal would get the job, regardless of its location. Some members of the board balked at the suggestion, saying it would put units with the same expertise in competition with each other. Others argued that it did not make sense for, say, a construction unit to take on a project outside its region because transporting equipment and moving work crews to distant project sites would increase project costs. Others countered that such arguments were pointless because competition among the units would encourage higher-quality work and reduce overall corporate costs.

QUESTION

What do you think of this idea? What are the pros and cons?

Notes

1. Joy PK. *Total Project Management*. New Delhi: Macmillan India Limited; 1998, pp. 378–380.
2. Procurement management phases as defined by PMBOK (6th edition of PMBOK combines "control procurement" and "close-out procurement" as one phase). *A Guide to Project Management Knowledge (PMBOK Guide)*, Newton Square, PA; 2017.
3. Adapted from Kerzner H. *Project Management: A Systems Approach to Planning, Scheduling, and Controlling*, 8th ed. Hoboken, NJ: John Wiley& Sons; 2003, p. 815.
4. See Hajek V.G. *Management of Engineering Projects*, 3rd edn. New York: McGraw-Hill, 1984, Chaps. 8 and 9; and Rosenau MD. *Successful Project Management*, Belmont, CA: Lifetime Learning; 1981, pp. 34–41.
5. Management of the complete project contracting process, including what and where to contract, soliciting and assessing proposals, reaching a contract agreement, and administering the contract, is also called "contract monitoring." See Hirsch W. *The Contracts Management Deskbook*, revised ed. New York, NY: American Management Association; 1986, Chap 6.
6. Adapted from Kerzner. *Project Management*, p. 827.
7. This section gives an overview of the important contracting issues. It is not intended to provide legal advice about contracts; for that you need an attorney or contracts specialist.
8. Hirsch. *The Contracts Management Deskbook*, pp. 290–315.
9. A complete description of project contracts is given books on contract management. A good sources is Hirsch. *The Contracts Management Deskbook*, pp. 43–75. For construction contracts, see Furst S and Ramsey V, eds. *Keating on Construction Contracts*, 8th ed. London: Sweet & Maxwell; 2006.
10. Internationally, two formats popular for engineering, services, and construction work are Fédération Internationale Des Ingénieurs-Conseils (FIDIC) and New Engineering Contract (NEC). In the United States, standard contract formats are used less often, and when they are, the parties often make revisions. Two common formats used in construction and real-estate development are contracts created by the American Institute of Architects (AIA) and American Society of Civil Engineers (ASCE).
11. Merrow EW. *Industrial Megaprojects: Concepts, Strategies, and Practices for Success*. Hoboken, NJ: John Wiley& Sons; 2011, pp. 286–287.
12. Ibid., p. 288.
13. Hajek. *Management of Engineering Projects*, pp. 82–83.
14. Anbari F. (ed). *Case studies in Project Management: The Chunnel Project*. Newton Square, PA: Project Management Institute; 2005.

Chapter 13

Project monitoring and control

We look at it and we do not see it.

—Lao-Tzu, Sixth century BC

Despite all the effort devoted to planning, scheduling, and budgeting in the definition phase, no plan is ever complete or perfect, and besides, things rarely go entirely as planned. Although it is certain that problems and deviations from the project plan will occur once project execution begins, it is not known a priori where or when. Monitoring and control is the process of tracking project performance, discovering areas where performance is lacking, uncovering extant or potential problems, overcoming obstacles, and keeping the project moving toward the target.

Planning and control are a major part of project management, but to be effective, *they must happen in that sequence*—planning first, then control. Without good plans and requirements, there is no clear target toward which to direct the project, and there can be no control.

13.1 Project monitoring

Project managers monitor progress using a variety of methods, measures, and sources—both formal and informal, often as specified in advance in the project plan. Using a variety of measures and sources increases the validity of the information obtained, particularly when they all lead to the same conclusion. Among primary ways for obtaining and conveying project information are status review meetings, observation, technology, and written reports.

Status review meetings

Status review meetings are among the most important ways to communicate project status and assess performance. Meetings can be informal or formal, convened as needed, or scheduled periodically or at milestones. Large projects require all kinds of meetings.

Informal reviews

Informal reviews (or called "peer reviews" because they are attended only by peers) are held frequently and regularly. Meeting attendance depends on the stage of work and issues at hand: usually only those team members, customer reps, supervisors, and managers who need to be involved participate. Before each meeting, project status, issue status, and estimated completion dates and costs are updated. Attendees with assignments are expected to give presentations.

A purpose of the reviews is to uncover problems and issues and agree on courses of action; consequently, bad news and problems are *expected* and openly confronted. The project manager acts as facilitator and encourages honesty and candor. Finger pointing, passing blame, or glossing over of conflict should be avoided since they waste time and discourage candor and attendance.

Problems surfaced in a review are noted on the issue log (described later); as an order of business in every meeting, all issues are reviewed and updated for progress. Always, the project manager—not a secretary or functionary—should lead the review, take notes and, where needed, write up and distribute notes. This reinforces the perception that the project manager is committed, involved, and in charge.

Where possible, project reviews are convened at a central meeting place—a *project office*, sometimes called the war room. This is a physical space for not only meetings but preparing, storing, and displaying project information. Gantt charts, networks, and cost charts are displayed on the walls for easy reference. The room provides whatever is needed to facilitate meetings: table, chairs, filing cabinets, computers, projector, teleconferencing equipment, and so on.

Standup meetings

The daily "standup meeting" is perhaps the most effective form of informal review. Intended to update status, identify problems, and expedite solutions, it is short (15 minutes; no one sits) and to the point. Usually held at the start of the day, the team gives a quick run-though of yesterday's progress and today's next steps. Problems that require more than a minute's reflection are deferred for a follow-up scheduled meeting. The occasional surprise attendance of a prominent person—senior manager from the contractor or customer—adds zip and keeps everyone on their toes.

Formal reviews

See Chapter 10

Formal review meetings to assess progress are scheduled weekly and at milestones or critical project stages. Two such reviews in design and development projects are the *preliminary design review* and the *critical design review*. These are convened and attended by management, outside experts, and the project sponsor or customer, as described in Chapter 10. They provide independent assessments of project performance, suggestions or instructions to improve the project, and sometimes a decision ("gate") to terminate the project or allow it to continue, depending on review results.

In every project, regardless of contractual obligations, the customer should assume some responsibility as project watchdog. One form of special formal review, a *project audit*, is undertaken by the customer to assess project progress. It can be conducted anytime in the project; at milestones; or upon significant changes to project costs, timeline, or goals. Audits are discussed in Chapter 10.

Observation and site visits

Most project managers would never rely solely on reviews, reports, or emails to track project progress. If they cannot be always at the project site, they make it a point to show up there often—unannounced and uninvited. At the site, they try to speak to team members informally at lunch or on break. In this way, they show active involvement in the project, learn what is happening, and build relations with the team.

Instead of inquiring about project "status," sometimes it is better to ask people about how life is—what is going well, what not so well, and what resources or support they need. Just because no one reports problems or complains does not mean everything is okay. Signs that problems might be brewing include team members being silent or not participating in meetings, avoiding discussions about the project, or giving conflicting reports about project status. The project manager watches people's facial expressions and body language. Rather than trying to talk to everyone, she concentrates on people whose tasks have traditionally been the most problematic. She tries to validate reported problems by getting at least two points of view.

Technology

Project managers also monitor work using technology—websites, video- and audio-conferencing, email, and cell phone. Many project management software products take advantage of web-enabled technology whereby managers and workers can display and update plans and reports on interactive websites. The technology is especially well suited for situations where the project team and stakeholders are geographically dispersed. Putting information on a project website via Internet or intranet affords the benefits of immediate information availability, rapid and easy communication between workers, and information that is current and communicated in real time. More is said about this in Chapter 18.

See Chapter 18

Video-conferencing and audio-conferencing can also be effective but require the appropriate technical facilities. Both also require careful scheduling so as not to waste people's time. Owing to the Covid-19 pandemic, millions of people worldwide have gained video-conferencing experience.

In long-distance, international projects, a suitable means for project monitoring is frequent one-on-one *telephone* conversations; these allow the project manager to gauge tone of voice, probe details, and get real-time feedback. Since, however, site managers and contractors might not always be truthful, the project manager additionally needs a trusted source at the site to actually *observe* work and report back progress. This is discussed more in Chapter 20.

See Chapter 20

These days, project managers everywhere, especially in construction, rely on cell phones and tablets for on-site communication. Increasingly, they adopt technologies associated with the so-called Internet of Things (IoT) and Fourth Industrial Revolution (Industry 4.0), including use of "Big Data" and predictive and prescriptive analytics to assess and guide projects.

A rule of thumb not only for monitoring work but for all project communication is this: the more sensitive or important the issue, the lower the technology to communicate it. Important/sensitive issues require on-site, face-to-face meetings. Less important/less sensitive issues can be addressed on the telephone. Reserve email solely for non-sensitive or minor issues. Always follow up important discussions or commitments in writing.

Formal reports and documents

Managers also rely on written reports and other documentation to monitor projects. On a large project, work package leaders and supervisors send the project manager weekly or monthly reports about work completed, current and forecasted costs, and updated completion schedules. Information accuracy in all reports depends partly on the number of channels through which the information had to pass to get from the source to the receiver; in general, the more channels, the lower the accuracy. Of course, formal reports tend only to reflect the past. Project managers know this, which is why they also gather real-time information through mobile devices, on-site reviews, walking around, talking to people, and making first-hand observations.[1]

Many others besides the project manager also monitor the project and need to be kept informed about project status. Company management wants to know about project progress; problems affecting profits, schedules, or budgets; and actions taken or needed. The project manager sends them summary reports on a weekly or more frequent basis. Other stakeholders (customers, activist groups, public agencies, stockholders—anyone who has influence over or a genuine interest in the project) also need to be kept up to date. To the customer, especially, the project manager sends frequent reports about progress and the impacts of any changes in project scope, schedule, and cost. Regardless of who is formally charged with communicating contract-related information to the customer, the project manager must personally ensure that the customer is always well informed, and she must be available to answer the customer's questions and requests. Frequent, honest communication with the customer and other stakeholders builds trust and avoids "surprises."

Documentation management

Projects generate numerous reports and documents, the volume of which can be overwhelming. Thus, in many projects, a *documentation management system* (DMS) is needed to ensure the required documents are created, conform to standards, and are organized and stored for easy access by authorized persons. A computerized DMS might be needed to track, store, access, and update versions of digital documents.

13.2 Communication plan

The specific methods and measures to be used in monitoring the project and, in general, for all project communication—both formal and informal—should be thought out in advance of the project and, ideally, be specified in a project communication plan. For larger projects, this plan would be included as part of the execution plan. The plan would specify: the expected reports and documents, their content, frequency, and who is responsible; expected meetings and reviews, their itineraries, advance preparations, time limits, attendance policy, and who will lead; and a tentative schedule for formal reviews and milestone meetings that includes participants, content, and so on. The plan also specifies important points of contact (who's-who) among the customer, contractor, subcontractors, supporters, and other interest groups.

The table in Figure 13.1 represents part of a communication plan, showing the expected meetings and reports and participants for each. Not shown, the plan might specify other meetings such as for safety and kicking off and closing out project stages. The table would be supplemented with details about the what, where, when, and how for each kind of meeting and report.

The communication plan should be distributed to everyone on the project team and discussed before the project begins. To ensure that everyone understands the required documentation and the content and format of each, the plan should include examples of good and bad documentation from previous projects. Much of this can be posted online. The plan might include a section on "informal communication" and ways to influence it positively.

Informal communication

Like elsewhere, much communication in projects happens informally, person to person and through the *grapevine*. Although informal communication is not especially dependable, garbles messages, and doesn't guarantee that people will ever get the information they need, it nonetheless is largely beneficial and vital. Some theorists posit that a vast network of informal communication is essential for any organization to perform well, since it fulfills social and work needs and tends to convey information more rapidly than formal methods.

Role/type Meeting/ report	Status meeting (frequency)	Status meeting minutes (frequency)	Business feasibility	Information request	Technical feasibility	Business brief	Project plan (frequency)	Problems and issues (frequency)	Business study	Use case analysis	System architecture	Detailed technical design	Other
Client	X	X	X			X	X	X	X	X			
Relationship manager		X	X	X	X	X	X	X	X	X	X		
Business analyst	X	X	X			X	X	X	X	X	X		
Project manager	X	X	X	X	X	X	X	X	X	X	X		X
Client project team	X	X	X			X	X	X	X	X			
IT project team	X	X					X	X	X	X	X		X
Client director		X	X			X		X	X				X
IT director		X	X	X	X	X	X	X	X	X	X		
Project sponsor		X	X			X			X				
IT VP		X	X						X				
Architect	X	X	X	X	X	X	X	X	X	X	X		X
Security/audit	X	X	X		X			X	X	X	X		
Internet operations	X	X	X		X		X	X	X	X	X		X
Intranet operations	X	X	X		X		X	X	X				
Legal/corporations communication		X	X		X			X	X				
Other													

Figure 13.1
Sample communication plan.

Managers cannot control informal communication, but they can influence and take advantage of it. One way is to bolster informality within the project by removing status barriers and inspiring casual conversations between managers and workers. Some companies insist that everyone—from the president on down—avoid titles, speak on a first-name basis, and maintain an "open door" policy. Offices are physically arranged to encourage informal communication—by removing walls and partitions, putting chairs and desks in "team groupings," and spot placement of lounges to encourage informal chats. Project managers attempt to do what the informal organization sometimes does: enable people involved in a problem or decision to directly communicate with each other.

13.3 Monitoring and control process

Project monitoring and control—the process of keeping the project moving in the direction as laid out by the execution plan—happens throughout the project. In simple terms, it involves measuring progress, assessing progress against planned objectives and requirements, and taking corrective action. The process can be compared to a home air-conditioning system, which works this way:

1. The desired room temperature is set on the thermostat.
2. The thermostat measures the actual room temperature and determines the temperature variance (actual temperature minus desired temperature).

3. If the variance is positive, the thermostat turns on the air conditioner until the actual temperature coincides with the desired temperature (i.e. variance becomes zero).

Virtually every monitoring and control process follows these same steps: (1) setting the performance standard or target, (2) comparing actual performance to the standard, and (3) taking corrective action to remove any difference.

In projects, the set *performance standards* step happens in the definition phase and early part of the execution phase. The standards are user requirements, technical specifications, budgeted costs, schedule due dates, and resource requirements.

The next step, compare *actual performance* to the standards, happens throughout the execution phase. Budgets, schedules, and performance specifications in the project plan are compared to actual expenditures, test results, work completed, and other measures.

The last step, take *corrective action*, occurs whenever actual performance significantly differs from planned performance: something is done to remove the difference—either improve performance to meet the target standards or revise the standards. In the latter case, the contractor must work with the customer to change the objectives, revise the requirements, or modify the plan. There should be no surprises, and any approved revisions should be reported to all involved stakeholders.

Worth repeating is that to keep the project aligned with standards (requirements, schedules, and budgets) there must first be a plan! *The precursor to project control is project definition and planning*: without clear, complete requirements and a good plan, there can be no control.

Data for monitoring

Data collected for project monitoring must relate to project performance standards as set by project plans, schedules, budgets, and requirements. Importantly, the data must reflect not only measures of the cost and time expended, which are measures of *input*, but measures of project *output*. Output measures address the deliverables and results as defined in project plans and requirements.

Typical data sources include material purchase invoices, worker time cards, change notices, test results, work orders, and expert opinion. The quantity and variety of data collected must be balanced: too much data will be overly costly to collect and scrutinize, too little will not adequately reflect project status and will allow problems to go unchecked. Data must be analyzed and results reported quickly enough to enable managers to quickly spot deviations from plans and take corrective action.[2]

How frequently should data be collected, assessed, and reported? A good rule of thumb is to assess work progress every week. This will ensure that even work packages lasting just a few weeks will be checked at least twice. For work packages lasting several months, assessments every 2 to 3 weeks might be adequate. The goal is to check the work often enough to enable accurate progress assessment and spot problems early, yet not so often that it becomes burdensome. The frequency also depends on the people doing the work: competent, motivated people can be monitored less often than less competent or less motivated people. The kind of data to be collected and frequency of collection should be specified in the project plan.

Internal and external monitoring and control

Project monitoring and controlling happen both internally and externally. *Internal control* refers to the *contractor's* procedures for monitoring work, reporting status, and taking action. *External control* refers to additional procedures imposed by others, such as the customer; these include:

- Frequent reports to the customer of schedules, cost, and technical performance
- Work inspections by the customer

- Customer audits of the contractor's books and records
- Strict terms in the contract on allowable project costs, pricing policies, and so on
- A customer project manager who works with the contractor project manager.

External control measures, especially the last one, can be a source of annoyance to the contractor, since they involve the customer's manager overseeing the contractor's manager. Nonetheless, it is sometimes necessary to protect the customer's interests, especially in cost-reimbursable projects. Ideally, the managers are able to work together amicably to establish compatible plans and work monitoring methods.

13.4 Control emphasis

In non-project situations, work performance is measured with *variance analysis* that compares the amount spent for work with the amount budgeted. In project situations, simple cost variance analysis is inadequate.

Example 13.1: Cost Variance Analysis

Consider the following weekly status report for the project "software development":

Budgeted cost for period = $12,000	Actual cost for period = $14,000	Period variance = $2,000
Cumulative budget to date = $25,000	Cumulative actual cost to date = $29,000	Cumulative variance = $4,000

The report indicates apparent budget overruns for both period and cumulative costs, with to-date cumulative costs overrun at $4,000. But because we do not know *how much work* has been completed, it is impossible to determine if the project is really over budget.

Suppose the $25,000 was the amount budgeted for completing 50 percent of software development. If 50 percent of the work had actually been completed as intended, then the project would, in fact, be over budget, and something would have to be done to reduce or eliminate the $4,000 overrun. But suppose only 30 percent of the work had been completed; in that case, the project would be clearly over budget (and behind schedule, too), and further cost overruns could be expected. As a third possibility, suppose that 70 percent of the work had been completed, which is substantially more work than was scheduled. Because of that, the project might not be over budget and might even be under budget for the amount of work performed.

The point of the example is that to be able to assess project status, looking at cost information is not enough. Project control implies control over five areas; in addition to cost, these are scope, quality, procurement, and schedule.

Scope control

Projects have a natural tendency to grow over time because of changes and additions to the scope, a phenomenon called "scope creep." These changes or additions reflect changes to the requirements or work and are usually accompanied by increases in time and cost. The aim of scope control is to identify where requirements or work changes are requested or occurring, ensure they are necessary and beneficial, manage their implementation, and wherever possible restrain or delimit the number of changes. Scope control is implemented through the *change control system* and *configuration management*, described later.

Quality control

See Chapter 10

Quality control is managing the work to achieve the desired requirements and specifications and taking preventive measures to correct for or reduce or eliminate work errors and mistakes. As discussed in Chapter 10, project quality control starts with a *quality management plan* that specifies what is necessary in each work package to ensure quality results, including tests, inspections, and reviews. In technical projects, progress toward meeting requirements is guided using a methodology called *technical performance measurement*, discussed later in the chapter.

Procurement control

The project manager is ultimately responsible for the quality, schedule, and cost of all items procured for the project. Often, she will visit and inspect subcontractors' and suppliers' facilities to make sure the companies are capable of meeting requirements. After the project is underway, she monitors progress by visiting their work sites and reviewing frequent status updates. The project manager does whatever is necessary to prompt or assist contractors/suppliers when problems arise. For all major outsourced items and services, contingency plans should be prepared, including possible contractual provision to transfer work to other contractors/suppliers in case the original ones encounter serious or unrecoverable problems. These contingencies are addressed in the procurement plan and the project risk plan.

Cost control

The purpose of cost control is not only to track variances in expenditures versus budgets but to minimize or contain cost changes and prevent unauthorized or inappropriate expenditures. Cost control seeks out where and why variances have occurred at both the work-package level and the project level using the cost-accounting function of a project management information system, as described in this chapter. Using the methods described later, the project manager periodically reviews actual and budgeted costs, assesses the work completed, and updates the project's expected completion cost and completion date.

Schedule control

Schedule control refers to managing the project to keep it on schedule. Even the most carefully planned projects fall behind schedule for reasons beyond anyone's control; these include necessary scope changes, weather problems, and resource shortages. Project managers employ a number of strategies and methods to keep projects on track and toward target completion dates. Following are some of them.

Time buffers and fever charts

A time buffer, also called a schedule reserve, is an amount of time added to the expected project duration to account for uncertainty. To implement a time buffer, extend the computed finish date by the buffer amount. If the estimated late finish date is July 31 and the time buffer is 4 weeks, the target finish date is set for August 31.

Time buffers are an aspect of critical chain project management, which prescribes locating buffers at the end of the project critical chain and the ends of all subpaths feeding into the critical chain. Once a project is underway, the amount of buffer "consumed" is tracked. Each time a task in the critical chain is delayed, it "consumes" the buffer time. The more of the buffer time consumed, the more likely it will be exhausted and the target finish date will be overrun. Hence, the project should be managed so as to minimize buffer time consumption.

Buffer consumption is tracked and controlled with a "fever chart," a graph that shows the percentage of project buffer consumed versus the percentage of the critical chain completed (Figure 13.2). Early on, a project will consume little of its buffer time; as the project progresses, however, the percentage of buffer consumed can be expected to increase and the plot on the graph to rise diagonally. Monitoring the graph enables the project manager to gauge whether the project will be completed early, on time, or late. A sharp upward trend, for example, indicates that the project is stalled—little progress is being made on critical chain tasks. In a healthy project, the slope of the line is shallow, and much of the project buffer remains unconsumed by the end of the project. Completing a project with buffer remaining is equivalent to completing the project *ahead* of the target finish date. Thus, to complete the project early, the project must be managed so as to minimize buffer consumption; the less buffer consumed, the further ahead is the project.

The chart has three zones. A plot in the yellow zone indicates potential for the project to overrun its target date; in the red zone means strong potential. The chart is updated weekly and quick action taken whenever the plot veers into the yellow or red zones. Tasks responsible for consuming the buffer are identified so managers can take action such as diverting more resources to them or decoupling them from the critical chain.

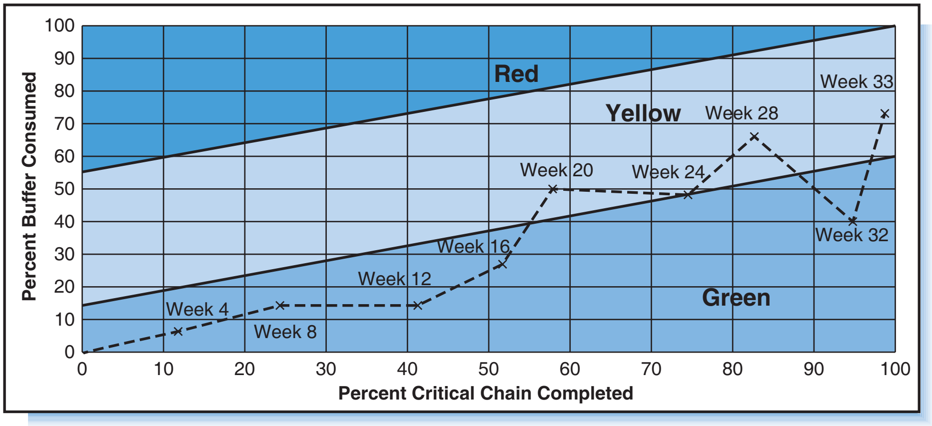


Figure 13.2
Fever chart: Percent buffer consumed versus percent critical chain completed. The fever chart is divided into green, yellow, and red regions to denote project status.

Example 13.2: Fever Chart Computation

Points on the fever chart are computed as follows; each week:

1. Estimate percent completed for each open task on the critical chain (CC). Multiply this percent by the estimated weeks needed for each task to get the weeks completed.
2. Sum the weeks completed for all open and closed (finished) tasks on the CC; this gives CC weeks completed. Then divide this sum by the estimated length of the entire CC to get percent CC completed (*x*-axis).
3. Compute: Elapsed weeks to-date – CC weeks completed = weeks buffer consumed. Compute: (Weeks buffer consumed)/(Project buffer length) = percent buffer consumed (*y*-axis)

The previous procedure can be modified using days. The results would be the same but more precise.

As an example, suppose the data points in the fever diagram in Figure 13.2 were derived from the project in Figure 13.3. Project status was assessed every 4 weeks (ordinarily, status should be assessed every week; 4 weeks is used here to save space). Based on the task percent completed, the percent CC completed and percent buffer consumed are computed as shown in Table 13.1.

Per the table, last line, the project is completed in 33 weeks. The amount by which the project finished ahead of target is 36 – 33 = 3 weeks.

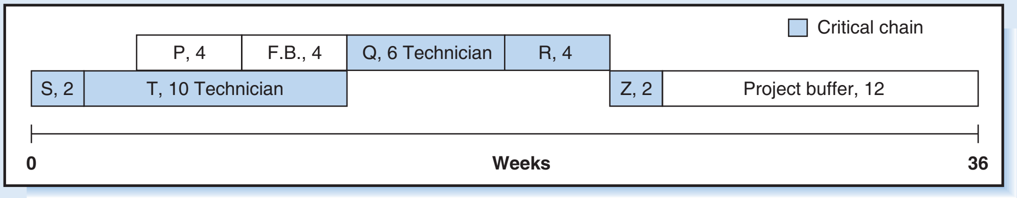


Figure 13.3
Critical chain = 24 weeks. Project buffer = 12 weeks

Table 13.1 Percent buffer consumed computation.

Week	Tasks & Percent Completed	Weeks Completed	Percent CC Completed	Weeks Buffer Consumed	Percent Buffer Consumed
4	S 100%; T 10%	2 + 0.1(10)	12.5%	4 – 3 = 1	8.3%
8	S 100%; T 40%	2 + 0.4(10) = 6	25%	8 – 6 = 2	16.7%
12	S 100%; T 80%	2 + 0.8(10) = 10	41.7%	12 – 10 = 2	16.7%
16	S, T 100%; Q 10%	2 + 10 + 0.1(6) = 12.6	52.5%	16 – 12.6 = 3.4	28.3%
20	S, T, 100%; Q 30%	2 + 10 + 0.3(6) = 13.8	57.5%	20 – 13.8 = 6.2	51.7%
24	S, T, Q 100%	2 + 10 + 6 = 18	75%	24 – 18 = 6	50%
28	S, T, Q 100%; R 50%	18 + 0.5(4) = 20	83.3%	28 – 20 = 8	66.7%
32	S, T, Q, R 100%; Z 50%	18 + 4 + 0.5(2) = 23	95.8%	32 – 23 = 5	41.7%
33	S, T, Q, R, Z 100%	22 + 2 = 24	100%	33 – 24 = 9	75%

The fever chart is one way to manage time buffers; the following example shows another way.

Example 13.3: Doling Out the Reserves: The Mars Pathfinder Project[3]

The goal of the Pathfinder Project was to land on Mars a skateboard-sized, self-propelled, six-wheel rover that would move over the terrain and send back photos and scientific data (Figure 13.4). The project's budget reserve was $40 million—about 30 percent of the total budget (a large percentage, but common in risky technological projects), and its time buffer was 20 weeks, about 13 percent of the project's 37-month design, build, and test schedule.

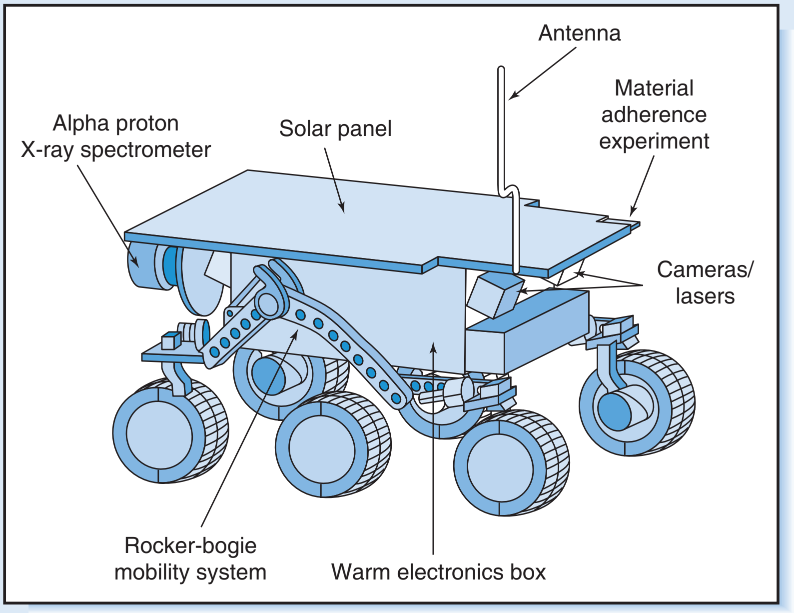


Figure 13.4
The Mars Pathfinder rover.

Once the project was underway, the question arose: How should the reserves be used? Using them too freely and too early would leave nothing remaining for later. Using them too stingily would stifle progress, increase risk, and result in leftover reserves that might have been put to good use. Management adopted the guideline to delimit the amount of the schedule reserves available for use in *each period* of the project. For example, *none* of it was to be used (no slippage allowed) at the start of system assembly and test. If problems arose, the guideline was to commit whatever budget reserves necessary to keep the project on schedule. (Time was a strategic issue: the launch date had to coincide with the exact relative positioning of Earth and Mars.)

The project was a success. Pathfinder landed safely, and the little rover sent back thousands of pictures. The project established a new standard by designing, building, and landing a spacecraft on Mars in half the time and at *one-twentieth the cost* of previous missions.

Prepare tasks to start early

Tasks or work packages on the critical path or critical chain should be ready to start at the earliest possible time; for that to happen, however, teams for each task need to know the status of the task's predecessors. Thus, in time-sensitive projects like Pathfinder, every task must provide its successor tasks with *daily status reports* stating the expected days remaining to complete and the earliest date when successor tasks should expect to begin work. The mandate is: *as soon as* immediate predecessors of a critical task are completed, teams assigned to successor tasks will begin work, even if they have to stop working on something else. In CCPM terminology, a daily status notification to enable tasks to status early, if necessary, is called a *resource buffer*.

Publicize consequences of delays and benefits of early finish

Everyone—team members, contractors, and suppliers—should know the consequences of a schedule overrun and the benefits of finishing early. The project contract might offer incentives for early completion and budget extra money for bonuses to workers who finish early.

Example 13.4: Meeting Launch Deadlines at Microsoft[4]

Microsoft meets product launch dates by utilizing visual freeze, internal target ship dates, and time buffers. A "visual freeze" date is a halt imposed on the product design that affects aspects of the product's visual appearance. The freeze date usually occurs at about the 40 percent mark of the schedule. Upon reaching that date, developers lock the product, thereafter allowing few if any changes to features such as menus, dialog boxes, and document windows. The freeze enables the user education group to prepare training and system documentation materials (aka "side items") concurrent with product final debugging and testing so the materials will be ready upon product release.

Microsoft also sets "internal target dates" that pressure developers to decide which product features must absolutely be included and which may be forgone—else they tend to keep adding features (bloatware) and ignore the schedule. This ensures the product will contain the minimal necessary features and still be released on time.

To account for overlooked or poorly understood tasks, difficult bugs, and changes in features, Microsoft adds time buffers to project schedules. The buffers, which can range from 20 to 50 percent of the total target schedule time, are used exclusively to cover uncertainties and non-routine tasks. The project team strives to meet the internal ship date, which is the launch target date announced to the public *minus* the time buffer.

13.5 Work packages and control accounts

Earlier chapters described the role of work packages and control accounts in project planning; not coincidentally, they are also key elements of project control. Each control account consists of one or more work packages; each work package is like a contract for a specific job with requirements, work description, budget, schedule, and so on. Thus, each work package and control account is a focal point for data collection, work progress evaluation, problem assessment, and corrective action. Large projects may be composed of hundreds of work packages, making it difficult to identify the sources of cost or schedule overruns. An advantage of a PCAS, described in Chapter 9, is that it can sort through all of the work packages and locate the sources.

See Chapter 9

Work authorization process

An important aspect of project control is *work authorization*, or *start-stop control*: project work is started only upon formal authorization and is stopped only upon review and acceptance. It applies to both the project as a whole and to each and all work packages. At the project level, the project manager can begin the project only upon authorization from the customer, program manager, and/or top management. The project manager then authorizes managers of contractors or departments to begin, and they in turn authorize managers and supervisors of work packages to begin, shown in Figure 13.5. The process is a continuation of the initiation, proposal, and authorization process described in Chapter 3 and Figure 3.9.

See Chapter 3

The same process also may apply to authorizing *phases* of a project: after each phase, the customer or other stakeholders evaluate the results of the phase and plan for the next phase, and if everything is acceptable, they authorize the next phase (this is the "phased project planning" process discussed in Chapter 4 and the "gating process" described in Chapter 18).

See Chapters 4 and 18

On large projects, authorization is subdivided into the stages of *contract release*, *project release*, and *work order release* or work requisition. After the customer awards the contract, the contract administrator prepares a contract release document that summarizes the contractual requirements and gives the project manager the go-ahead. The project comptroller or accountant then prepares a project release document, which authorizes project funding.

Individual work tasks or packages begin only upon receipt of a *work order* (or "engineering order," "shop order," "site instruction," or "test order," depending on the kind of work). As the scheduled start date for a task draws near, the project manager or project office releases the authorization document to the contractor or department to begin work. For simple projects or activities, verbal authorization might suffice.

Work progress and percent complete

Upon beginning work, data for each work package about *actual* costs and progress are periodically collected and entered into the PCAS, which then consolidates the data and generates performance reports for each work package and department and the entire project.

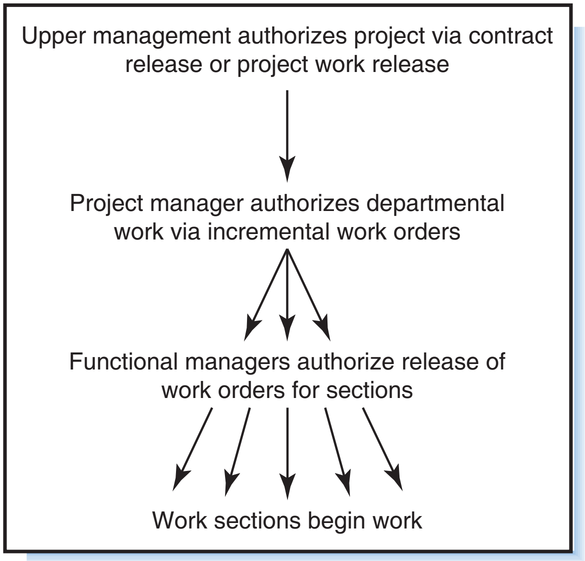


Figure 13.5
Project work authorization process.

In large projects, assessing the impact of work progress on schedules is the responsibility of the departmental manager or team supervisor in charge of the work. Each week, the supervisor reviews the tally of labor hours for each task as entered on time cards (or the electronic equivalent). She notes tasks completed and tasks still "open" and estimates the time still needed to complete open tasks. She also estimates the *percent complete*, which is the percentage progress for the task, and records it on a Gantt chart showing all completed and open tasks.

Figure 13.6 is an example showing the status of the LOGON Project as of week 20. Percent complete is represented by highlighting the bar for each task. Highlighting the whole bar indicates 100 percent complete; highlighting a quarter of the bar means 25 percent complete, and so on. Work packages K, L, M, N, O, P, and Q are all open (underway but not yet completed); K, L, M, and Q are behind schedule (the highlighted portions are to the left of Week 20); O is ahead (the highlighted portion is to the right of Week 20).

Each week, the work package supervisor tallies current expenses. Labor hours as reported on time cards are converted into direct labor cost. The costs for direct labor, material, and level of effort (testing, support, etc.) for completed and open tasks are added to the costs of work from prior periods and the sum multiplied by the overhead percentage rate. Late charges and outstanding costs (a frequent source of cost overruns) are also included. The supervisor documents any estimated changes to budgets or schedules for remaining work and forwards to the project manager a report showing costs of all work completed in prior periods plus work accomplished in the current period. This information, after validation by the project manager, is entered into the PCAS, which accumulates costs to date for all work packages and prepares a summary report. Periodically the project manager reviews these reports to reassess the project and estimate the work still needed and the cost to complete the project; as described later, these provide forecasts of the completion date and project cost at completion. When a task or work package is completed, its budget is closed to prevent additional unauthorized billing.

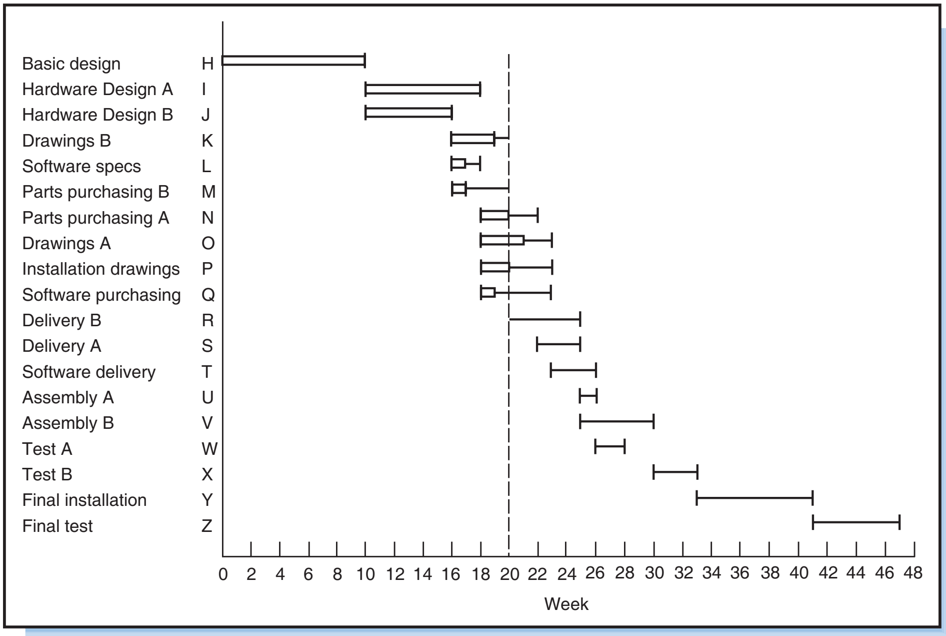


Figure 13.6
Gantt chart showing work status as of week 20.

Measures of work progress

How are work progress and percent complete measured? Accrued expenses and time elapsed are easy to measure, but neither says much about *actual* work progress; thus, project managers often must rely on other, sometimes subjective, measures. In a survey of ways to measure project performance, Thompson identified the following.[5]

1. *Supervisors*. Managers and supervisors assess progress by direct observation, asking questions, and reviewing project reports and documentation.
2. *Milestones*. These are easily measured end-points of tasks or transition points between tasks; examples are completion of drawings, reports, and design documents or solutions of specific technical problems.
3. *Tests and demonstrations*. Described earlier, these can range from simple tests of system components to full-system and user acceptance tests. They are a good way to measure technical progress at intermediate stages of the project.
4. *Outside experts*. These are experts invited to serve on a review panel. The panel assesses project status by observing work in progress, talking to project personnel, and reviewing documentation.
5. *Status of design documentation*. Experienced project managers can determine when a design is nearly finished by the "completeness" of documents such as drawings, schematics, models, manuals, and test procedures.
6. *Resources utilized*. A request for or change in resources may reflect progress; for example, tasks nearing completion often require special facilities, personnel, and equipment for testing and implementation.
7. *Telltale tasks*. Tasks such as concept design, requirements definition, feasibility analysis, and repeated testing typically happen early in a project; their happening later in the project signifies a *lack* of progress.
8. *Benchmarking or analogy*. Certain tasks or the entire project may be compared to similar tasks or projects as a crude way to weigh relative progress.
9. *Changes, bugs, and rework*. Because ordinarily the number of bugs, problems, change requests (discussed later), and so forth should decrease as a project nears completion, a remaining high number may indicate lack of progress. This is discussed later under "issues tracking."

13.6 Performance analysis and earned value management

Earned value management (EVM) is a quantitative approach to assessing the performance of a project or any portion of it. It involves comparing three variables: BCWS, ACWP, and BCWP. These are industry-standard acronyms; to save ink, we will abbreviate them as PV, AC, and EV, respectively.

See Chapter 9

1. *PV* is the *planned value* (or *budgeted cost of the work scheduled*, BCWS)—the sum cost of all work and apportioned effort scheduled to be completed within a given time period as specified in the *original budget*. For example, in Chapter 9, Table 9.5 and Figure 9.15 show the cumulative and weekly expenses for the LOGON project. These amounts represent PV. In week 20, for example, to-date PV is \$512,000 and weekly PV is \$83,000.
2. *AC* is the *actual cost* (or the *actual cost of the work performed*, ACWP)—the actual expenditure as of a given time period.
3. *EV* is the *earned value* (or *budgeted cost of the work performed*, BCWP)—the value of the work performed so far (both fully and partially completed work packages). The value is determined by the *original budget*. Thus,

- For a completed work task, EV is the same as the PV for that task.
- For a partially completed work task, EV is computed as the *percent complete* for the task multiplied by the budget for the task. (Alternatively, it is computed as 50 percent of the task budget when the task is started, then 100 percent of the task budget when it is completed.)

Application of these variables and EVM to track and assess project performance is illustrated in the following example.

Example 13.5: EV versus PV in the Parmete Company[6]

The Parmete Company has a $200,000 fixed-cost contract to install 1,000 parking meters. The contract calls for removing old parking meters from their stands and replacing them with new ones at a cost of $200 per meter.

Parmete estimates that 25 meters can be installed each day. At 25 meters per day and $200 per meter, the project should finish in 40 working days with a total PV of $200,000. Also on that basis, the accumulated planned value of scheduled work (PV) as of *any given day* can be determined by multiplying the number of working days completed as of that day by the cost of installing 25 meters ($200 times 25). For example, as of day 18,

$$\text{PV} = 18 \text{ days} \times (25 \text{ meters}) \times (\$200) = \$90{,}000$$

That is to say, the project schedule and budget specify that as of the 18th day of work on the project, $90,000 worth of work should have been done. Notice that PV is always associated with a specific date on the project schedule.

In contrast, the *earned value* for any given day represents the value of the work *actually* done in terms of the budget. In this project, EV is the number of meters *actually* installed *to-date*, times the $200 budgeted for each meter. Suppose, for example, that as of the 18th day on the project, 400 meters had been installed; thus,

$$\text{EV} = (400 \text{ meters}) \times (\$200) = \$80{,}000$$

In other words, as of day 18, $80,000 worth of work has been performed. Now, given that $90,000 worth of work was *supposed* to have been performed, the project is $10,000 worth of work *behind schedule*. Notice the $10,000 does not represent a cost savings but rather an amount of work that should have been done but was not. It represents 50 parking meters, or 2 days' worth of work, meaning that as of day 18, the project is 2 days behind schedule. (The 2 days is referred to as the time variance, or TV.) Thus, EV is a translation of project cost into work progress. As of day 18, the project has made 16 days' worth of work progress. This is represented on the graph for PV and EV in Figure 13.7.

Besides completed tasks, EV should also reflect tasks started but not yet completed (open tasks). For example, suppose before quitting at the end of day 18, the meter installer had just enough time to remove an old meter but not to install a new one: the work on that task was 50 percent completed. If this were meter number 401, then EV as of day 18 would be the cost for the first 400 meters plus 50 percent of the cost for the 401st:

$$\text{EV}=\$80{,}000+(0.50)(\$200)=\$80{,}100$$

Thus, the EV as of day 18 is $80,100, which represents slightly more than 16 days [$80,100/(25 × $200) = 16.02 days] of work completed.

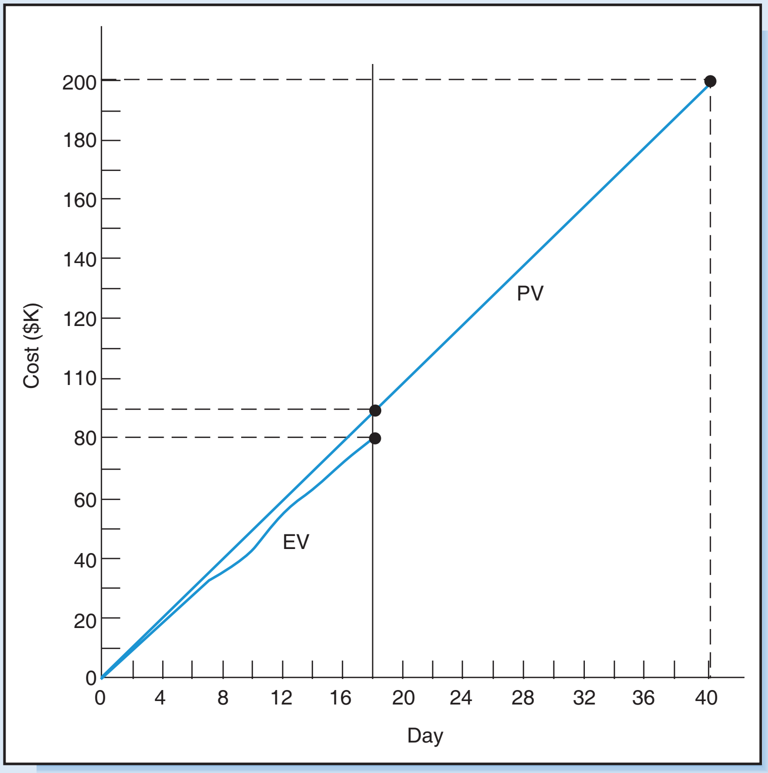


Figure 13.7
Graph of PV and EV for parking meter project.

The variables PV, AC, and EV can also be used to compute variances that reveal different aspects of a project's status. For example, assume for the LOGON Project in week 20,

$$PV = \$512{,}000$$
$$AC = \$530{,}000$$
$$EV = \$429{,}000$$

Using these figures, three kinds of variances can be determined, shown in Figure 13.8.

1. *Schedule variance:* $SV = EV - PV = -\$83{,}000$.
2. *Time variance:* Refer to Figure 13.8: See EV for week 20, then see the week where PV equals this EV (about week 19); thus, $TV = (20 - 19) = 1$ week.
3. *Cost variance:* $CV = EV - AC = -\ \$101{,}000$.

Positive SV suggests the project is ahead of schedule; negative SV suggests it is behind; thus, an SV for week 20 of $-\$83{,}000$ means the project is behind schedule. TV shows approximately how far behind

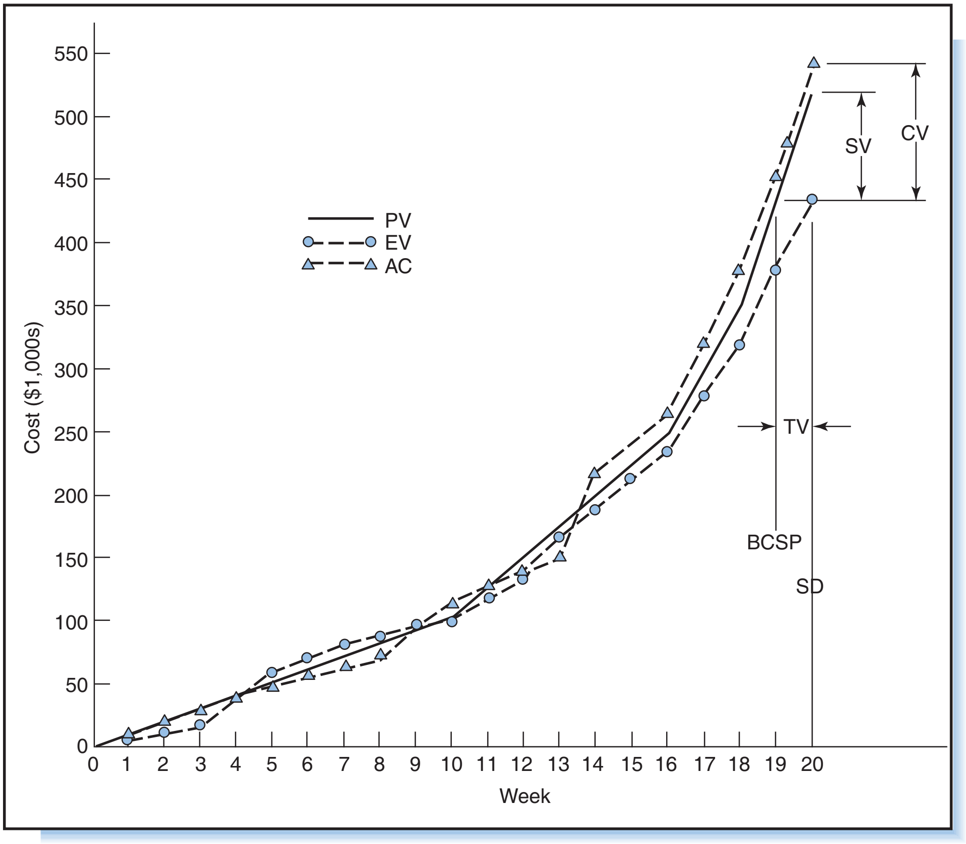


Figure 13.8
LOGON project status as of week 20.

schedule, in this case about 1 week, because the EV of $429,000 is roughly the value of work (PV) that *should* have been completed about 1 week earlier.

Negative CV indicates that the project is overspending for the work completed; positive CV indicates it is underspending. A CV of −$101,000 indicates that LOGON is overspending.

Work package analysis and performance indexes

Figure 13.8 represents project status as of week 20. But a complete assessment of project status requires an assessment of all the work packages. With information from the PCAS, however, a figure like Figure 13.8 can be prepared for every work package and control account.

Refer back to Figure 13.6, which shows the status of all LOGON activities as of week 20: activities H, I, and J are completed and have been closed; Activities K through Q are "open" and underway. Other activities have yet to begin. This gives a general *overview* of the status of each work package, although a better measure is given by computing two *performance indices*:

1. Schedule performance index: SPI = EV/PV
2. Cost performance index: CPI = EV/AC

Table 13.2 LOGON performance report week 20 cumulative to date.

Activity	PV	AC	EV	SV	CV	SPI	CPI
H*	100	100	100	0	0	1.00	1.00
I*	64	70	64	0	−6	1.00	0.91
J*	96	97	96	0	−1	1.00	0.99
K	16	12	14	−2	2	0.88	1.17
L	36	30	18	−18	−12	0.50	0.60
M	84	110	33	−51	−77	0.39	0.30
N	40	45	40	0	−5	1.00	0.89
O	20	28	24	4	−4	1.20	0.86
P	24	22	24	0	2	1.00	1.09
Q	32	16	16	−16	0	0.50	1.00
Project	512	530	429	−83	−101	0.84	0.81

*Completed

Values of SPI and CPI greater than 1.0 indicate that work is ahead of schedule and under budget; values less than 1.0 indicate behind schedule and over budget.

Table 13.2 shows performance information for all LOGON activities as of week 20. The CPI and SPI indices show trouble spots and their relative magnitude: L, M, and Q have fallen the most behind schedule (because they have the smallest SPIs), and L and M have the greatest cost overruns relative to their sizes (because they have the smallest CPIs). This indicates that the project is "somewhat" over cost (CPI = 0.81). It might also be behind schedule (SPI = 0.83), although maybe not, depending on whether behind-schedule activities are on the critical path.

Focusing *only* on the project level or *only* the work package level to assess project status can be misleading, and the project manager should scan both levels back and forth. If she looks only at the project level, good performance in some activities may hide poor performance in others. If she looks only at individual work packages, she can easily overlook the cumulative effect from slightly poor performance in many activities: small cost overruns in many individual work packages can add up to a large overrun for the project. For example, SV in Table 13.2 (−\$83,000) suggests that the entire project is behind schedule (Figure 13.8, TV = −1 day), yet looking back at Figure 13.6 reveals that only one of the behind-schedule work packages, Activity M, is on the critical path. Since Activity M appears about 3 weeks behind schedule, the project must also be 3 weeks behind schedule—not 1 week as estimated by the project-level TV.

See Chapter 7

The importance of monitoring performance at the work package level is further illustrated by an example from the ROSEBUD project. Figure 13.9 is the cost report for Work Package L for month 2. (Numbers in the PV columns are derived from the month 2 column in the budget plan in Figure 9.8, Chapter 9.) Current period and cumulative numbers are the same because Work Package L begins in month 2.

See Chapter 9

The performance indices for ROSEBUD Work Package L are:

$$SPI = EV/PV = 0.80$$

$$CPI = EV/AC = 0.74$$

indicating both schedule and cost overruns as of month 2. Suppose the project manager investigates the costs for Work Package L and discovers the following:

Project ROSEBUD Date Month 2
Department Programming Work Package L Software specifications

Charge	Current period					Cumulative to date				
	PV	EV	AC	SV	CV	PV	EV	AC	SV	CV
Direct labor										
Professional										
Associate										
Assistant										
Direct labor cost	6,050	4,840	6,050	−1,210	−1,210	6,050	4,840	6,050	−1,210	−1,210
Labor overhead	4,538	3,630	5,445	−908	−1,815	4,538	3,630	5,445	−908	−1,815
Other direct cost										
Total direct cost	10,588	8,470	11,495	−2,118	−3,025	10,588	8,470	11,495	−2,118	−3,025
General/administrative	1,059	847	1,150	−212	−303	1,059	847	1,150	−212	−303
Total costs	11,647	9,317	12,645	−2,330	−3,328	11,647	9,317	12,645	−2,330	−3,328

Note: EV is for 80 percent of work scheduled and labor overhead is increased to 90 percent of labor cost.

SPI: EV/PV = 0.80 CPI EV/AC = 0.74

Figure 13.9
Cost chart for ROSEBUD project as of month 2.

First, although AC = PV for direct labor, only 80 percent of work scheduled for the period was performed (EV = PV × SPI = 6050 × 0.80 = 4850). Second, although AC = PV for direct labor, the AC and PV for labor *overhead* are different due to a rate increase from 75 percent to 90 percent during month 2. Whereas PV would reflect the old rate (0.75 × 6050 = 4538), AC would reflect the new (0.9 × 6050 = 5445). The point: the fact that total AC exceeded total PV in this case has no bearing on the actual performance of the work package but stems from a change in the overhead rate, something over which the project manager has no control.

Now look at Figure 13.10, the cost report for the same work package but for month 3. The performance indices for cumulative figures are:

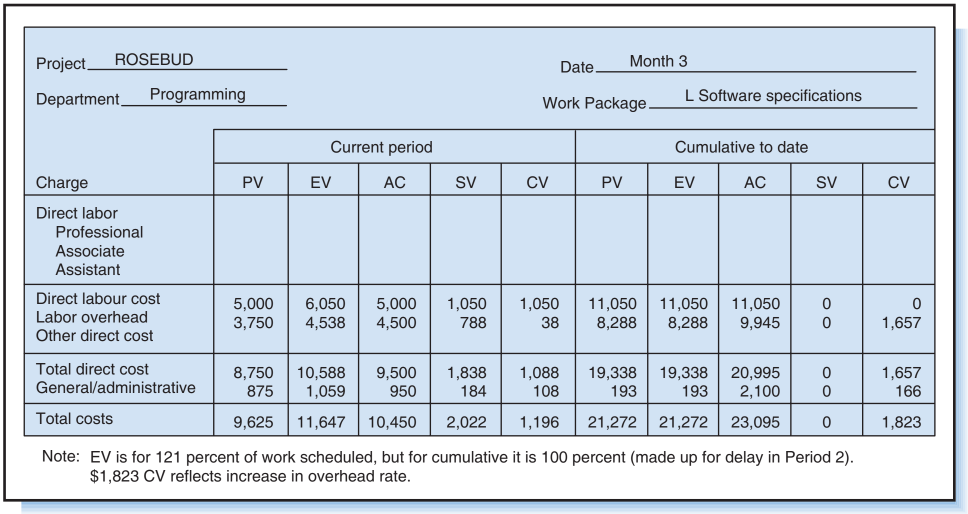
$$\text{SPI} = \text{EV}/\text{PV} = 1.00$$

$$\text{CPI} = \text{EV}/\text{AC} = 0.92$$

Notice first that although direct labor AC = PV for the month, more work was performed than was planned for the month (EV > PV), making up for the work deficit in month 2 and resulting in the task being completed on schedule (indicated by SPI = 1.00). The work package has negative CV—caused by the increase in the labor overhead rate from 75 percent to 90 percent. The point? Of the numerous factors that affect project work progress and costs, some are beyond the project manager's control. To determine the sources of variances and places where the project manager can or must act requires scrutiny of costs and performance *at the work package level*. Project-level analysis is simply inadequate.

Monitoring with performance indexes and variances

By using project-level CPI and SPI, the project manager gets a quick "ballpark" estimate of the project's performance to-date. Although the estimate might be somewhat inaccurate, it enables tracking of broad trends in project performance. The plot of SPI against CPI in Figure 13.11 is an example: LOGON



Project ROSEBUD

Date Month 3

Department Programming

Work Package L Software specifications

Charge	Current period PV	EV	AC	SV	CV	Cumulative to date PV	EV	AC	SV	CV
Direct labor Professional Associate Assistant										
Direct labour cost Labor overhead Other direct cost	5,000 3,750	6,050 4,538	5,000 4,500	1,050 788	1,050 38	11,050 8,288	11,050 8,288	11,050 9,945	0 0	0 1,657
Total direct cost General/administrative	8,750 875	10,588 1,059	9,500 950	1,838 184	1,088 108	19,338 193	19,338 193	20,995 2,100	0 0	1,657 166
Total costs	9,625	11,647	10,450	2,022	1,196	21,272	21,272	23,095	0	1,823

Note: EV is for 121 percent of work scheduled, but for cumulative it is 100 percent (made up for delay in Period 2). $1,823 CV reflects increase in overhead rate.

Figure 13.10
Cost chart for ROSEBUD project as of month 3.

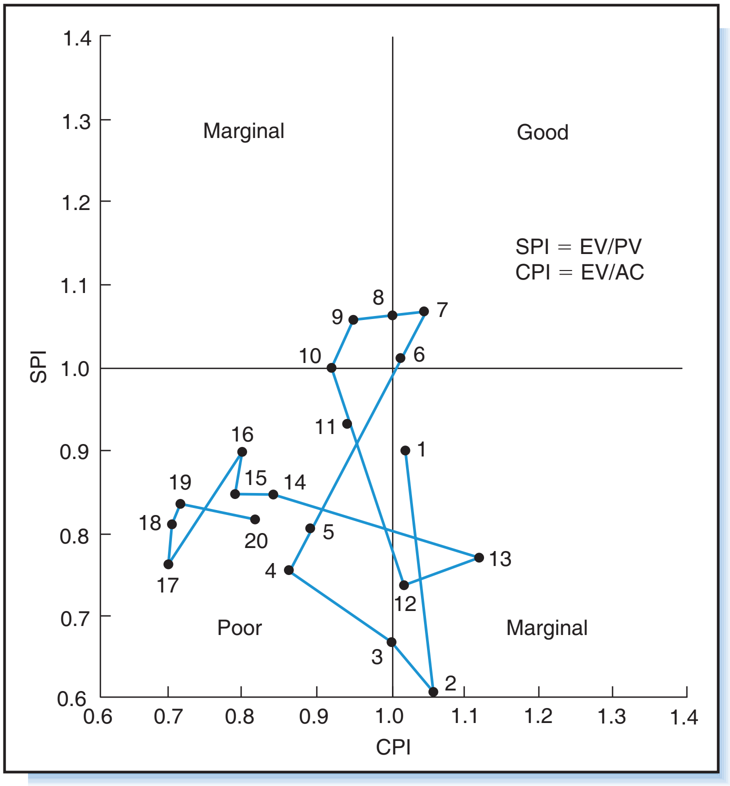


Figure 13.11
LOGON project cost/schedule performance plotted for months 1 through 20.

Table 13.3 Example of variance limits.

Work Package A	Variances greater than $2,000
Work Package B	Variances greater than $18,000
Department C	Variances greater than $6,000
Department D	Variances greater than $38,000
Project	Variances greater than $55,000

performance started out (points 1, 2, and 3) in the marginal and poor regions, briefly recovered, and then drifted disturbingly back to and *remained* in the poor region (points 11 through 20). The project manager should be searching to identify reasons.

Rarely do actual and planned performance measures coincide, so nonzero variances are more the rule than the exception. This leads to the question: What amount of variance is necessary to justify taking action?

Table 13.3 shows variance limits for different project levels—work package, department, and project. Only when a variance exceeds a limit are corrective measures considered. In some projects, the limits are allowed to vary. In research projects, the limits are initially set high but are lowered as the project moves forward. This coincides with project risk, which typically starts out large but diminishes as the project progresses.

Use of both upper and lower variance limits on costs and schedules helps identify places where work quality is in question. A project running ahead of schedule and under budget—an apparently desirable situation—might in fact be riddled with cutting corners and shoddy workmanship. For technical performance, both upper and lower variance limits on technical requirements are necessary: lower limits to ensure minimal requirements are met, upper limits to discourage excessive or unnecessary development work.

Updating time estimates for tasks/work packages

Following each progress review, it might be necessary to update the scheduled completion dates of individual tasks or work packages. In general,

$$\text{Forecasted finish date for a task} = \text{Start date} + \text{Time remaining}$$

where Time Remaining is determined in two ways. The first way is to compute it as a function of the days worked so far and current progress, that is:

$$\text{Time remaining} = \frac{\text{Percent of time remaining}}{\text{Percent progress per day}}$$

where

$$\text{Percent progress per day} = \frac{\text{Percent of task completed so far}}{\text{Days worked on task so far}}$$

The other way is to simply accept the opinion of a reputable source ("It'll take another 5 days to finish the job"). This way often yields a more accurate estimate than the first way because it accounts for any recent changes in the rate of work progress.

Either of these methods is okay for updating completion dates for individual tasks but not for the project, since, as mentioned earlier, the latter depends on whether delayed tasks are on the critical path. In general, EVM alone should not be used to predict the project completion date.

Example 13.6: Revising Task Completion Date

A task starts on July 10 and is planned to take 12 days (weekends included). After 5 working days (end of July 14), the leader estimates that the task is 20 percent complete. If the rate of progress stays the same, what is the forecast completion date of the task?

Five days of work represents an estimated 20 percent complete, so the work progress is 20 percent/5 = 4 percent per day. Thus, to complete the remaining 80 percent should take 0.80/0.04 = 20 working days. The revised completion date is July 15 + 20 = August 4.

Now, assume instead that the team leader believes that the remainder of the task will proceed much faster than 4 percent per day and that, at most, 10 more working days will be required. If the team leader's estimate is considered credible, the revised completion date would be July 25.

Estimated cost at completion

Periodically the project manager prepares a *to-complete* forecast; this is an estimate of the cost remaining to complete the project, computed as:

$$\text{ETC (Estimated cost to complete project)} = (\text{BAC} - \text{EV})/\text{CPI}$$

where BAC is the budgeted total cost for the project (= total PV at target completion).

This forecast plus the actual project cost to-date yields a forecast of the project total cost *at completion*,

$$\text{EAC (Estimated cost at completion)} = \text{ETC} + \text{AC}$$

The following two examples illustrate.

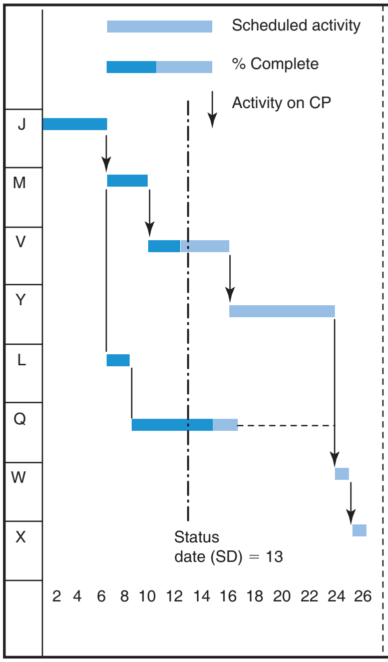
Example 13.7: Forecasting ETC and EAC for the ROSEBUD Project

Figure 13.12 shows the ROSEBUD project Gantt chart with percent complete and EVM metrics as of week 13. Given this information, how much more will the project likely cost to be completed, and how much will it cost at completion?

The value of the work completed so far (EV) is $268,081. The total budgeted amount for the project (BAC) is $344,205; hence, the value of the *work remaining* is BAC – EV = $76,124.

The cost performance for the project so far is:

$$\text{CPI} = \text{EV}/\text{AC} = 268{,}081/288{,}657 = 0.9287$$



	Status as of Week 13				
Budget at Completion	% Scheduled	PV	% Com- plete	EV	AC
J 31,362	100	31,362	100	31,362	30,550
M 138,571	100	138,571	100	138,571	155,180
V 20,945	50	10,473	30	6,284	8,933
Y 20,352	0	0	0	0	0
L 21,272	100	21,423	100	21,272	20,644
Q 100,846	50	50,423	70		
W 4,235	0	0	0	0	0
X 6,622	0	0	0	0	0
344,205		252,101		268,081	288,657

Figure 13.12
ROSEBUD Project status as of week 13.

This means the project is receiving less than 93 cents value for each dollar spent. At that rate, the estimated to-complete cost is:

$$\text{ETC} = 76{,}124/0.9287 = \$81{,}968$$

meaning another \$81,968 will be spent. Since \$288,657 has already been spent, the project estimated at-completion cost is:

$$\text{EAC} = \text{ETC} + \text{AC} = 81{,}968 + 288{,}657 + = \$370{,}625$$

This is an overrun of \$370,625 – \$344,205 = \$26,420, or 7.7 percent.

Notice that according to EV, the project is slightly ahead of schedule (EV = 268,081) > (PV = 252,101); more likely, however, it is *behind* schedule because Activity V is on the critical path and appears roughly 1 week behind schedule according to the Gantt chart.

Example 13.8: Forecasting ETC and EAC for the LOGON Project

From discussion earlier in the chapter, for the LOGON Project at week 20,

$$\text{CPI} = 429{,}000/530{,}000 = 0.81, \text{ thus,}$$
$$\text{ETC} = (990{,}000 - 429{,}000)/0.81 = \$692{,}593, \text{ and}$$
$$\text{EAC} = 530{,}000 + 692{,}593 = \$1{,}222{,}593$$

Lacking other information, a crude estimate of the revised project completion date is shown on Figure 13.13 by extending the EV line, keeping it parallel to the PV line, until it reaches the level of BCAC, $990,000. The *horizontal* distance between the PV line and the EV line at BCAC is roughly the schedule overrun for the project; in Figure 13.13, the estimated completion date is week 50, roughly 3 weeks later than the initial target of week 47.

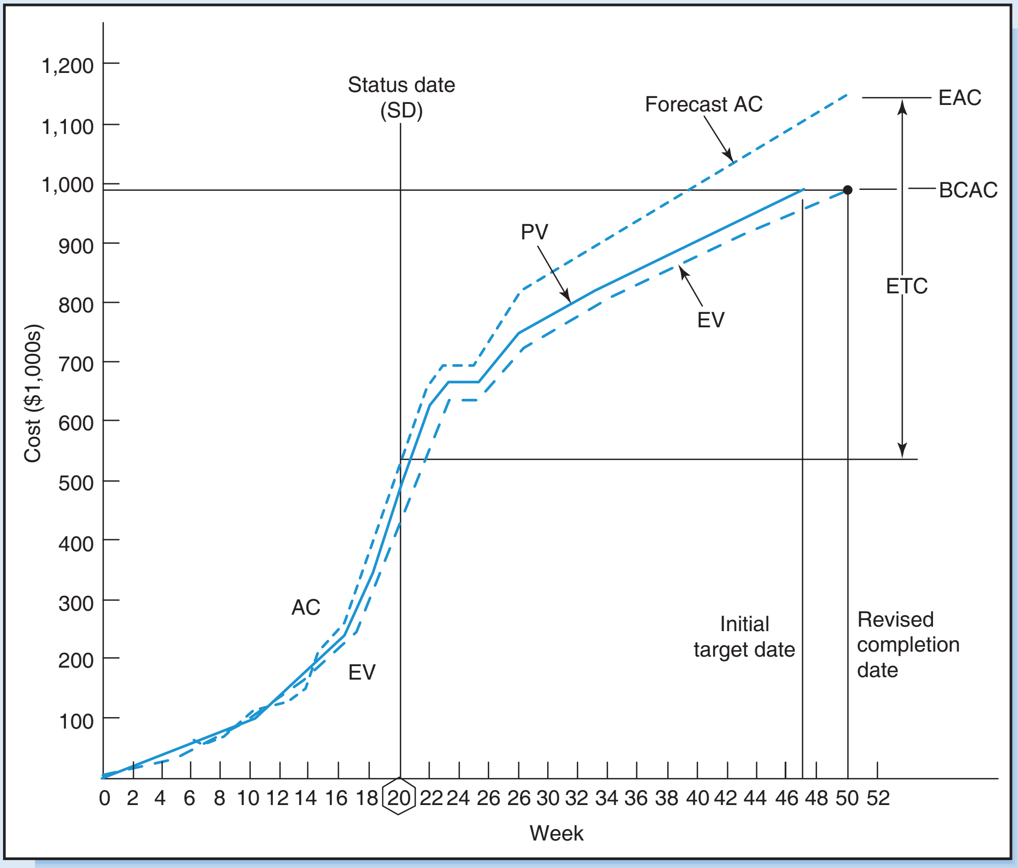


Figure 13.13
LOGON Project status chart and forecast as of week 20.

As mentioned earlier, however, this revised completion date remains to be verified, since any project delay will depend on whether the behind-schedule activities are on the critical path. From earlier discussion, we know that Activity M is on the critical path; since it is 3 weeks behind schedule, the LOGON Project is likely also 3 weeks behind.

Figure 13.13 shows another line, "Forecast AC," which is an extension of the current AC line up to the EAC level of $1,159,630 and the revised completion date of week 50. This gives a running estimate of how "actual" costs might rise until project completion.

It should be noted that the at-completion estimates assume that conditions and resources will neither improve nor worsen, which the LOGON project manager should question. Given the size of the current overrun ($101,000 as of week 20) and that the project is less than half finished, what is the likelihood of finishing all remaining work for $692,593 without *additional* overruns? (If it seems unlikely, the figure should be revised again according to best-guess estimates.) Also, what is the likelihood that the project will finish by the revised estimate of week 50? As of week 20, the EV is equivalent to the PV at week 19, which means, in terms of budgeted cost, work remaining on the project is

$$47 \text{ weeks(target date)} - 19 \text{ weeks} = 28 \text{ weeks}$$

However, given the current SPI = 0.84, it seems more likely the project has 28/0.84 = 33.3 weeks remaining. The project is now in week 20, so the revised completion date is 20 + 33.3 = week 53.3.

Earned value management shortcomings

Earned value metrics can be inaccurate and so must be treated with caution. For example, negative CV (overrun) can arise because of overhead charges that originate outside the project and have no bearing on project performance. Similarly, positive CV (underrun) can occur simply because bills have yet to be paid. EV assumes that expenses occur uniformly throughout a task or project. Whenever payments occur in periods other than when expenses are incurred or budgeted (as happens in reality), the CV is skewed. This leads some companies to apply EV methods to some cost factors (e.g. labor-costs for their own employees) and not others (e.g. procured items requiring advance payment). In the end, the sources of costs should always be scrutinized to verify apparent overruns or underruns.

Assessing progress in terms of time and forecasting completion dates using EV methods should always be accompanied by additional information, since project delays depend on whether delayed activities are on the critical path. The EV method relies on estimates of percent complete. Accurate percent complete estimates are possible whenever work can be measured in uniform units (e.g. number of bricks laid, miles of asphalt laid, number of identical fixtures installed, etc.) but not when work output (e.g. drawings produced or lines of code written) cannot be measured in uniform units (different drawings or code lines require different times to produce). Beyond these caveats are others.[7] In short, EVM metrics should always be used cautiously and in combination with information from other sources.

EVM and critical chain project management can be used in combination—provided that the purpose of each is clearly differentiated. EVM is a cost monitoring and reporting method; as mentioned, it does not distinguish "critical" activities on the schedule. CCPM is a scheduling tool; it does not address costs. The two methods occasionally give conflicting signs about project performance (SPI or TV in EVM vs. buffer consumption in CCPM). One way to address this is to use EVM for cost tracking and reporting (perhaps as required by a customer) but to use buffer consumption and CCPM for resourcing and scheduling decisions.[8]

Technical performance measurement

Besides costs and schedules, project performance depends on meeting technical requirements. *Technical performance measurement* (TPM) is a method for tracking the history of technical objectives or requirements over time. Its purpose is to provide (1) a best estimate of current technical performance and progress to date and (2) an estimate of technical performance at project completion. Both estimates are based upon results from models, simulations, tests, or demonstrations.[9]

To perform TPM, first specify technical performance measures that are *key indicators* for the end-item system. These measures should be tied to customer requirements and represent major performance drivers. A large-scale system might have a dozen high-level measures, in which case it is necessary to first define the design parameters upon which each technical measure depends and to set required values for these parameters. Examples of performance measures include:

Availability
Back-up utility
Safety
Speed
Survivability
Maintainability
Flexibility
Cycle time
Efficiency
Output rate

Capacity
Response time
Security
Setup time
Durability
Range
Variance
Cost
Utilization
Error/defect rate

Size/Space
Reliability
Power/thrust
Interface compatibility
Interoperability
Simplicity/complexity
Signal-to-noise ratio
Trip time
Idle time
Weight

Periodically during the project, performance is calculated or measured and compared to targets. Initial measures are based upon estimates from computation, modeling, and simulations; later measures are derived from test and demonstration results on actual hardware and software. Estimates and actual measures of a technical objective are plotted on a TPM chart that shows progress toward achieving the objective. If actual performance for one part of the system *exceeds* the target or objective by some margin, then sometimes that margin can be traded off against targets for other parts of the system where performance is lacking or at risk. This is illustrated next.

Example 13.9: TPM for Design Tradeoff Decisions

Based on Example 11.5 in Chapter 11, design target weights for components of a spacecraft navigation system were set at 44 pounds for Subsystem A and 26.4 pounds for Subsystem B. Design margins were also set for the subsystems to cover the risk of not meeting these targets; margins are amounts by which target values can be exceeded and still achieve system requirements, and the margins for A and B are 6 pounds and 13.6 pounds, respectively.

See Chapter 11

The TPM chart in Figure 13.14 shows design progress (actual versus target values) for the two subsystems; such charts are used to make design tradeoff decisions. This chart shows current performance and design targets at three project milestones:

1. At the time of the *preliminary model demonstration*, the actual measured weights for both subsystems were too high, although Subsystem A was relatively much closer to its target than was Subsystem B.

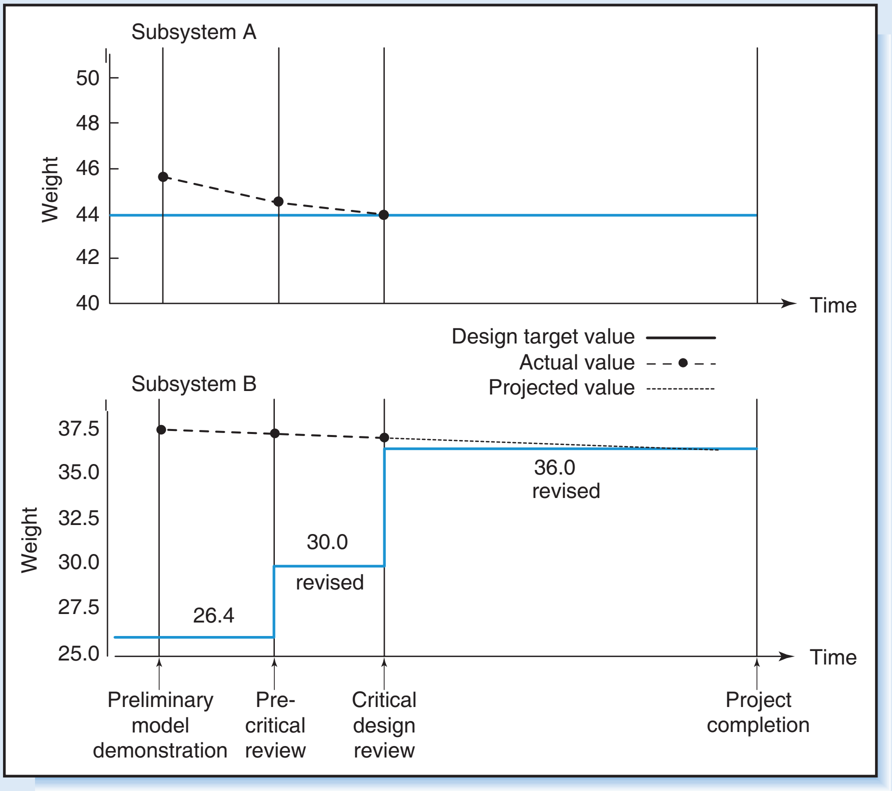


Figure 13.14
Time-phased TPM charts for Subsystems A and B.

2. By the time of the *pre-critical review*, Subsystem A had been improved and was close to its target weight; however, Subsystem B was still far away from its target. It was clear that Subsystem A might be able meet its target of 44 pounds, but Subsystem B would *not* be able to meet its target of 26.4 pounds. The decision was made to reduce Subsystem A's unused design margin by 3.6 pounds and to increase Subsystem B's design target by that amount to 30 pounds.
3. As of the *critical design review*, Subsystem A had met its target, but Subsystem B still lagged behind its; further, it was anticipated that only limited additional improvement in B was possible. The decision was made to transfer the remaining 2.4 pounds from Subsystem A's unused design margin to Subsystem B's target and to use 3.6 of Subsystem B's remaining design margin, both to increase Subsystem B's design target to 36 pounds. The dotted line for Subsystem B beyond the critical design review is the improvement still necessary to achieve Subsystem B's revised target value.

13.7 Issue management

An *issue* is an emergent problem, question, or matter in dispute. It can stem from anywhere, but it is something that must *be resolved*. Issues that originate from earlier identified risks can be resolved with the mitigation or contingency responses in the risk plan. Most issues, however, will not have been anticipated and must be dealt on the spot. Not every detail can be addressed in the project plan, and not every circumstance can be anticipated. Issues will *arise* and will require follow-up actions.

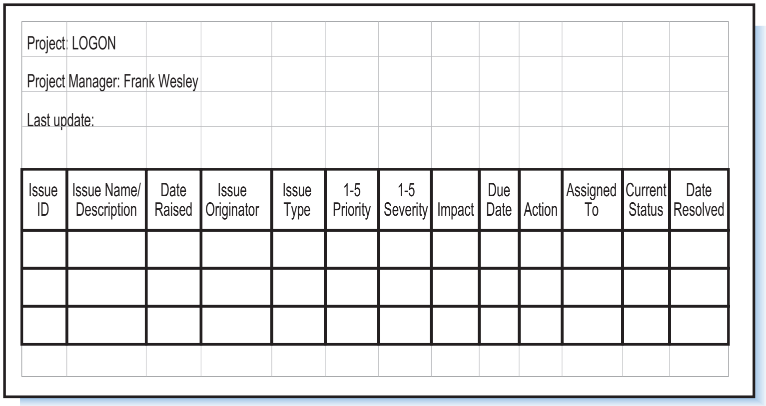
Issues, risks, and changes are related: a materialized risk (a risk that has arisen or is certain to arise) or a change request can result in an issue, or an issue can result in a change request or create a new risk. Each involves an "action item"—that is, a response, either a change request, issue resolution plan, or risk mitigation strategy. A project will encounter numerous issues, and for each, the project manager must assess its impact on the schedule, budget, other tasks, resources, and end-item quality.

Like risks and changes, issues need to be managed. Every issue needs to be documented, prioritized, tracked, resolved, and closed out. Similar to controlling changes (discussed next), issue management involves the steps of identification, documentation, analysis/evaluation, communication, action, monitoring, and closure. These steps can be described in relation to the issue log in Figure 13.15. The log, which is a record of all issues encountered, is retained throughout the project and updated whenever issues newly arise or change status.

As shown in the figure, each issue has an *ID* (simple alphanumeric identifier), *issue name/description, date raised*, and *originator*. The issue *type* categorizes the issue according to function, origin, action, or impact. For example, some companies specify issue type as "technical," "organizational," "stakeholder," or "procurement"; others use "Risk," "Change request," or "Emergent (problem)." *Impact*, if known, is the possible or certain consequence of the issue if not properly resolved.

Each issue is assessed for its importance to the project and/or the end-item by the project manager, project team, or others and is assigned a *priority* (e.g. 1–5) that is based on the *severity* (1–5) of the issue and its impact. The result of the assessment is a recommended or specified action to resolve the issue with a *due date* and *assigned-to person*.

The status of all issues is monitored frequently. Weekly status meetings start with a review of the issues log and an update of each issue's *current status*; this might be indicated by a single letter representing, for example: **N**ot started, being **A**nalyzed, **X**—cancelled, action in **P**rogress, **C**ompleted/resolved,



Project: LOGON

Project Manager: Frank Wesley

Last update:

Issue ID	Issue Name/ Description	Date Raised	Issue Originator	Issue Type	1-5 Priority	1-5 Severity	Impact	Due Date	Action	Assigned To	Current Status	Date Resolved

Figure 13.15
Issues log.

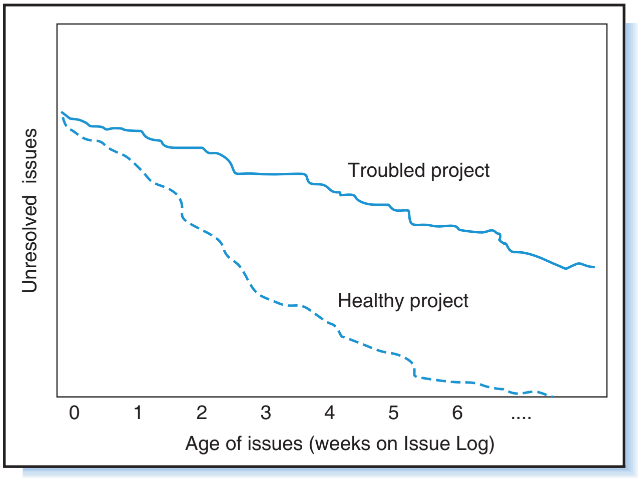


Figure 13.16
Number of unresolved issues versus age of issues.

or **E**scalated. The assigned-to person is responsible for reporting on and providing substantiating proof of the status. The *date resolved* is recorded for closed-out issues. Stubborn issues are "escalated"; that is, they are referred to a higher authority—senior management, sponsor, or customer—whoever has the authority, resources, or capability to resolve the issue.

See Chapter 11

For medium and large projects, issue management follows a process roughly analogous to risk management (substitute "issue" for "risk" in Figure 11.1 in Chapter 11) and change control (substitute "issue" for "change" in Figure 13.17, described later).

One way to gauge project progress is by monitoring issue status. All projects encounter issues, but the "healthy" ones resolve them expediently. In contrast, when issues remain unresolved, the issue backlog grows and becomes increasingly difficult to handle. Figure 13.16 shows the number of unresolved (A, P, or E) issues at a particular time in the project and how long they have been on the log. The shallow decline in the top curve represents a troubled project: numerous issues are unresolved, and most are many weeks old. The bottom curve represents a healthy project where issues are resolved rather quickly.

13.8 Change control

During the project, changes to the end-item system and project plan are inevitable, for numerous reasons: planning oversights, new opportunities, or unforeseen events and problems. Such changes require modifying the work; reorganizing or adding personnel; and trading off among time, cost, and performance. Changes to specifications and sacrifices to technical performance are sometimes necessary to meet time and cost constraints.

The impact of changes

Generally, the larger and more complex the project, the greater the number of changes and the more likely that actual costs and schedules will deviate from original targets. Changes are a chief cause of cost and schedule overruns and poor relationships between contractors and clients. Each change has a ripple effect: in response to an emergent problem, elements of the end-item and project plan must be changed, but in chain-reaction fashion, these changes then require changes to other elements of the end-item and project.

In general, the further along the project, the more detrimental the effect of changes. Design changes made to a component during system assembly and testing often lead to rework or redesign of other components. Changes made still later in construction and installation cause even more trouble: work must be interrupted, torn down, and redone and materials scrapped. Morale is affected, too: people see their work dismantled, discarded, and redone; pressure grows to get the project back on budget and schedule.

Reasons for changes

Projects typically experience the following kinds of changes:[10]

1. Changes in project scope and specifications. As a rule of thumb, the more uncertain the project, the more likely that scope and specifications will be altered during the project.
2. Changes in design because of errors, omissions, unknowns, afterthoughts, or revised needs. Mistakes or omissions must of necessity be corrected or accommodated, but customers often try to squeeze in unnecessary changes that are beyond the original scope (but, they hope, within the original price).
3. Changes mandated by changing government regulations (health, safety, labor, environment), labor contracts, suppliers, or other stakeholders in the environment.
4. Changes believed to improve the rate of return of the project.
5. Changes perceived to improve upon original requirements. People often seek to improve upon their work; although desirable for the customer, such improvements can expand the project beyond its original scope and requirements.

Examples of the previous changes include: (1) after designing a space probe, increasing its payload requirement to allow for additional necessary but unanticipated hardware; (2) encountering and having to reroute a buried cable during excavation; (3) interrupting work because of labor problems or municipal code violations; (4) altering the design capacity of a refinery under construction to increase the refinery's output; (5) adding more features to an already acceptable software design (bloatware) to enhance the perceived marketability. Note that changes 1, 4, and 5 are *discretionary*; that is, they can be rejected, while 2 and 3 are *de facto*; that is, they already "happened" or must be accepted.

Change control process and configuration management

When any aspect of the project plan (e.g. scope statement, schedule, or budget) or a design (e.g. a performance criterion) is first approved, it is referred to as the *baseline*. Thereafter, whenever there are approved changes to the project plan or design baseline, these must be reflected in a new baseline, referred to as the *second baseline*, *third baseline*, and so on. These documents might all be retained and updated in the project's document management system.

To formally manage the changes that will occur during the project and reduce their negative impacts, managers employ a formal *change control process*. The process, summarized in Figure 13.17, ensures that all changes, discretionary and de facto, to design and work tasks are documented, formally reviewed, and assessed and accepted only as necessary. It also ensures that changes are reflected in the project plan and other project and design documents.

Says Harrison, the process should:[11]

1. Continually identify changes as they occur.
2. Reveal the impact of changes on project costs, duration, and other tasks.

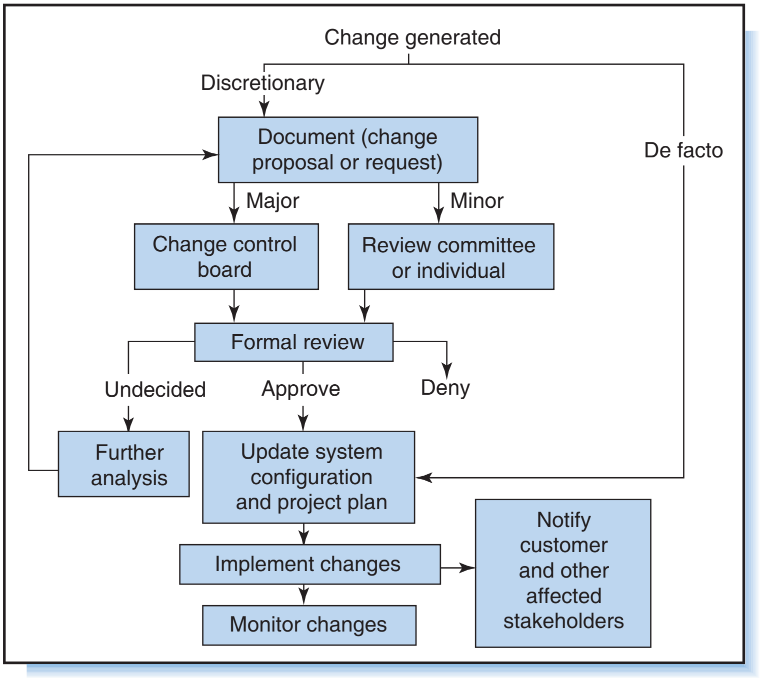


Figure 13.17
Change control process.

3. Accept or reject proposed changes based upon analysis of impacts.
4. Communicate changes to all parties concerned.
5. Specify a policy for minimizing conflicts and resolving disputes.
6. Ensure that changes are implemented.
7. Report monthly a summary of all changes to date and their impacts on the project.

The change control process is established early in the project and thereafter used to appraise the impact of proposed changes on cost estimates, schedule, and plans and to trace any variance in current performance and original estimates to specific approved changes. Change control is part of a broader process for controlling and integrating changes into the design, development, building, and operation of the end-item system, which is called the *configuration management process*, discussed in Chapter 10.

See Chapter 10

To control and minimize work and design changes, the change control process includes the following procedures:[12]

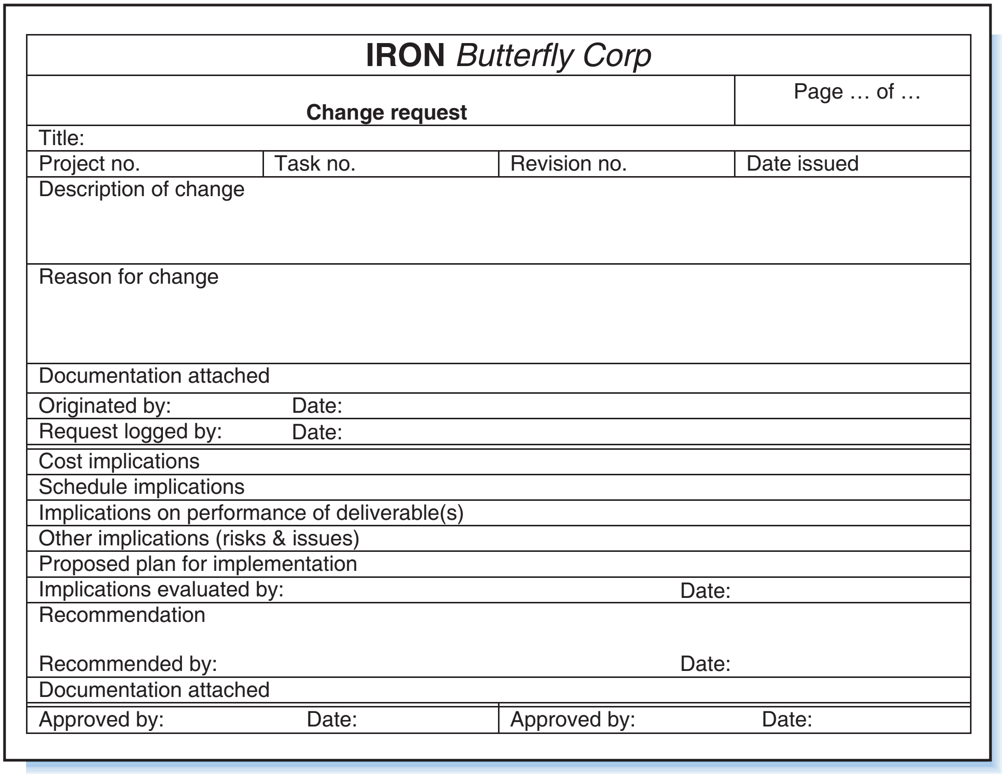
- Requiring that original SOWs, work orders, schedules, and budgets be unambiguous and *agreed to* by persons responsible.
- Close monitoring of work to ensure it *meets* (not exceeds) specifications.
- Carefully screening work for changes in work scope or cost or schedule overruns and taking quick, corrective action.
- Requiring formal request and approval of all discretionary changes.

- Requiring similar control procedures of all contractors and suppliers for all purchase orders, test requests, and so on.
- Assessing the impact of all changes on the end-item and project and revising designs and plans to reflect the impact.
- Freezing the project against all non-essential design changes at a predefined stage; this prohibits additional design changes so the next stage (fabrication, construction, or coding and testing) can begin. The freeze date is set early in the project, and project personnel are constantly reminded of it.

A key part of the change control process is the change request document, Figure 13.18, which provides information about and rationale for a proposed change. Any project team member or other stakeholder can request a change by submitting a change request. Everyone, regardless of role, title, or position, must follow the same request procedure.

In large projects, a *change control board* meets weekly or bi-weekly to review change requests, assess their impacts, and decide which changes to reject and which to approve. The board consists of the project manager, functional managers, the contract administrator, and customer reps.

Any proposed or enacted change that impacts the time, cost, or work of any task and related tasks must be documented. Everyone involved in the project has the potential to recognize or originate changes, and everyone must be expected to bring them to the attention of the project manager.



IRON *Butterfly Corp*

Change request

Page … of …

Title:

Project no.	Task no.	Revision no.	Date issued

Description of change

Reason for change

Documentation attached

Originated by: Date:

Request logged by: Date:

Cost implications

Schedule implications

Implications on performance of deliverable(s)

Other implications (risks & issues)

Proposed plan for implementation

Implications evaluated by: Date:

Recommendation

Recommended by: Date:

Documentation attached

Approved by: Date:	Approved by: Date:

Figure 13.18
Example of change request document.

13.9 Problems with monitoring and controlling projects

No matter how thorough and conscientious the project manager or sophisticated the project control system, monitoring and controlling projects can be problematic for the following reasons:[13]

1. The monitoring and control process focuses on only one factor, such as cost, and ignores others such as schedule and technical performance. This happens when control procedures are issued by one functional area, such as accounting, and other areas are not involved. Forcing compliance to one factor results in excesses or slips in other areas; for example, overemphasis on costs can lead to schedule delays or shoddy workmanship.
2. Project team members resent attempts to monitor and control their work (this happens especially when they were not sufficiently involved in planning the work) or do not comply with control procedures. Managers encourage this by ignoring those who don't comply with control procedures.
3. Project team members do not report problems they are aware of. They may not understand the situation; if they do, they might be hesitant to reveal it. The information they do report may be fragmented and difficult to piece together.
4. The control system relies entirely on self-appraisal of work progress and quality, and people provide biased information; this is a major obstacle to effective project control.
5. Managers act indifferently about controversial issues, believing that with time problems will resolve themselves. This leads some workers to believe that management doesn't care—an attitude likely to spread to others throughout the project.
6. Managers overseeing several projects misrepresent charges such that overruns in one project are offset by underruns in others (or within a project, overruns in some work packages are offset by underruns in others). The practice distorts historical data that could be used for cost estimating future projects; it is also unethical when it results in mischarging customers.

Management must be aware of these problems and work to eliminate them from the monitoring and control process. Above all, it must strive for a process that is impersonal, objective, and uniformly applied to all aspects of the project—people, parties, and tasks.

13.10 Project management information systems

The formal planning and control methods described in this book do not require any more input data or information than is, or should be, available in any project. What they *do* require is, in a word, a *system* for collecting, organizing, storing, processing, and disseminating that information—*a project management information system* (PMIS).

PMIS software

Methods such as EVM, change control, and configuration management require processing and integrating a hefty amount of information, especially for a large project. As computers are good at this, PMIS software has become essential for project planning and control. In fact, without software, it would be difficult to do much of the analysis required to plan and control large projects.

There are numerous kinds of PMIS project software packages that vary widely in capability, flexibility and price. Simpler PMIS software packages are limited in what they can do but usually are good at whatever that is; once simple software has been mastered, it is easy to upgrade to more sophisticated software.

PMIS features

Following is a rundown of the kinds of analytical capabilities, outputs, functions, and features offered by PMIS software. Important to note is that among the many available software packages, most do not have all of these capabilities; some perform only the most basic functions.

Scheduling and network planning

Virtually all project software performs project scheduling using network-based algorithms to compute early and late times, slack times, critical paths or critical chains. Among the capabilities to look for are type of procedure (CPM, PERT, PDM, CCPM), maximum number of allowable activities, format for activities and events (some use a WBS scheme), and quality and clarity of outputs (e.g. network, Gantt chart, tabular reports, or multiple types).

Resource management

Most software performs resource loading, leveling, and allocation, but packages vary in analytical sophistication and quality of reports. Major considerations are maximum number of resources permitted per activity or project, kind of loading/scheduling techniques used (resource-limited, time-limited, or both), split scheduling (stopping and restarting activities), interchangeable usage of different resources, and rate of resource usage.

Budgeting

Software varies greatly in the way it handles costs and generates budget and cost summary reports. In some, cost and expense information are not treated explicitly; in others, cost accounting is a major feature. PMIS software for large projects should have a cost and budgeting module (like the PCAS described in Chapter 9) that is integrated with modules for planning, scheduling, procurement, and tracking.

See Chapter 9

Managing multiple projects and project portfolios

Some software allows data to be pooled from different projects for *multiproject* analysis, planning, and control. This feature combines information from several concurrent projects to form a picture of the overall state of the organization. Some software systems provide a "dashboard" or overview of all projects. Managers can readily distinguish which projects are performing well from those experiencing problems or overruns—an essential capability for project portfolio management (Chapter 19). By clicking on a particular project, they can zoom in to view more detailed information about the project.

See Chapter 19

Cost control, performance analysis, and change control

Here is where project software capabilities differ considerably. To perform the control function, a system must be able to compare actual costs and work completed to budgeted and planned costs and work. Among features to consider are the software's ability to compute and report cost and schedule variances and EVM metrics (performance indices and forecasts to-complete). The most sophisticated software packages "roll up" results and allow aggregation, analysis, and reporting at all levels of the WBS. They also permit modification and updating of existing plans to reflect actual start and finish dates and costs. Plus, they help manage and reveal the impacts of change requests. Software with simulation capabilities integrates network, budget, and resource information and allows the project manager to ask "what-if" questions under various scenarios.

Interface and flexibility

Some PMIS software is compatible with and ties into existing databases for payroll, purchasing, inventory, ERP, cost-accounting, or other PMISs; some can be used with popular modeling, risk analysis, and database management systems (DBMSs).

Systems vary widely in their flexibility. Many perform a narrow set of functions; others allow the user to develop new applications or alter existing ones, depending on need. Among the applications available are change control, configuration management, responsibility matrixes, expenditure reports, cost and technical performance reports, and technical performance summaries. Many systems allow easy access through a browser to a variety of business applications and databases utilizing Internet technology.

Web-enabled project management[14]

Many project management software products take advantage of web-enabled technology that offers plans and reports on interactive websites. This technology is well suited for situations where the project team and stakeholders are geographically dispersed. Putting information on a project website or other Internet or intranet network affords the benefits of immediate information availability, rapid and easy communication between workers, and information that is current because it is communicated in real time.

With web browser–integrated project management software, team members can report progress and retrieve assignments through their own individual web pages. The manager can aggregate information received from scattered worksites to get an overview of the entire project.

In most cases, the necessary tools are already at hand. Web-enabled project software requires just one thing: access to a web browser. Most everyone uses the Internet, so team members readily adapt to web-based methods for sending and accessing project information. The costs for overhead, update, and maintenance of web-based communication are very low.

Intranets and group productivity[15]

An *intranet* is a private computer network that uses Internet standards and protocols to allow communication among people within an organization. It provides access to a common pool of information from computers within the organization. The intranet is accessible only by organizational members and other authorized parties, though access can be extended to trusted external organizations, partners, or clients through an extended network called an *extranet*. With an intranet, it is easy for users to access *groupware* and to store reports, profiles, calendars, and schedules. It is also easy to locate information in these documents using special *document-sharing tools* such as file hosting services, newsgroups, chat rooms, and electronic white boards. These tools are especially useful for sharing pictorial information about product design requirements and descriptions.

One of the most common ways that project managers use intranets is for collecting information about time spent on projects. The information is retained in a project database and then processed by project management software to report and tally time spent and time still needed to complete the project.

In the past, video- or audio-conferencing were the only ways for geographically dispersed teams to hold meetings, but today, video, voice, and data can be shared over the intranet or Internet at desktop locations. The information shared can be in the form of a spreadsheet, text document, presentation, graphic, photo, engineering schematic, video file, or live streaming. Other ways for participants to collectively share project information and add comments and view others' contributions are online *discussion forums* and *chat rooms*.

At Boeing, for example, designs—which are stored electronically and kept current to reflect the most recent changes—are available immediately to anyone who needs them. Notification of any change is sent via email to everyone who needs to know, as specified on a responsibility matrix (persons with "N" - Notification sometimes called "I" - Informed responsibility). As long as team members have access to a computer and browser, they can participate in meetings. Engineers in Kansas having trouble assembling a mockup can send video images to designers in Seattle who can *see* the mockup, assess the problem, and offer suggestions; absent that technology, designers would have to *go* to Kansas. Managing technology-enabled meetings and virtual teams is discussed in Chapter 16.

A few words about email. Any experienced project manager will say it is an important communication tool but will advise you that it is no substitute for face-to-face or phone meetings, especially when it comes to making decisions.

PMIS in the project life cycle

Figure 13.19 shows ways that a PMIS can assist the project manager in all phases of the project life cycle. The following example illustrates this use.

Example 13.10: Sigma Associates' PMIS for Project Planning and Control

Sigma Associates, the architectural/engineering firm mentioned in Chapter 9, Example 9.6, uses a PMIS for project planning and control. So ubiquitous is Sigma's PMIS in its operations that employees think of it as a member of the team; they call it "Sally."

Once a project is approved, Sally is used routinely to compare the original or current baseline project plan with actual performance, raise warnings about discrepancies, and forecast schedule and cost outcomes.

Each week, Sally accumulates information about current costs and estimates of time spent on each activity received from project participants. Non-labor expenses and client reimbursements are input through the company's general ledger system.

Biweekly, managers estimate the hours needed to complete each activity, which Sally converts into a percentage completed. The system multiplies budgeted labor hours by these percentages to determine the estimated labor hours needed to bring the activity to completion (a form of earned value). By comparing this estimate with actual labor expenditures from time cards, a project manager can determine whether the activity is moving at its budgeted pace. Sally makes actual-to-plan comparisons and reports discrepancies, which managers use to spot problems. Whenever a project manager fails to provide the biweekly estimated hours, Sally sends a prompt as a reminder.

Sally uses the anticipated hours-to-complete to prepare estimates of labor requirement loads for the remainder of the project. These estimates are used to adjust the remaining labor loadings and to make necessary revisions to schedules.

The comptroller uses Sally to forecast the timing and amounts of client billing and the timing of expected payments according to each client's payment history. Based on the percentage of work completed, the system computes estimates of earned client fees and compares them to actual project expenses in a monthly profit/loss analysis. Sally also generates monthly reports of net profit summarized by office, department, and project manager. It also combines net profit for all projects to give a picture of the company's financial health.

Sally also checks the correctness of the hours charged by employees on time cards by comparing hours with dates on the schedule and withholds any cards with discrepancies and sends memos to the employees. Each week, it sends a summary report of rejected cards to the comptroller.

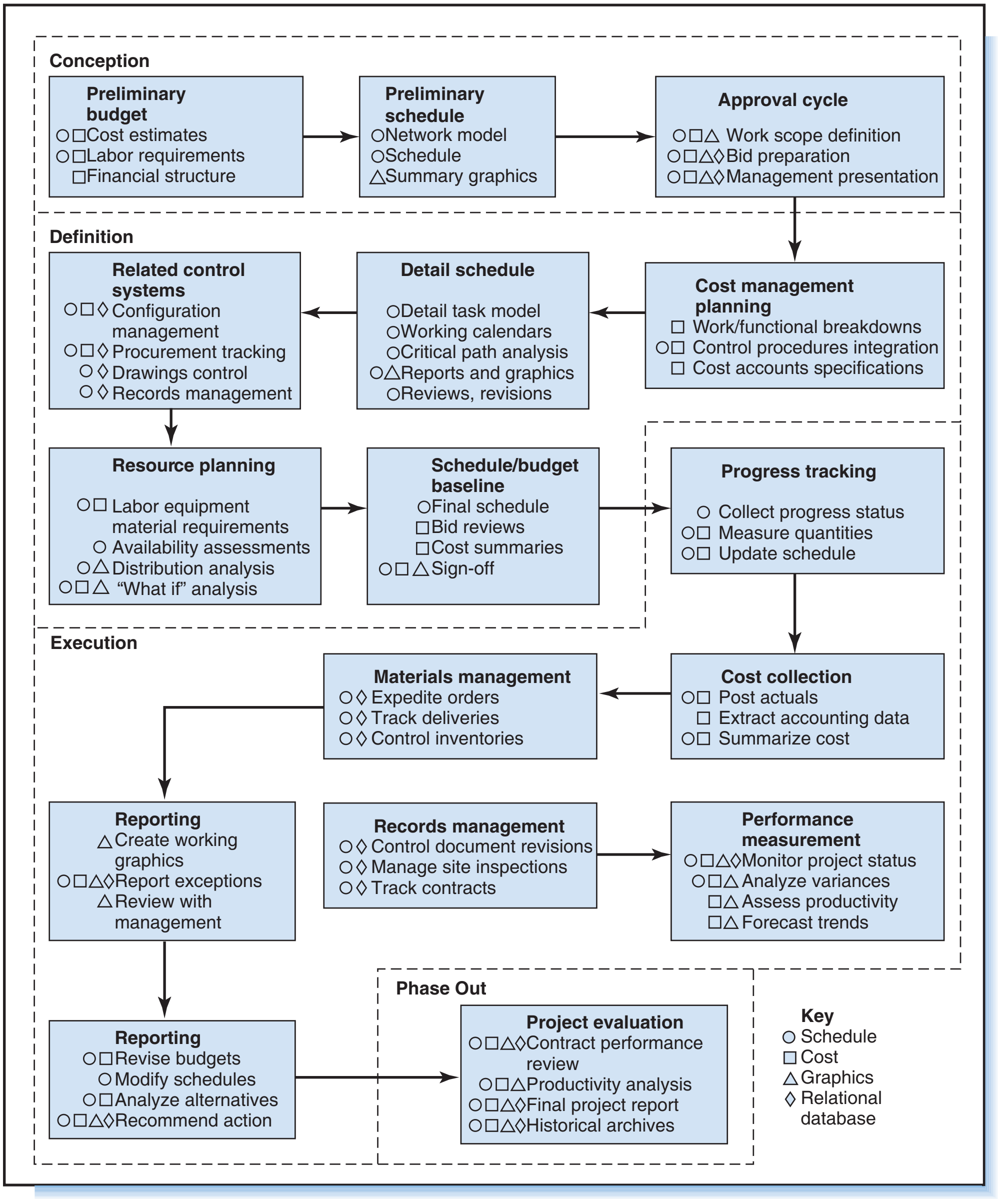


Figure 13.19
PMIS functions in the project life cycle.

Fitting the PMIS to the project

Most PM information software is no match for the capabilities of Sally, but that's okay, since such capabilities are not always required. The purpose of a PMIS, in the words of Palla, is to "get the right information to the right person at the right time so the right decision can be made for the project."[16] Any PMIS able to do this is the right one. Firms often use more than one kind of PM information software—say, Microsoft Project for smaller projects and Primavera for large ones. Various industries have expanded the functions of PMIS to meet their requirements, as explained in Example 13.11.

Example 13.11: Building Information Modeling[17]

Building information modeling (BIM) refers to software for three-dimensional modeling plus standards and processes for integrating building design and construction management. Its purpose is to create a digital model of a building, plus capability to integrate this with information from the PMIS for use in the building's construction and upkeep. It is used by architects, engineers, and contractors in a variety of projects for civil, energy, and highway engineering; urban planning; and rail and offshore facilities.

BIM is more than a design tool; its key feature is the plethora of information capabilities it provides—information that can be associated with almost every aspect of a building project—costs, schedules, and performance ratings. Designers and managers are able to analyze and preview not only the physical structure they intend to create but the construction process to be used and the management of the structure throughout its life cycle. Project managers are able to access a wealth of information on their tablets for tracking and controlling the project. While the BIM technology requires more upfront analysis, modeling, and planning than other, less comprehensive design and management approaches, it is claimed to reduce costs, shrink schedules, increase reliability, and improve quality and coordination.[18]

Industry applications of BIM vary. So-called 3D BIM enables modeling and provides visual representations and documentation of the design (similar to computer-aided design), 4D BIM adds information for project scheduling and control, 5D BIM adds information about quantities for cost analysis and control, and 6D BIM adds information for facilities maintenance.

While project management software is essential for efficiently handling the computational aspects of project management, its role should be seen in context, since computer systems are of limited value regarding numerous aspects of project management—identifying and negotiating with key stakeholders, choosing key subcontractors, motivating the team, and resolving interpersonal conflicts, to name a few. Yet many a novice project manager attends a 1-day software seminar and gains the impression that project management consists of little more than creating a WBS and Gantt chart on a computer (!).

13.11 Summary

Throughout the project execution phase, the monitoring and control process guides the project to keep it moving toward scope, budget, schedule, and quality objectives.

Project monitoring and control relies on a variety of sources and measures for collecting and communicating information, including formal and informal reviews, observations, technology, and formal written project status reports. Frequent site visits, stand-up meetings, and one-to-one conversations are the best sources, although formal reviews and audits conducted by experienced outsiders provide independent assessments of project performance. The kinds of reports and reviews and details about contents, formats, schedules, participants, and points of contact are specified in the project communication plan.

Project control means directing the project to keep it moving toward project objectives and in conformance with the project plan. This requires control over the project scope, quality, procurements, cost, and schedule. Project control begins with project goals, requirements, and a project plan. Without requirements and a plan, there can be no control.

The focal points of control are the individual work packages and control accounts. Virtually all control activities—authorization, data collection, progress evaluation, problem assessment, and corrective action—occur at the work package/control account level. The monitoring and control process begins with authorization; once authorized, work is continually tracked with reference to the project plan for conformance to scope, quality, schedules, and budgets. Key technical measures are monitored to gauge progress toward meeting technical objectives. Performance to date is reviewed using the earned value concept, and estimates of project cost and completion date are periodically revised.

Whenever costs and schedules move beyond pre-established limits, or new opportunities or intractable problems arise, the work must be replanned and rescheduled. Changes are inevitable, but every effort is made to minimize their impact on cost and schedule overruns. A formal change control process and configuration management ensure that changes are documented, assessed and authorized, and communicated.

In many projects, PMIS software performs planning and control functions such as scheduling, resource management, budgeting, tracking, cost control, and performance analysis. Many utilize web-based technology, which provides the benefits of ready accessibility at remote sites, ease of usage, and reliability and currency of information.

SUMMARY OF VARIABLES

PV = planned value = budgeted cost of work performed (BCWS)
AC = actual cost of work performed (ACWP)
EV = earned value = budgeted cost of work performed (BCWP)
SV = schedule variance = EV − PV
CV = cost variance = EV − AC
BAC = budgeted cost of project at completion = total budgeted cost
SPI = schedule performance index = EV/PV
CPI = cost performance index = EV/AC
ETC = estimated cost to complete project = (BAC–EV)/CPI
EAC = estimate cost of project at completion = AC + ETC
TV = time variance

Review Questions and Problems

1. Why is it better to rely on a variety of information sources for project monitoring rather than just a few? Give some examples of how several sources are used to monitor projects.
2. What are the advantages of the following ways to monitor projects: (a) daily standup meetings, (b) formal reviews, (c) first-hand evaluation, (d) technology, (e) formal written reports?
3. What is the purpose of internal peer reviews? When are they held? Who participates?
4. What is a formal critical review? When are formal reviews held, and what do they look at? Why do outsiders conduct it? Why would a customer or project supporter want a formal review?
5. Discuss the role of the project manager as both sender and receiver of project reports.
6. What is the purpose of the communication plan? What is the content of the plan?
7. What are the three phases of the monitoring and control process?
8. Explain the differences between internal and external project control.
9. Why is scope change control an important part of the project control process?
10. Discuss quality control as applied to projects.

11. What are the principal causes of project schedule overruns? Discuss at least four practices that may be used to reduce schedule variability and keep projects on schedule.
12. Describe the work authorization process. What does a work order usually include?
13. Discuss different ways of measuring ongoing work progress.
14. If a cost or schedule variance is noticed at the project level, how is it traced to the source of the variance?
15. Discuss common causes of project scheduling overruns and management practices that may reduce these overruns.
16. Refer to Example 13.2.
    a. Suppose in week 28, the team discovers a procedural error that negated all work done so far on Task R. What are the revised values for percent CC completed and percent buffer consumed for week 28? Where in the fever chart is the project?
    b. Recompute percent CC completed and percent buffer consumed as of the following weeks for the percent tasks completed in each: 16: S, T 100%; 20: S, T 100%, Q 10%; 24: S, T 100%, Q 40%; 28: S, T, Q 100%; 32: S, T, Q 100%, R 50%. As of week 32, does it appear the project can be completed by week 36?
17. Explain PV, AC, and EV and how they are used to determine the variances AV, SV, CV, and TV. Explain the meaning of these variances.
18. What does it signify if cost or schedule index figures are less than 1.00?
19. Explain TPM, its purpose, and how it is conducted.
20. What is an "issue"? Explain "issue management" and how it is implemented through the issues log.
21. Explain ETC and how it is related to EAC.
22. Discuss reasons the project manager tries to resist project changes.
23. What should the change control process do? Describe procedures that minimize unnecessary changes.
24. What aspects of project control fall under contract administration?
25. What are some difficulties encountered when attempting to control a project?
26. Use the networks in Figure 13.20 to determine ES, LS, EF, and LF for all activities (number in activity box is duration in days). Apply the buffer concept to the critical path. For Network

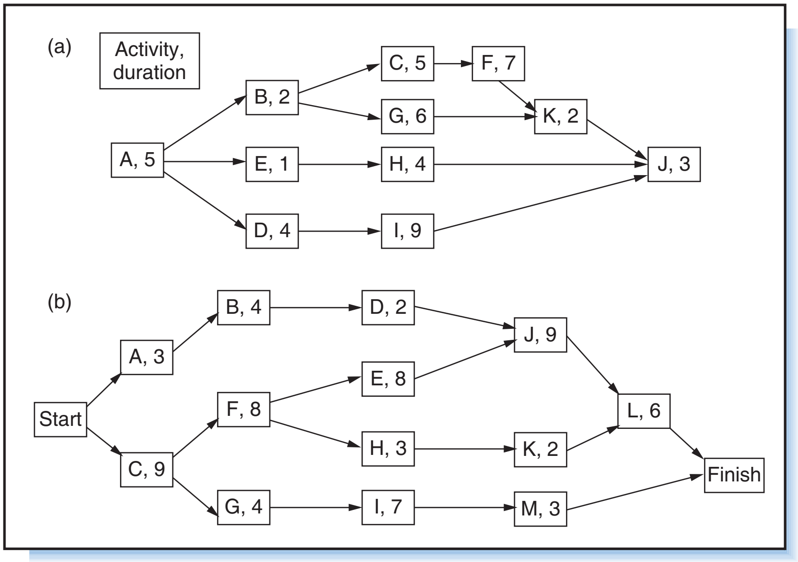


Figure 13.20
Two project networks.

(a), use a 3-week time buffer for the critical path and a 1-week time buffer for every path that feeds into the critical path. For Network (b), use a 4-week time buffer on the critical path and a 2-week buffer for every path that feed into the critical path.

27. In the LOGON Project, suppose the status as of week 22 is as follows (note usage of the longer acronyms; some project management books and software packages use these and not the shorter acronyms PV, AC, and EV).

BCWS = $628,000
ACWP = $640,000
BCWP = $590,000

Answer the following questions:

a. What is the earned value of the project as of week 22?
b. Compute SV and CV.
c. Draw a status graph similar to Figure 13.13 and plot BCWS, ACWP, and BCWP. Show SV and CV. Determine TV from the graph.
d. Compute SPI and CPI. Has the project performance improved or worsened since week 20?
e. Using BAC = $990,000, compute ETC and EAC. How does EAC compare to the week 20 estimate of $1,222,593? From your status chart, determine the revised completion date. How does it compare to the revised date (week 48–49) as of week 20?
f. Are the results from Part (e) consistent with the results from Part (d) regarding improvement or deterioration of project performance since week 20?

28. The budgeted cost as of April 30 for a work package is $18,000. Suppose on April 30 the supervisor determines that only 80 percent of the scheduled work has been completed and the actual expense is $19,000. What is the BCWP? Compute SV, CV, SPI, and CPI for the work package.

29. Using the status chart in Figure 13.21:

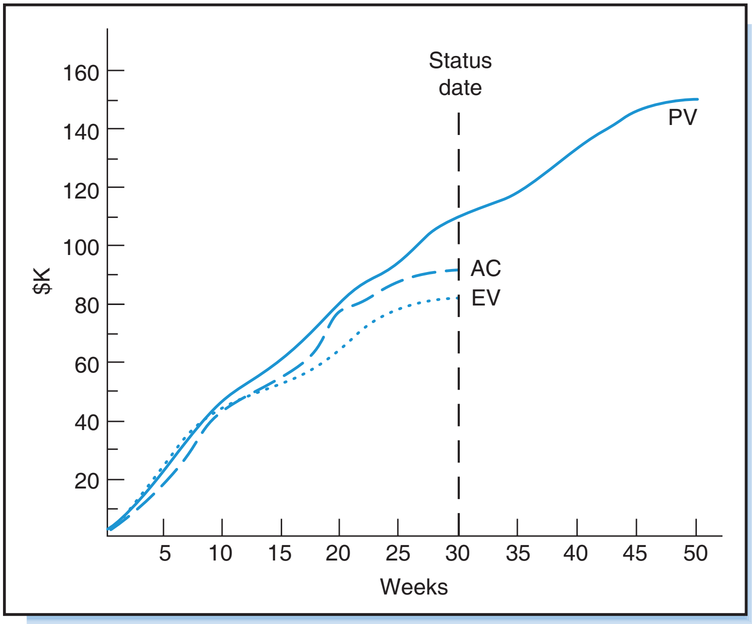


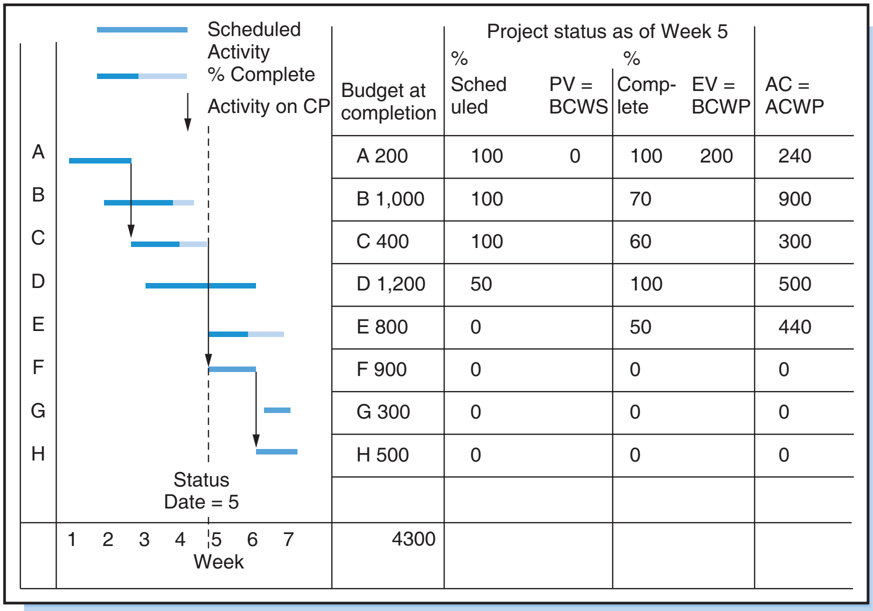
Figure 13.21
Project status as of week 30.

   a. Estimate values for SV, CV, and TV, and use them to compute SPI and CPI for week 30. Interpret the results.
   b. Compute ETC and EAC. Estimate the revised completion date and sketch the lines for forecast AC and forecast EV.

30. Assume for the following problems that work continues during weekends.
   a. A task is planned to start on April 30 and takes 20 days to complete. The actual start date is May 3. After 4 days of work, the supervisor estimates that the task is 25 percent completed. If the work rate stays the same, what is the forecast date of completion?
   b. Task C has two immediate predecessors, Tasks A and B. Task A is planned to take 5 days to complete; Task B is planned to take 10 days. The early start time for both tasks is August 1. The actual start dates for Tasks A and B are August 2 and August 1, respectively. At the end of August 4, Task A is assessed to be 20 percent completed and Task B 30 percent completed. What is the expected early start time for Task C?

31. Refer to Problem 26 and Figure 13.20.
   a. For Network (a), suppose after 7 weeks, activities A, B, and E have been completed, D is 50 percent completed, and C is 80 percent completed. What is the revised early completion date for the project?
   b. For Network (b), suppose after 25 weeks, activities A, B, C, F, E, G, and I have been completed, and D and H are ready to begin in week 26. What is the revised early completion date for the project?

32. For the following questions refer to Figure 13.22.
   As of week 5, for the project:
   a. What is the planned value (PV)?
   b. What is the earned value of the work completed (EV)?
   c. What is actual cost of the project (AC)?
   d. What is the value of work remaining?



	Project status as of Week 5				
Budget at completion	% Sched uled	PV = BCWS	% Comp- lete	EV = BCWP	AC = ACWP
A 200	100	0	100	200	240
B 1,000	100		70		900
C 400	100		60		300
D 1,200	50		100		500
E 800	0		50		440
F 900	0		0		0
G 300	0		0		0
H 500	0		0		0
4300					

Figure 13.22
Project status as of week 5.

e. What is the CPI?
f. What is estimated cost to complete the project (ETC)?
g. What is the estimated cost at completion (EAC)?
h. What is the estimated cost variance at completion and the percent overrun or underrun?
i. According to EV, is the project ahead of or behind schedule?
j. According to the critical path (A–C–F–H), is the project ahead of or behind schedule?

Questions About the Study Project

1. How often and what kinds of review meetings were held in the project? Why were they held? Who attended them?
2. When and for what reason were special reviews held?
3. How was follow-up ensured on decisions made during review meetings?
4. Was there a project meeting room? How often and in what ways was it used?
5. Describe the kinds of project reports sent to the project manager, top management and other managers, and the customer and other stakeholders. Who issued these reports?
6. Did the project manager encourage open, informal communication? If so, in what ways?
7. What kinds of external controls, if any, were imposed by the customer and other parties on the project?
8. What kinds of internal controls were used? (For instance, work package control, cost account control, etc.) Describe.
9. Describe the project control process:
    a. How was work authorized to begin? Give examples of work authorization orders.
    b. How was data collected to monitor work? Explain the methods and procedures—time cards, invoices, and so on.
    c. How were the data tallied and summarized?
    d. How were the data validated?
10. Was the concept of earned value (budgeted cost of work performed) used?
11. How was project performance monitored? What performance and variance measures were used? Was the buffer management concept used? Explain.
12. How were problems/issues pinpointed, tracked, and acted upon?
13. Were the concepts of forecasting ETC and EAC used? If so, by whom? How often?
14. Were variance limits established for project cost and performance? What were they? How were they applied?
15. When cost, schedule, or performance problems occurred, what action did the project manager take? Give examples of problems and what the project manager did.
16. What changes to the end-item or project goal occurred during the project? Describe the change control process used. How were changes to the plan or system reviewed, authorized, and communicated? Show examples of change control documents.

CASE 13.1 CYBERSONIC PROJECT

Miles Wilder, project manager for the Cybersonic project, considers himself a "project manager's project manager." He claims to use the principles of good project management, starting with having a plan and using it to carefully track the project. He announces to his team leaders that status meetings will be held on alternate Mondays throughout the expected year-long project. All 18 project team leaders must attend and give rundowns of the tasks they are currently working on.

All the team leaders show up for the first status meeting. Seven are currently managing work for the project and are scheduled to give reports; the other 11 are not yet working on the project (as specified by the project schedule) but attend because Miles wants them to stay informed about project progress. The meeting is scheduled for 3 hours; the team leaders are to report on whatever they think important. After 4 hours of reports by five of the leaders, Miles ends the meeting. Several major problems are reported that he tries to resolve at the meeting. Specific actions to resolve some of them are decided, and Miles schedules another meeting for 2 days later to address the other problems and hear the remaining two reports. Some of the team leaders are miffed because they'll have to change their schedules to attend the meeting.

Miles arrives an hour late at the next meeting, which, after 3 hours, allows enough time to resolve all the problems but not enough for the two leaders to give reports. Miles asks them if they are facing any major issues or problems. When they respond "no," he lets them skip the reports but promises to start with them at the next meeting 2 weeks later. A few of the team leaders are assigned actions to address current problems. Some of the attendees feel the meeting was a waste of time.

Before the next meeting, some of the leaders inform Miles they cannot attend and will send representatives. This meeting becomes awkward for three reasons. First, several new problems about the project are raised and, again, the ensuing discussion drags out and there is insufficient time for everyone to give a status report; only six of a scheduled eight team leaders give their reports. Second, some of the leaders disagree with Miles about actions assigned at the previous meeting. Because no minutes had been taken at that meeting, each leader had followed his/her own notes about actions to take, some of which conflict with Miles's expectations. Third, people at the meeting who are "representatives" are not fully aware of what happened at the previous meetings, do not have sufficient information to give complete reports or answer questions, and are hesitant to commit to action without their team leaders' approval.

The next several meetings follow the same pattern: they run over schedule, fewer team leaders and more representatives attend, status reports are not given because of inadequate time, people disagree over problems identified and actions to be taken. The project falls behind schedule because problems are not addressed adequately or quickly enough.

Miles feels that too much time is being wasted on resolving problems at the meetings and that many problems should, instead, be resolved entirely by the team leaders. He instructs the leaders to work out solutions and changes on their own and to report at status meetings only the results. This reduces the length of the meetings but creates other complications: some team leaders take actions and make changes that ignore project dependencies and conflict with other leaders' work tasks. Everyone is working overtime, but the Cybersonic project falls further behind schedule.

QUESTIONS

1. Why is Miles's approach to tracking and controlling the Cybersonic project ineffective?
2. If you were in charge, what would you do?

CASE 13.2 SA GOLD MINE: EARNED VALUE AFTER A SCOPE CHANGE[19]

The team at South African (SA) gold mine was tasked with sinking a 2,000-meter-deep ventilation shaft and excavating space for a station at the bottom. The plan was to sink the shaft within 20 months at a cost of R65,000 (about US$10,000) per meter of shaft depth. For the station at the bottom, 30,000 m^3 of rock would have to be excavated within 3 months at a cost of R700 per m^3. The plan assumed a uniform earned value over time.

After the work had begun, the scope of the project was changed to include excavation for a new station halfway down the shaft (Figure 13.23) with a volume of 20,000 m^3. It was agreed that the additional work would have to be done at the same excavation rate as the bottom station, but since removal of the rock required hoisting only 1,000 meters (instead of the 2,000 meters for the bottom station), the team agreed on the cost of R500 per m^3 for the new station. Since limited working space and available resources would delimit the amount of work that could be done simultaneously, everyone agreed that the new station would delay the sinking of the shaft. After 13 months, the shaft had reached a depth of 1,400 meters below surface and excavation for the halfway station was completed. The actual cost at this time was R90 million, which was more than was budgeted for the period. This provoked a cash-flow problem at that stage, and executive management requested an earned value report. Information on the relative amounts of time spent on excavating the new station and sinking the shaft was not available.

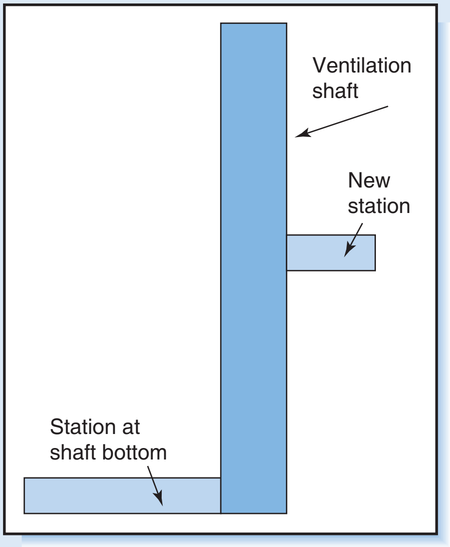


Figure 13.23
Mine shaft.

QUESTIONS

1. Calculate the CV, SV, TV, CPI, and SPI.
2. Prepare a graph to illustrate the initial plan for the work, including the excavation for the station at the shaft bottom, as well as the changed plan. Indicate the earned value and the actual cost after 13 months.
3. Regarding the cash-flow problem that was aggravated by the high rate of spending, discuss the desirability of performing projects faster than planned.

CASE 13.3 CHANGE CONTROL PROCESS AT DYNACOM COMPANY[20]

At Dynacom Company, any change that potentially affects project scope is subject to a rigorous review and approval process. Anybody requesting a change must document and present it to the team lead. If the team lead approves the request, she enters it into the company's change request system, which the project manager checks each day. The project manager then meets with the team lead and original requester to discuss the change's likely impact on the project. If they conclude the change is worthwhile, the project manager schedules a meeting with the entire team to discuss the need for the change, its impact on schedule and budget, and the risks. Sometimes a team approves changes immediately; other times, it takes a few days or weeks of review. If the team approves the change, it sends a recommendation to the technical change management board (TCM) for a final decision. The TCM board has no association with the project and consists of upper managers and other project managers. If it accepts the recommendation, the project manager makes the necessary changes to work schedules, budgets, and other documents. Dynacom is a rather conservative company, and the process has served well in helping it to avoid risks associated with changes.

A drawback is that the process takes 3–5 weeks to decide on a change request. As a result, project managers sometimes implement changes before they are approved. For example, Karen, the manager of a project on a very tight schedule and running behind, needed to make changes on the critical path. She worried that if she waited for approval of the changes, the project would fall too far behind and might be cancelled. Intent on getting the project back on schedule and willing to risk breaking the rules, she made the changes immediately and assumed the TCM board would accept them, which it did.

QUESTIONS

1. What is your opinion of the change control process at Dynacom? What are the benefits and drawbacks?
2. What do you think about Karen bypassing the process to make changes?

CASE 13.4 STATUS REPORT FOR THE LOGON PROJECT

Assume the LOGON Project began as scheduled in May 2020. In late September—after the project had been underway 20 weeks—Midwest Parcel Distribution (MPD) Company, the customer, requested Frank Wesley, the project manager, to prepare a written summary status report about progress to date. Review Appendices A and B at the end of the book for background about the project; see Appendix C for information on the budget and scheduled dates for milestones and deliverables. Prepare the report as if you were Frank. Note that the report is for MPD's top management and should address issues of most importance to them: deliverables and other requirements, schedule, and budget, as noted in Appendix C, end of book. The report should also note any problems encountered to date, anticipated challenges, and recommended suggestions or changes to the plan.

CASE 13.5 FORMAL AND INFORMAL COMMUNICATION

As he walks out of the president's office, Philip shakes his head. It was clear that the president was a bit embarrassed that she did not know the details of her company's configuration management system; she seemed even more embarrassed that she will have to cancel an agreement she made last night at a dinner meeting with her counterpart in HeavyEng, a contractor. "In a way it serves her right," he mutters.

Since Philip was appointed procurement manager at TechnoVehicle, several issues relating to communication have come up, especially concerning the development of a vehicle that the company has been designing and for which HeavyEng made the prototype and is preparing to produce. The product is a state-of-the-art firefighting vehicle on order by several airports. Philip has been concerned about the constant meetings between the engineering staffs of the two companies and the numerous design modifications it has apparently led to. However, he also realizes the necessity of such meetings to ensure cost-effective manufacturing. And now the president called him in to say that she had told HeavyEng's president that TechnoVehicle will in the future supply HeavyEng with electronic copies of the drawings instead of the "hard" copies they have been supplying. He had to inform her that the "hard" copies of the drawings—not the electronic ones—are under configuration control and that what she agreed to at the dinner meeting would simply not work.

After an hour of mulling around in the office, he calls the president's assistant to request a meeting; the agenda: formal and informal communication. Then he calls the engineering manager to arrange a meeting with the two of them on the same topic.

QUESTIONS

1. Why do you think Philip is upset about the agreement between the two presidents?
2. What similarity is there between the communication between the two presidents and the communication between the engineering staffs of the two companies?
3. What message should Philip convey during the two meetings he has scheduled?
4. Why is Philip's idea of face-to-face meetings with the president and the engineering manager a good one?
5. What is a good general rule regarding formal and informal communication for any project?

Notes

1. See Turner J. and Muller R. Communication and cooperation on projects between the project owner as principal and the project manager as agent. *European Management Journal* 22(3); 2004: 327–336.
2. The terms "variance" and "deviation" are used here interchangeably, although in some contracts, variance refers to small changes in the project plan for which compensation or correction is expected, whereas deviation refers to large changes that require a formal contractual response.
3. Muirhead B. and Simon W. *High Velocity Leadership: The Mars Pathfinder Approach to Better, Faster, Cheaper*. New York, NY: Harper-Business; 1999, pp. 40–42.
4. Cusumano M. and Selby *R. Microsoft Secrets*. New York, NY: Free Press; 1995, pp. 204, 221, 256–257, 417.
5. Thompson C. Intermediate performance measures in engineering projects. *Proceedings of the Portland International Conference on Management of Engineering and Technology*. Portland, OR, July 27–31, 1997, p. 392.
6. Methods to determine EV (BCWP) are explained in Pham T. The elusive budgeted cost of work performed for research and development projects. *Project Management Quarterly*; March 1985: 76–79; for EVM, see Fleming Q. and Koppleman J. *Earned Value Project Management*. Upper Darby, PA: Project Management Institute; 1996.
7. Lukas J. Earned Value Analysis—Why it doesn't work. *AACE International Transactions*, EVM.01.1-EVM.01.10; 2008, see www.icoste.org/LukasPaper.pdf, accessed April 11, 2019.

8. Issues of EVM vs. CCPM are discussed in Newbold R., Budd C.S. and Budd C.I. *Protecting Earned Value Schedules with Schedule Margin*. ProChain Solutions, 2010, www.prochain. com/pm/articles/ProtectingEVSchedules.pdf, accessed January 5, 2016.
9. For examples of analytical models used for TPM, see Eisner H. *Computer-Aided Systems Engineering*. Upper Saddle River, NJ: Prentice Hall; 1988, pp. 297–326.
10. Harrison F. *Advanced Project Management*. Hants, England: Gower; 1981, pp. 242–244.
11. Ibid., pp. 245–246.
12. Ibid., p. 244; Archibald R.D. *Managing High-Technology Programs and Projects*. New York, NY: John Wiley & Sons; 1976, pp. 187–190.
13. Roman. *Science, Technology, and Innovation*, pp. 327–328, 391–395.
14. Portions of this section were prepared with the assistance of Elisa Denney.
15. Palla R. Introduction to micro-computer software tools for project management. *Project Management Journal*; August 1987: 61–68.
16. Ibid.
17. Green E., BIM 101: What Is Building Information Modeling? *Engineering.com*; February 3, 2016, www.engineering.com/BIM/ArticleID/11436/BIM-101-What-is-Building-Information-Modeling.aspx; Harvard University Construction Management Council. *Introduction to Building Information Modeling*, https://home.planningoffice.harvard.edu/files/hppm/files/harvard_bim-intro.pdf, accessed July 23, 2019.
18. A leading case study is the stadium design for the Singapore Sports Hub. See Coliseum. Global Sports Venue Alliance, www.coliseum-online.com/singapore-sports-hub-pioneer-using-bim, accessed July 23, 2019.
19. Source: Mr. P. Joubert of Anglo Platinum.
20. Adapted from Quane J., Kosin M., Heinlen L., Mahoney S. and Quantraro F. *Cyberdyne Project Planning Management Investigation Report*, Quinlan School of Business, Loyola University Chicago, May 2007.

Chapter 14

Agile project management and lean

It is better to make many small steps in the right direction than to make a great leap forward only to stumble back.

—Chinese Proverb

Great things are not done by impulse but by a series of small things brought together.

—Vincent van Gogh

Some methods of project management that are well suited for projects in construction, infrastructure, and product development are poorly suited for projects where the solutions or end-item requirements are uncertain or likely to change. This is precisely the case for projects in software development. In 2001, a group of 17 developers met to address this problem and created *The Agile Manifesto* report wherein they proposed a set of management principles better-suited to software development, namely:

> Individuals and interactions over processes and tools
> Working software over comprehensive documentation
> Customer collaboration over contract negotiation
> Responding to change over following a plan.[1]

For each principle, the implication is that the things on the left (e.g. individuals and interactions) should take *precedence over* the things on the right (processes and tools).

Innovative practices in project management arise constantly, and the *Manifesto* endorsed some that had previously been applied only on a limited basis. Accompanying the *Manifesto* was the rise of "agile software development," which was the precursor of *agile project management* (APM) and particular management practices such as Scrum, described in this chapter. APM is a form of project management *methodology* and contrasts with the more traditional waterfall methodology as covered throughout this book.

Lean—short for lean production—refers to the Toyota Production System, the management system that helped propel Toyota to the forefront of the automotive industry. The creators of *The Agile Manifesto* were inspired by Toyota's lean principles—continuous improvement, elimination of waste, and respect for people[2]—so it is no coincidence that APM and lean somewhat overlap. But, as this chapter discusses, lean applications extend beyond software development projects and have taken hold elsewhere, especially in product development projects.[3]

14.1 Traditional project management

All projects can be conceptualized in terms of the life cycle phases of conception, definition, and execution, but exactly what happens in each phase depends on the kind of project and, in particular, on how clear, complete, or well understood are the problem/goals and solution/end-item of the project. When these are well understood, the project moves readily through the phases: goals and the solution/end-item are established in conception, requirements and the project plan are drawn up in definition, and work toward the goals/requirements is undertaken in execution. But in many projects, the solution/end-item is not certain and neither are the requirements. Sometimes the problem/need is uncertain. Such projects cannot "readily" move through the phases. They get stuck in conception or definition.

Traditional project management methodology, or TPM—the so-called *waterfall methodology*—applies to projects where the problem/goals and the solution/end-item are well understood and can be defined early in the project. The phases of definition and execution proceed somewhat smoothly and happen only once: the solution/end-item requirements and project plan are clearly laid out in definition, and the work is undertaken in compliance with the plan in execution (Figure 14.1). TPM projects are plan-driven projects; the execution phase means, simply, "execute the plan."

Incremental traditional project management

A variant of this approach allows for implementing (or launching) the end-item in a series of increments. With "incremental TPM," the end-item is implemented stepwise, piece by piece, allowing some elements of it to begin use before the entire end-item is completed (Figure 14.2). For example, in a project to build a resort, some accommodations are completed and occupied even though the rest of the resort is still under construction, or in a high-rise construction project the lower floors are completed and occupied even though the upper floors are still being constructed. Decisions about when the increments are to be built and implemented are based upon dependencies among them (which pieces need to precede which others) and on market or financial considerations. Besides allowing the customer to begin using parts of the end-item earlier, incremental TPM provides opportunities to experiment with and learn about the end-item system and identify needed changes or improvements. But incremental TPM is still TPM: it assumes that the solution/end-item is well understood and clearly defined early in the project; the only difference is that the end-item is demarcated into discrete elements, to be implemented in a series of steps, say 6 weeks or 6 months apart.

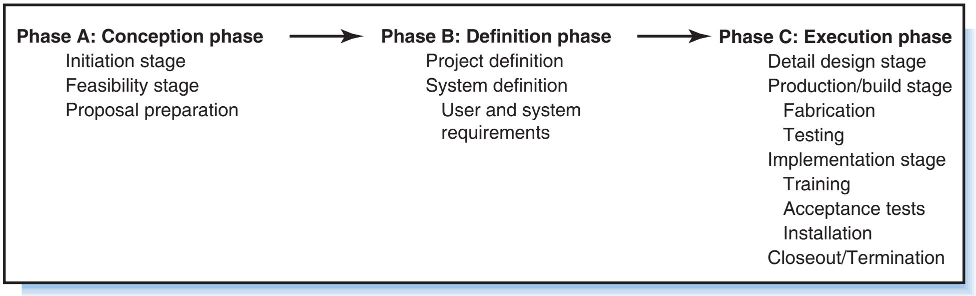


Figure 14.1
TPM methodology: applies when problem/goals and solution/end-item can be well defined.

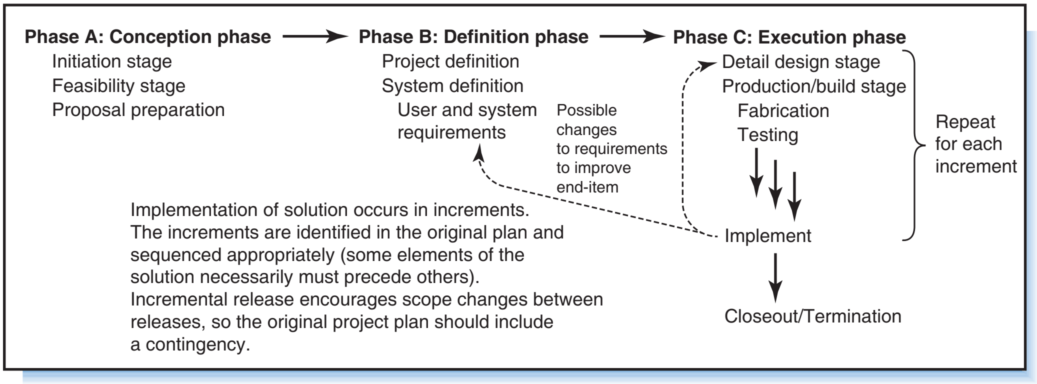


Figure 14.2
Incremental TPM: applies when problem/goals and solution/end-item are well defined and the end-item is to be built/launched in increments.

Inappropriate use of traditional project management

See Chapter 13

When the solution cannot be clearly identified or is uncertain (e.g. development of a revolutionary new technology or radically different product), the end-item requirements are very difficult to define and the project very hard to plan. As a result, both requirements and plan must be developed over time, as things become better understood. The consequence of this is that the requirements and plan will change and expand, perhaps often. The traditional change control process described in Chapter 13 is ill suited for such continuous change and tends to lengthen project duration, increase costs, and, ultimately, yield mediocre or poor results.

Inability to clearly define a problem or solution should not be confused with ignorance. Maybe little is known, but usually *something* is known, and that something might be enough to start a project. Unlike TPM, wherein much or all of the project plan is created in the definition phase, an alternative is to hold off on planning, *acknowledge* that relatively little is known, and use the project as the vehicle *to learn more*. Rather than implementing a known solution, the project focuses on *learning what the solution should be*. Rather than moving through the definition and execution phases once, the project cycles through them iteratively in a learn-as-you-go fashion. The project still begins with initiation and ends with closeout, but whether the phases/stages in between happen once or repeatedly depends on the certainty of the solution/end-item.

14.2 Agile project management

Project management methodologies that accommodate uncertainty in an iterative, learn-as-you-go manner are referred to as agile project management. In such projects, the customer/developer does not know or is unclear about the desired solution and cannot define the end-item requirements up front. Referring to the diamond model in the Introduction, APM is more suited to projects with relatively high novelty (newness to market), high technology (technological uncertainty), and low complexity (relatively small system scope). Thus, the purpose of the definition phase is to identify, as best possible, the customer's wants, needs, or basic requirements and create a *high-level* project plan. Detailed requirements and features of the end-item will be developed later in a series of iterations. The high-level plan specifies the anticipated number, length, and objectives of the iterations.

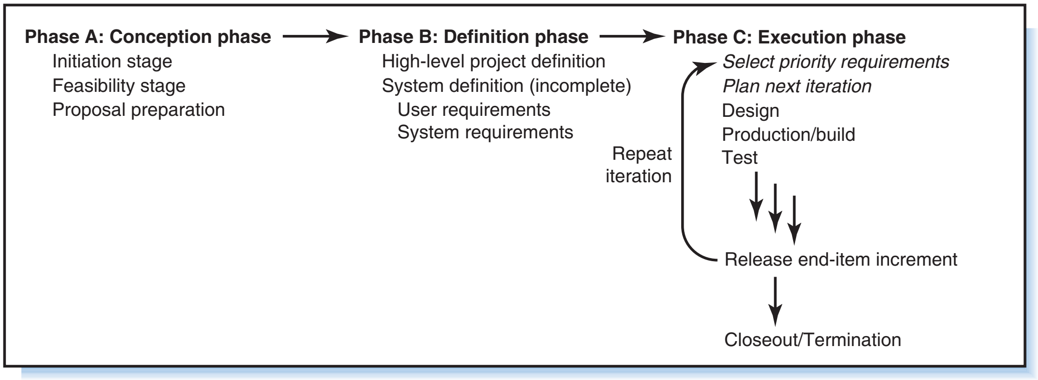


Figure 14.3
APM: applies when problem/goals are well defined but solution is poorly defined.

Learning from iterations

Iterations occur in the execution phase (Figure 14.3). Each iteration leads to discoveries and better-defined requirements; each concludes with a “release” or end-item “increment”—a partial solution that addresses the customer’s needs or problem but in a limited fashion. Planning happens on a just-in-time basis: at each iteration, the customer and team assess progress made so far and plan for upcoming iterations. Thus, each iteration includes not only the typical execution stages of design-build-test but also aspects of the definition phase—requirements definition and project planning. The main emphasis in planning and execution is on creativity and delivering a solution of immediate value; budgets and schedules are of less or little importance.

To facilitate learning and discovery, the iterations tend to be short, in some cases a few or several months, in others just 2–4 weeks each. At the end of each iteration, the outcome is assessed: Does it provide the expected benefits? Is it useful and usable? How is it lacking, or what is wrong with it? This enables improvements to the releases of subsequent iterations so that by project closeout, the cumulative increments will have fully or substantially met the customer’s needs and wants.

Agile project management variants[4]

APM comes in several forms, and the one to use depends on what we know about the solution or end-item. For example, do we know a range of different, possible solutions but not the best *one* to choose? Do we know the best solution but not *details* about it? Or, do we simply not know the solution, or even the problem?

Take the second case—the solution is known but not the details. In that case, the execution phase is repeated iteratively, as described, and the purpose of each iteration is to discover and integrate newly identified details—features and functions—into the solution/end-item. The project might have no deadline and will continue until either the customer is satisfied or the budget runs out. The customer is involved throughout the project, assessing changes/additions to the solution with each iteration, and giving feedback to the development team. The spiral model is an example.

Example 14.1: The Spiral Model

In a spiral-model project, the end-item or product is released in a series of cycles, each cycle taking a few to several months.[5] Also called "iterative prototyping," each cycle includes the usual stages of analysis, design, develop, test, integrate, and so on and results in a prototype. The first cycle delivers, optimistically, a product prototype, which the customer uses and assesses. The process repeats, each cycle delivering an improved prototype version based upon customer feedback from earlier versions (Figure 14.4). After a number of cycles—either as predetermined or whenever the customer is fully satisfied—the prototype becomes the "production" or operational version of the end-item.

Although the spiral model is most commonly applied to incrementally develop a prototype design that will ultimately lead to a final product, it can also be applied to successively improve an existing product. An example is a software product or software portion of a hardware product, where every few months or annually, an upgraded or enhanced version of the product is released. This "outward spiral" of product improvement (Figure 14.4) continues for as long as the product remains "improvable" and viable in the market.

There is a big difference between APM (including the spiral model) and incremental TPM. With incremental TPM, which applies to all kinds of end-items, including one-of-a-kind items (e.g. space station, aircraft carrier, skyscraper, highway), the overall end-item does not "evolve." Although portions or elements of the end-item might evolve—be upgraded, improved, or expanded, the overall end-item does not; its fundamental structure/composition is set at the start of the project and remains so forever. Furthermore, the overall end-item/solution and the elements to be added incrementally are usually known and defined early in the project.

With APM, details of the solution and end-item system *evolve and expand* with each iteration; this is of necessity since much about the solution is uncertain, and a purpose of the iterations is to *discover* and *define* the details. Each iteration begins with a limited understanding of some aspect of the solution and builds on knowledge gained from the releases of previous iterations. The process iteratively *converges* on a complete solution.

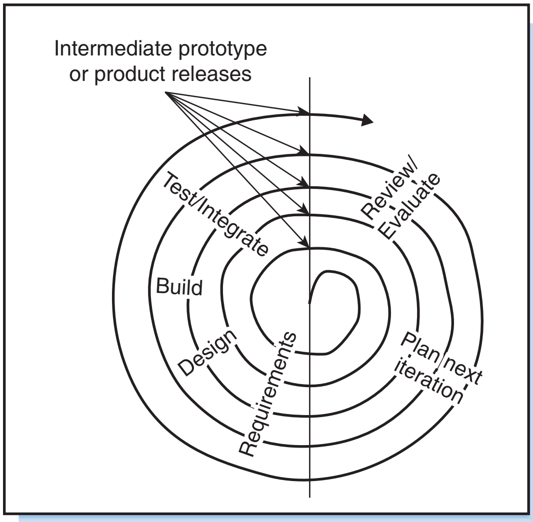


Figure 14.4
Spiral development methodology.

Modern products are a combination of hardware and software. Often the hardware must be developed using the TPM approach, although the software might more appropriately use an APM approach. A challenge in managing such projects is to coordinate the APM iterations so that the needed software will be available to integrate with the hardware that is being developed with TPM-waterfall methodology.[6]

In APM, typically the duration of each iteration corresponds to how much is known about the solution: the less known, the *shorter* the duration. When the solution is somewhat well known, as is common in spiral-model projects, each iteration can last several months. When it is less well known, the iterations must be shorter. In the popular Scrum method of APM, the iteration lasts just weeks.

14.3 Scrum[7]

The Scrum version of APM is shown in Figure 14.5. The main focus of Scrum (the term Scrum derived from a facet of rugby football) is on creating a software product with the "desired" functions and features. Initially, these functions and features are unknown, so the process starts with a list of customer needs and wants called a "product backlog." The backlog, which is created by the customer or a representative called the "product owner," typically consists of a list of wants, needs, or "stories" that describe how a user might use or benefit from the product. The number of iterations in the process is set in advance in the project plan.

Just before each iteration—called a "sprint"—the development team and product owner review the product backlog and select from it a few items to be the focus the next sprint; these items constitute the "sprint backlog." The team agrees on the functionality it must design and build to address those items and that the necessary work can be fit within the sprint timeline or "time-box," which is typically 2–4 weeks. During the sprint, the team meets briefly each morning to review progress and determine the day's tasks. At the sprint's conclusion, the team releases a "potentially shippable product" (PSP), and it reviews its work performance for lessons learned to apply to subsequent sprints.

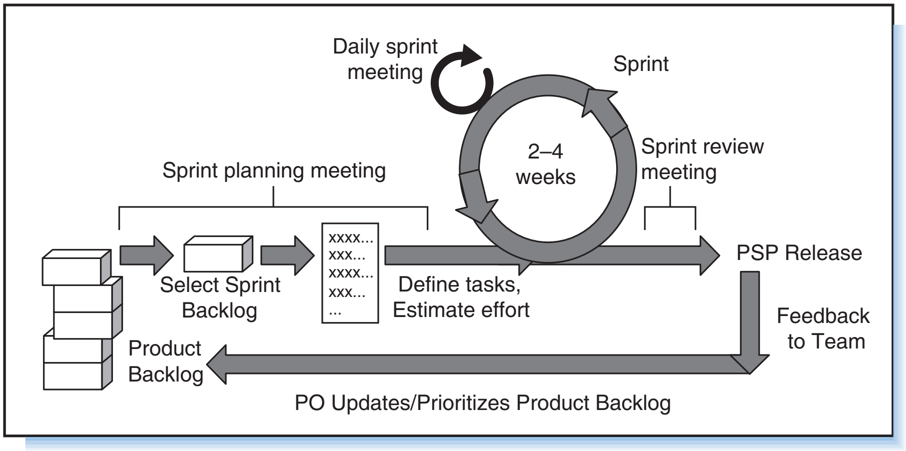


Figure 14.5 Scrum process.

Source: Adapted from Schwaber K. and Beedle M. *Agile Software Development with Scrum*. Upper Saddle River, NJ: Prentice Hall, 2002.

Scrum roles[8]

Management responsibilities in Scrum are shared among three roles: Scrum master (SM), product owner (PO), and project team. There is no project manager, so a "traditional" project manager in a Scrum organization must change roles: if she is good at facilitating, she might be the SM; if she is knowledgeable about customers and the business, she might be the PO; if she likes being hands-on and in the thick of doing technical things, she might be a team member.

Scrum master

The SM is responsible for facilitating team collaboration and keeping the team project-focused. The SM works full-time on the project and serves as coach, advisor, enforcer of Scrum rules, and sometime administrator. Unlike a project manager, he does not make decisions for the team. He can tell people what they need to do and help train or facilitate them, but he cannot tell them how they should do it. The SM should be familiar with the organization wherein the project is conducted and know how to remove barriers and get the needed resources.

Product owner

The PO is responsible for ensuring the team knows what the product is or might evolve into, and who the customers and competitors are. The PO sets the "vision" of the end-item/product—how it should perform, when it must be completed, how much it should cost—and keeps reminding the team of it by frequently updating the product backlog and discussing backlog items with the team.

The PO represents the "customer" and therefore must thoroughly understand the customers, users, business, or market. She must be good at communicating with and listening to customers, users, and the team. In Scrum, the PO is *the* decision-maker regarding product matters and any product-related issues facing the team and, thus must have decision-making authority in the organization.

The SM and the PO should not be the same person, and a tension should exist between the roles: the PO pushes for more in the product, but the SM pushes back whenever he feels the PO is asking too much of the team.

Project team

Team membership depends on whatever the project requires—analysts, programmers, testers, and so on. Members work primarily in their own specialties but also contribute to all other specialties. Work assignments are tentative because members are expected to provide assistance wherever it is needed. If a member finishes her task early, she is expected to start a new one or help others, regardless of specialty. Says Cohn, in Scrum, there is no "my work" and "your work"; there is only "our work."[9]

Through rotating and sharing of roles (which similarly occurs in concurrent engineering, discussed in Chapters 4 and 15), members develop an understanding of every task in the project. Everyone is able to do and does a little of everything. Since everyone participates in all tasks, they know what has been and still needs to be done. This reduces the amount of work "hand-offs" (transferring work from one person to another) and need for formal documentation.

See Chapters 4 and 15

Team structure

Scrum teams are small, typically five to ten people; Amazon calls them "two-pizza" teams. This affords big advantages: smaller teams are better able to retain focus on project goals and enjoy greater interaction, participation, and satisfaction among members. They also tend to finish projects with less total effort and in less time.

A Scrum team is self organizing and self managing. It decides itself how it will achieve goals and divide up and monitor work. (Some outside management is still necessary, however, to set project-level goals and boundaries and remove high-level barriers.)

Sprints are fast paced and emphasize rapid learning, so real-time communication among team members is essential. Typically, Scrum team members work full-time on a project. They also work at the same location, although Scrum has also been successfully applied in projects where members are distributed across the world and rely on the Internet and technology to keep in touch. In large projects, the work is apportioned among many two-pizza Scrum teams.[10]

Product backlog

Scrum substitutes all-at-once, upfront definition at a single time with step-wise definition spread over multiple sprints. Customer needs and wants as listed in the *product backlog* are minimally defined—initially in the form of "user stories" or "epics," and are refined and expanded over time. Since the desired functions/features and other details of the product are initially unknown, it is more practical to define the product in terms of stories than specific requirements. Each story is a simple statement from the user's perspective about a product's potential use, benefits, functionality, or capability, typically written on a 3 × 5 card or sticky note and in the format "As a <type of user>, I want <some goal> because <some reason>." The focus of each sprint is to satisfy a few user stories. A user story that has multiple goals and is too large to be addressed in one sprint is called an epic. Epics must eventually be broken down into simpler user stories that can each be handled in a sprint.

The stories and features that appear in a product backlog can be written at different levels of detail. Stories that are specific and well understood and can be addressed in a single sprint are placed at the top of the backlog. Stories that are broader and less well understood are placed farther down. Epics start out low on the backlog; as the project progresses, they are divided into user stories and moved up. The PO maintains the backlog—adding, deleting, updating, and reprioritizing items.

In Scrum, the main emphasis in system definition shifts from documentation to discussion. Prior to each sprint, the team discusses stories in the backlog with the PO and chooses the ones it best understands and wants to attack in the next sprint; these form the *sprint backlog*.

For each story selected, the team and PO define "conditions of satisfaction" (COS), which state what the user expects and doesn't expect. The COS and user stories constitute the sole "requirements documentation" for a sprint. When the product is required to comply with regulatory laws or perform complex calculations, the requirements are specified in terms of realistic examples that illustrate what the product must be capable of doing.

Sprints

The goal of each sprint is to deliver a working product—usually software. This product is called a "minimum viable product" or a "potentially shippable product"—PSP. Although not a complete product or solution, and not necessarily without bugs, the PSP meets all the requirements set by the PO (e.g. the COS) and the project team (e.g. completion of all development stages) for the sprint. Each PSP is a stand-alone working product, and with it, the customer gets a usable product and the team gets feedback about how much it has done so far on the product and how much it has yet to do. Even if the project is terminated midstream, the customer benefits from the PSPs delivered so far.

Within each sprint, all steps to produce a PSP are performed (analysis-code-test-checkout), although they are *overlapped* and done in "chunks"; this means a little analysis, a little coding, and a little testing on one feature, then a little analysis-coding-testing on another, and so on. The credo is, "Do a little of everything, all the time." At any given moment, different features are in different stages of work—analysis, coding, testing, and so on, which is why team members must be capable of doing anything whenever it is needed.

As mentioned, the sprint duration is fixed or time-boxed, usually 2–4 weeks, based on whatever time the team decides. Time-boxing simplifies planning and estimating, since the team learns how much it work can do each sprint (work rhythm) and is able to monitor its output rate. Knowing its work rhythm, the team selects user stories for each sprint backlog that it thinks it is capable of achieving within the time box. The time-box duration is held constant throughout the project; it is strictly enforced, and rarely is overtime allowed. A typical project involves many sprints, and teams are most effective when they work at a uniform, sustainable work rhythm. If the team cannot finish everything in the sprint backlog, the PO decides which items to drop—and to be picked up in later sprints.

Once a sprint is underway, the PO steps out of the way but is always available to respond to team requests.

Sprint increments versus production versions

Although each sprint produces a new end-item increment or PSP, rarely are companies able to absorb new increments of such frequency into their operational or production environments. Most companies are able to implement revised "production" or user-operated versions only a few times a year—although when they do, each version will incorporate improvements from all the sprint increments released up to that point. Meantime, so that the development team can receive frequent practical feedback, a focus group of about ten people representing the company and its key users reviews and critiques the released increments or PSPs for every sprint. This provides the development team with useful information about needed changes and improvements to address in upcoming sprints. After, say, six sprints or 6 months, the accumulated improvements are incorporated into the production version of the product.

Planning and control

See Chapter 4

Scrum plans are developed progressively. A high-level plan is prepared early in the project, but it contains only basic information about the solution/end-item and has few details. Any commitments specified in the plan tend to be flexible. The planning process in Scrum is analogous to the rolling-wave, phased approach described in Chapter 4, the difference being that the "goal" and its associated requirements in Scrum projects are somewhat fluid and the path to reach them somewhat unclear.

As the team's knowledge about the project expands, so do details about the project plan. This progressive refinement of the plan has many benefits: it avoids planning for things that are unknown or uncertain, it defers decisions until there is adequate information, and it allows wiggle room to change direction. Project planning, work review, and control happen in a series of team meetings before, during, and after each sprint.

Sprint planning meeting

Before each sprint, the team devotes 4–8 hours to preparing for the next few sprints. It selects user stories from the product backlog to make up the next sprint backlog. For each item on the sprint backlog, the team determines the specific tasks to be done and the estimated time; this enables the team to know that the work it has chosen is "doable" within the sprint time-box and, later, to track its progress during the sprint. The team also selects stories for the following two sprints (e.g. before sprint 2, it plans for sprint 2 and creates backlogs for sprints 3 and 4, although the backlogs can be changed).

Daily sprint (a.k.a. daily Scrum) meeting

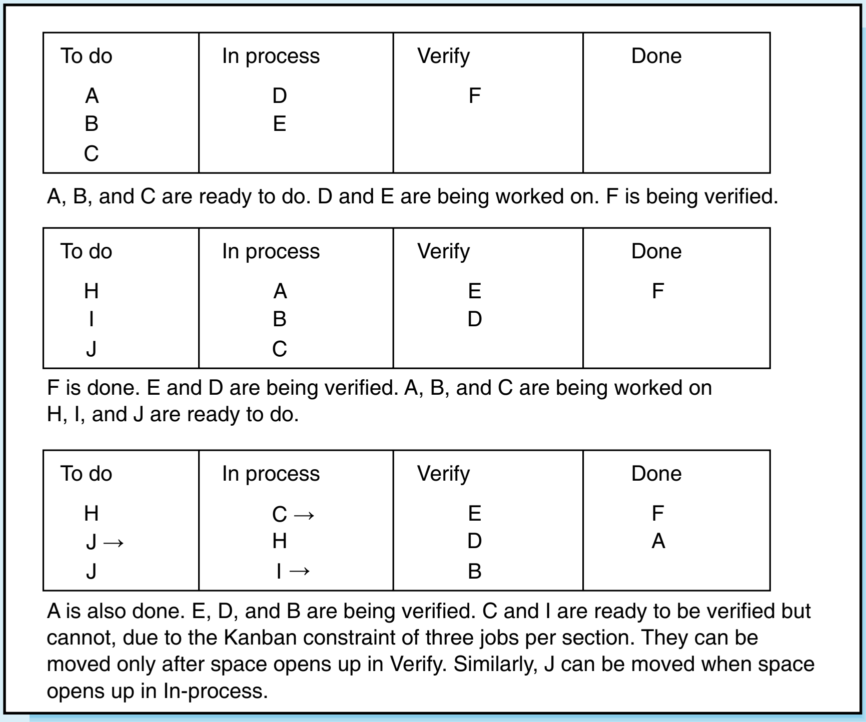
The team meets each morning during the sprint for 15 minutes to review progress and update its status via a white board and burn down chart (Examples 14.2 and 14.3). The meetings are fast-paced and held at the same time and location every day. They address: what did you do yesterday, what will you do today, and are you facing any obstacles? Team members discuss what they must do, and the Scrum master learns what barriers he must remove.

Tracking and control

Scrum uses simple, visual tools for tracking and controlling work. Following are two examples.

Example 14.2: White Board[11]

Each job is written on a sticky note and placed on the "To do" section of a white board; *To-do* is the first of a hypothetical four-step process followed by *In-process* (being done), *Verify* (done correctly), and *Done* (Figure 14.6). Each job is one kind of task (e.g. analysis, code, or test) that must be done for a user story on the sprint backlog. Different kinds of tasks can be represented by different-color notes. As jobs progress, the notes are moved from one section on the white board to the next. Suppose the development team has decided that no more than three jobs at a time can be in a section; that is, when a section has three notes, no more are allowed. Restricting the jobs in each section like this, called Kanban, prevents the team from taking on additional tasks before it has completed existing tasks, and it keeps work moving at a uniform pace—called the *velocity* or *cycle time* (discussed later). Simply by scanning the white board, the team can see at any given time which jobs are holding up progress and need additional resources.



To do	In process	Verify	Done
A	D	F	
B	E		
C			

A, B, and C are ready to do. D and E are being worked on. F is being verified.

To do	In process	Verify	Done
H	A	E	F
I	B	D	
J	C		

F is done. E and D are being verified. A, B, and C are being worked on H, I, and J are ready to do.

To do	In process	Verify	Done
H	C →	E	F
J →	H	D	A
J	I →	B	

A is also done. E, D, and B are being verified. C and I are ready to be verified but cannot, due to the Kanban constraint of three jobs per section. They can be moved only after space opens up in Verify. Similarly, J can be moved when space opens up in In-process.

Figure 14.6
White board for tracking and controlling work tasks.

Example 14.3: Burn Down Chart[12]

Progress in each sprint is also tracked with a burn down chart—a chart that shows remaining work effort (work backlog) on the vertical axis and sprint days on the horizontal axis (Figure 14.7). Work effort—the amount of "sweat" the team devotes to a sprint—can be measured by whatever way the team prefers—story points, hours or days of effort, and so on. During the sprint planning meeting, the team identifies the jobs or tasks it will perform, allocates the jobs among the team, and assigns "story points" or estimated hours or days of effort to each. If story points are used, the team assigns points to each task in proportion to the estimated effort required to do it (the more effort required, the more points assigned); if hours of effort are used, the team estimates the number of labor hours needed to complete each task.

The total estimated hours of effort for all tasks must fit within the time-box—the number of hours available in the sprint. For example, a team with six members working nominal 6-hour days (= 36 labor hours per day) for 4 weeks (20 days) will have 720 labor hours of effort available, so the work required to complete user stories in the sprint backlog must be doable within 720 hours. In fact, in selecting stories from the product backlog, the team keeps a running tally of the hours of effort involved, and it selects

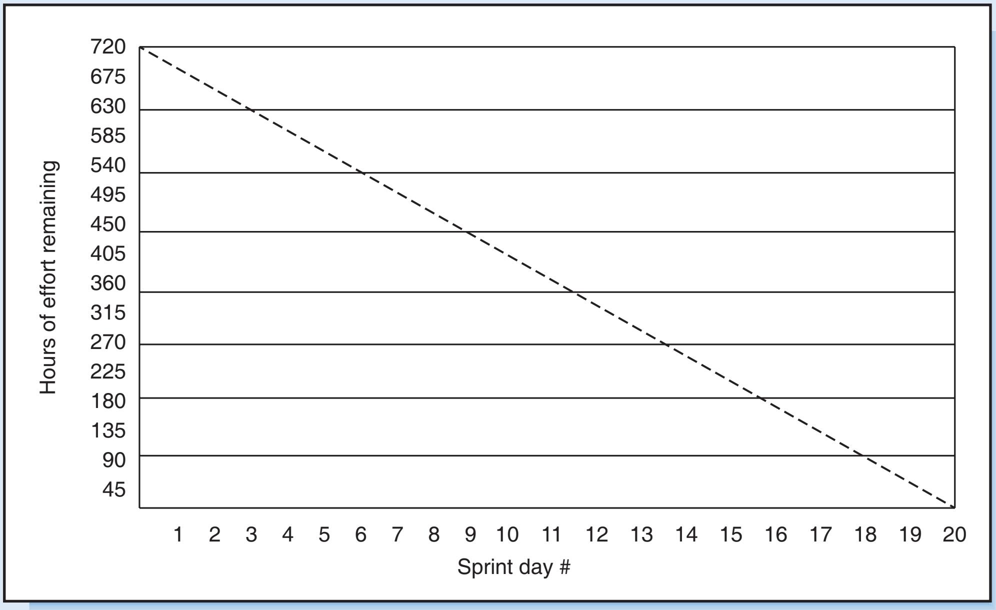


Figure 14.7
Burn down chart, estimated, expected performance.

no more stories than can be "fit" within the available labor hours of effort. Although a team will certainly work at least 8 hours a day, by using 6 hours a day in the estimate, it is being conservative and somewhat guaranteeing that it will be able to complete the work in the sprint backlog.

Continuing the same example, at the start of the sprint, the team will have 720 "hours of effort remaining"; if it were to complete every task exactly in the time estimated, then, theoretically, each day the hours of effort remaining on the burn down chart should decrease by 36 hours (Figure 14.7).

In reality, of course, tasks take more time or less time than estimated. Whenever a task takes less time and finishes early, a new task is started. At the end of the day, each team member records the tasks she completed and provides an estimate of the hours of effort still remaining to complete any task she is still working on. For example, suppose on day 7, a team member starts Task A, which was estimated at 6 hours, and finishes it in only 3 hours. Immediately thereafter, she starts Task B and works on it for the rest of the day. Suppose Task B was estimated to take 8 hours, but at the end of day, the team member estimates 2 hours of work still remain. (This can be done using percent complete. If an 8-hour task is estimated at 75 percent complete, that equates to 0.75 × 8 = 6 hours completed and 2 hours remaining). Thus, at the end of day 7, considering only Tasks A and B, the hours of effort remaining on the chart will be reduced by 6 hours (estimated time) for Task A and 6 hours (8 estimated – 2 remaining) for Task B. Working faster than expected shows up on the burn down chart wherever the plotted line is steeper than the estimated expected line. In Figure 14.8, this happened on days 2, 3, 8, and 11.

If tasks take longer than expected, the hours of effort remaining will decrease less rapidly than estimated, and the slope of the plot on the burn down chart will be shallower than (or the reverse of) the estimated line. In other words, at the end of the day, even though the team may have actually worked well over 36 labor hours, if it did not complete its assigned tasks for the day, the hours of effort remaining will be reduced by less than 36 hours. For example, suppose one day, some team members did not complete their assigned tasks, and they estimate that to do so will require 31 more hours. Thus, for that day, the

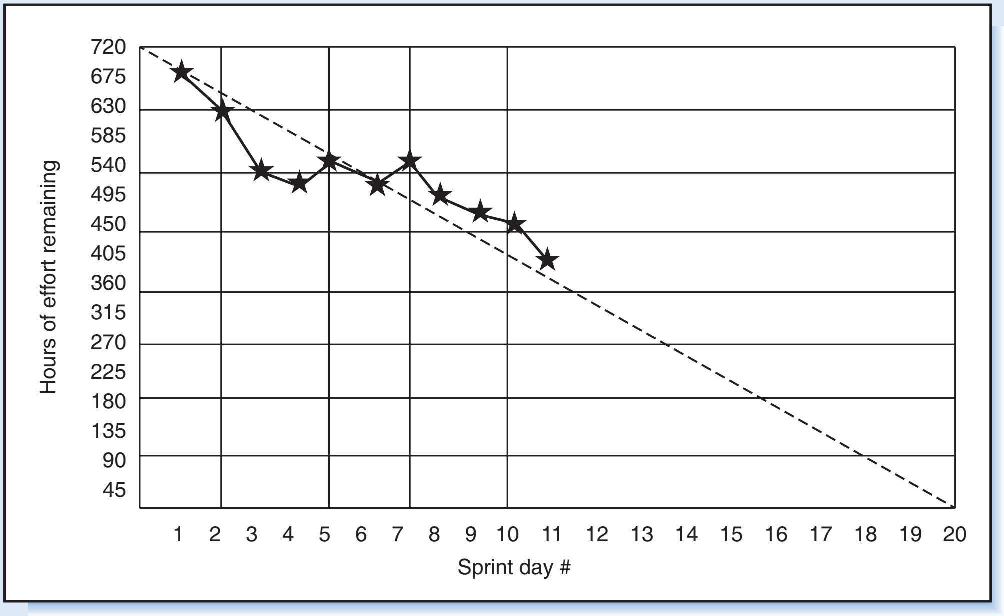


Figure 14.8
Burn down chart, actual performance as of 11 days.

hours of effort remaining will be reduced by only 5 hours (36 – 31), not 36 hours as expected. Of course, if, at the end of a day, the estimated hours remaining for tasks that should have been done that day exceed 36 hours, then the hours of effort remaining on the chart will *increase*. In Figure 14.8, this occurs on days 5 and 7.

Monitoring the chart, the team can readily identify problems with work scope (number and size of tasks), pace, quality, or errors in the estimated times. It can also gauge its day-to-day progress and whether it will be able to complete the sprint backlog within the time-box.

Work pace in Scrum is called "velocity." Figure 14.8 shows roughly 405 hours of effort remaining at end of day 11. Thus, the team has completed 720 – 405 = 315 hours of effort, and its velocity is:

Effort Completed/Elapsed Days = 315 hours/11 days = 28.6 labor hours/day

If the team maintains this velocity, it will finish the remaining work in 405/28.6 = 14.2 days, which means it will take 11 + 14.2 = 25.2 or 26 days to do all the intended tasks—and exceed the 20-day time-box by 6 days.

When a sprint or entire project falls behind schedule, that is, the planned work cannot be completed within the time-box, then the project scope—*not quality, resources, or schedule*—is changed. Doing so enables the project to meet its most important goals without compromising quality, increasing costs, or extending schedules. This is as it should be. If the PO had put 50 features in the prioritized product backlog, and if 40 of those were delivered in the specified number of sprints, then by the end of the project, the PO will have gotten a fully functional and operational product with the 40 highest-priority features—all within the time and money allotted.

Sprint review/retrospective meeting

Concluding each sprint is a 1-day, two-part meeting. In the first half of the meeting, the team reviews the work it had planned, completed, and not completed, and it presents or demos the completed parts to the PO or customer. In the second half, it reflects on what went well in the sprint, what not so well, what it learned, and what it needs to do and improve in the next sprint.

14.4 Agile project management controversy

Many of the methods and tools of TPM were developed in the 1950s to address projects in construction and large-scale systems and product development—the kinds of projects illustrated in this and other project management books. But applied to software development, the same methods and tools led to widespread failure. Simply, software development is different from construction and hardware development—the motivation for *The Agile Manifesto* and APM.

Bits versus atoms projects

But it works the other way, too: APM methods developed for software development (so-called "bits") projects are of only limited applicability in hardware ("atoms") projects. Paraphrasing Paul Lohnes:

> When dealing with "bits", which do not have physicality (weight, mass, form, length, height, etc.), requirements can readily be changed if the customer is willing to pay for the rework.
>
> But when dealing with deliverables that involve "atoms", which do have physicality, that is a different matter.[13]

For example, once an aircraft (a hardware product) has been designed with an 18-meter diameter fuselage, a later change in requirements to 18.5 meters would necessitate significant redesign to many of the fuselage's components and to components in related systems, which involves significant time and cost. You cannot design and build an airplane (or an artificial heart, or a bridge) through iterative sprints. Simply, APM doesn't work there. Neither will it work in projects that *require* thorough requirements definition and project documentation, such as pharmaceuticals, where development is regulated by laws.

You *can*, however, design and build some of an airplane's avionics software through sprints,[14] which raises an important point. More and more, products once thought of as hardware are actually hardware–software products, and the software part overshadows or dictates the hardware part. Cell phones are an example, but so are airplanes, some of which are able to fly only by virtue of the software. Thus, although APM methods may be limited to software end-items, given the ubiquitousness of software-within-hardware, APM's applicability is vast and growing.[15]

Agile project management: a project management methodology?[16]

Some have argued that APM is not a project management methodology, per se, but a *product development methodology* aimed primarily at creating software products, not managing projects. While it is true that APM originated and has been applied mostly in software development projects, we think practices for "development" (of hardware, software, and systems in general) sufficiently intertwine with management and leadership to merit calling them project management, and we have done so throughout this book (see Chapters 2, 3, 4, 13, 15).

Project management principles

With the spread of "agile practices," some proponents have prescribed that they replace TPM practices, no matter the kind of project. But *The Agile Manifesto* was not intended to debunk TPM, and a reasoned approach to project management says not to replace one methodology or set of practices with the other but to choose selectively from both depending on the nature of the project, the end-item, and the stakeholders.

Whether the deliverables are bits or atoms, principles and practices associated with "good project management" remain the same—the differences being in when, where, and how they are applied. For example, defining requirements is always important: if it *can* be done early and all at once, it *should* be done that way, as in TPM; if it cannot, then it will have to be done iteratively and evolutionarily, as in APM. Either way, learning the requirements and striving to meet them is a major part of project management.

Project control is important too: TPM uses Gantt charts, networks, earned value, and formal change-control methods; APM uses controlled iterations—time-boxed and tracked with white boards and burn down charts. Both sets of methods serve to keep projects on schedule and moving toward goals.

APM has been called "lightweight" project management because it emphasizes informal communication and minimum documentation. But APM applies to projects for which the solutions/end-items are vague or unknown, so there isn't much to document, and creating documentation for its own sake wastes time. APM replaces documentation's information storage and sharing functions with something better: face-to-face communication. People in small, co-located teams working on small tasks in short time bursts know most everything about the project that can be known, and they share it verbally. They do not need documentation. But APM does not eliminate the need for documentation: the end-item must still be documented for the same reasons as in TPM: to enable operators and future developers to understand the end-item, its functioning, capability, and limitations.

In summary, tools and methods of APM are clearly appropriate and desirable for software deliverables, but are less so or won't work for some physical deliverables. APM has a proper place among project management practices, although many projects still require a more formal and structured approach to definition and execution. It would be incorrect to try to replace TPM with APM; it would be more appropriate to consider APM as an addition to the project management toolbox. The following shows one successful application of APM to a non-software project.

Example 14.4: Wikispeed Car Project[17]

Imagine what it would take to develop a safe, road-worthy, four-passenger automobile that gets 100 miles/gallon (2.35 L/100 km) and do it in a relatively short time. The instigator of this challenge was a $10-million X-Prize offered by Progressive Insurance (X-prizes have become a familiar way to spark innovation; see, e.g. SpaceShipOne, described in Chapter 1). The Seattle-based Wikispeed Corporation was formed to accept the challenge, and, using APM methods, it was able to design and build a fully operational prototype that met requirements in just *3 months*.

The project team comprised 44 mostly volunteer members arranged into self-organizing teams. Using the Scrum model, the teams worked in 1-week sprints. Each sprint was devoted to deciding on the highest-priority aspects of the car to address and then creating and testing the car components to address them. In every sprint, a team would (1) identify what the customers want, (2) define those wants in terms of clear requirements and tests, (3) prioritize the tests, (4) create car components that met the tests, and (5) show results to customers to learn if that was what they really wanted. The teams employed white boards and Kanban to track and control work progress.

The car was designed and built based on *modular design* methodology (mentioned in Chapter 2). This enabled the project team to focus on different pieces of the car simultaneously and to rapidly try alternatives for each (e.g. substitute a gas engine with an electric one; strengthen door panels to meet federally mandated side-impact tests) and ensure that all the pieces would fit together.

See Chapter 2

Despite deviating from typical Scrum principles such as small development teams (the Wikispeed team had 44 members, though sprint teams had fewer), co-location (members were distributed geographically across four countries), and daily sprint meetings (instead, hour-long weekly standup meetings were held), the team was able to effectively prioritize requirements, conduct sprints, communicate progress and issues, and get customer feedback, mostly via electronic media.

Wikispeed did not win the X-Prize, although it did very well, creating a fully functional car on a shoestring budget that placed 10th out of over 100 competitors, some from well-established automobile corporations. The company has grown to over 140 volunteers working part-time and continues to innovate and improve a car that someday might be ready for the marketplace.

The purpose of the Wikispeed example is not to suggest that APM directly applies to or is widely used in hardware development projects but rather to show that aspects of APM can be effectively applied there and elsewhere by adjusting it to the circumstances.

14.5 Lean project management

Lean production refers to the concept of doing work for the least time, resources, and effort without diminishing quality or output. Lean equates to "no-waste," where waste is anything that adds to the cost but not to the value of a product or end result. Toyota, the originator of lean production, identified particular kinds of wastes. Those most relevant to project environments are overproduction (production beyond what is required), inventory (holding excess materials or unneeded resources), extra processing (doing more work or higher quality than needed), waiting (delaying work), defects (incorrect or inadequate work), and motion (unnecessary work hand-offs or transfer). An additional waste is non-utilized human talent, that is, not taking full advantage of workers' ideas, skills, and abilities.[18]

Lean production emphasizes "product flow," the concept that anything moving through a multistage process should flow unhindered from one stage to the next. In manufacturing, the "flow" is of materials moving through the production process and being transformed or assembled into a product. In projects, the flow is of information and sequences of work tasks to create conceptual or physical end-items.

Despite originating in manufacturing, many lean production concepts and practices apply to projects; these include *small batch flow*, *minimal waiting*, *cycle timing*, *standardization*, *minimum handoffs*, *visual management*, and *Kanban*. Not coincidentally, these concepts overlap with APM practices; hence, APM is sometimes referred to as "lean project management." Yet lean concepts and practices can be found in all kinds of projects, not only in bits-oriented (software) projects but also in atoms-oriented (construction)[19] and bits- and atoms-oriented (product development) ones.[20]

Small batch flow[21]

Look at a Gantt chart or network diagram; what you see are project stages or activities linked in order of precedence. You might see "Requirements" followed by "Code," "Code" followed by "Test," "Test" followed by "Integration," and so on. The implication is that the stages or activities are done in sequence. Upon completion of one, the results and work are transferred to the next.

In manufacturing, work moving from stage to stage like this is called "batch production," and the implication is that work moves through the process in *batches*. If the size of the batch is 40 items, 40 items are processed at each stage, and nothing moves to the next stage until all 40 are completed. Forty items go to stage 1, then 40 go to stage 2, and so on. In a project, the batch might constitute 40 requirements, 40 drawings, 40 coded modules, 40 tests, and so on.

Figure 14.9 shows how this works. Upon completion of the Requirements stage, all requirements are released to the Code stage; upon completion of the Code stage, all coded modules are released to the Test stage. The key word is "completion": all work in one stage must be completed before any results are released and the next stage can begin. In a product-development company, you can sometimes see this happening as stacks of paper (requirements, drawings, work orders, and other documents) move from department to department. Digital information also moves like this, but it is less obvious since it is stored and transferred unseen.

The example in Figure 14.9 requires 4 weeks per stage and results in a release and transfer every 4 weeks. But there is an alternative way for this to happen, which is to transfer *some* of the work at each stage, *every week*. For example, instead of waiting until all requirements are completed, transfer whatever requirements are completed each week so the next stage can get started.[21] Figure 14.10 illustrates this, showing work flowing from stage to stage on a weekly basis. Now, it might be possible to transfer the work more often than this—daily or even item by item. Transferring individual items—requirements, coded modules, test result, and so on—like this, between stages, one by one, is called "one-piece flow," meaning that everything moves through the project in batches as small as size one.

Reducing the batch size like this has many benefits.

Project duration

With smaller batches, project stages overlap, and the project finishes sooner. In Figure 14.9, where results are transferred between stages every 4 weeks, the project takes 16 weeks to complete. In Figure 14.10, where results are transferred weekly, the project takes 7 weeks.

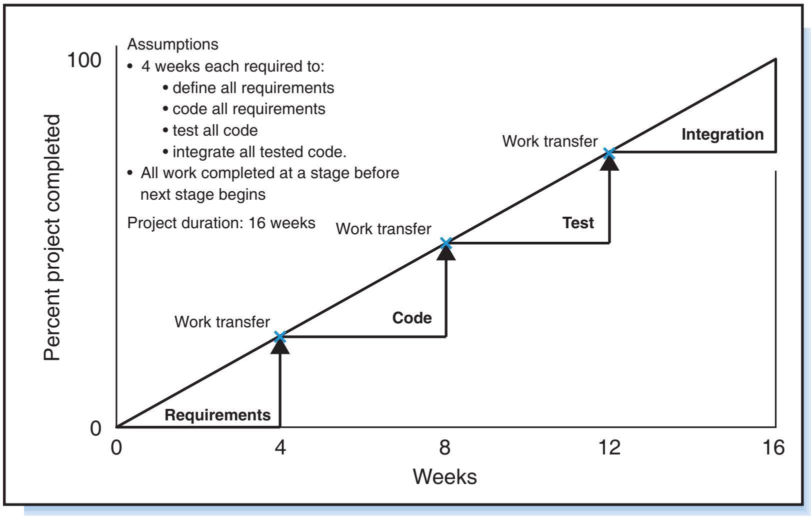


Figure 14.9
Four-stage process, work transferred monthly at completion of each stage.

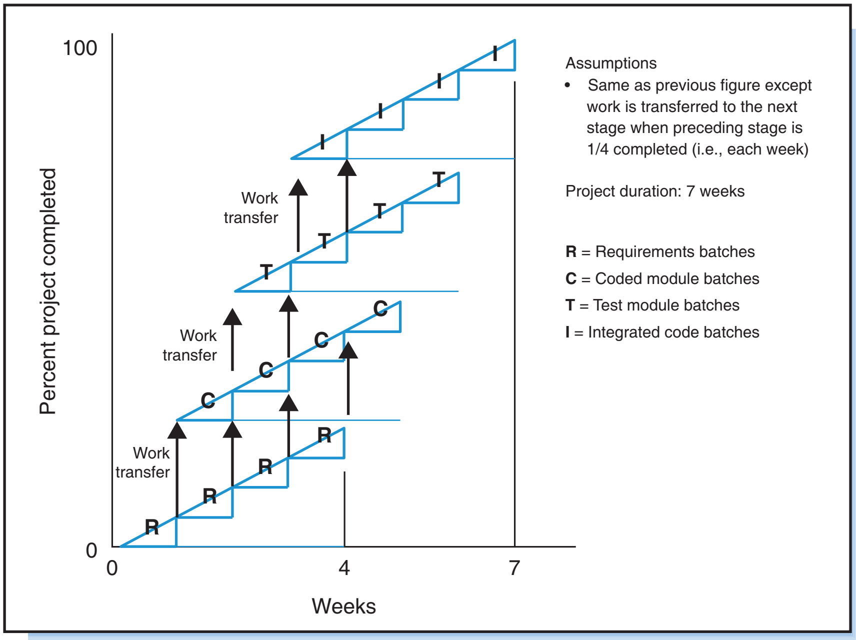


Figure 14.10
Four-stage process, work transferred weekly.

Quality

Suppose a mistake made in Requirements is not detected until Test, which per Figure 14.9 happens 4 or more weeks after the Requirements stage is completed. If the mistake affected subsequent requirements and coding, many requirements and much code might have to be redone.

With the smaller batches in Figure 14.10, the mistake will be detected in the Test stage less than 2 weeks after it originated in Requirements. At week 3, some requirements and half the coding will have yet to be done, and the mistake will not yet have influenced them. Also, at week 3, the Requirements and Code stages are still underway; the people in those stages, having recently worked on the affected requirements and code, will more readily be able to identify the source of the mistake and correct for it.

Feedback

The quality benefit of smaller batches stems from accelerated feedback. In Figure 14.9, the Requirements and Code stages have no opportunity to receive feedback from the Test and Integration stages. Requirements and Code will have been completed; the only way for those stages to benefit from information gained in later stages is to restart them. People who worked in those earlier stages will have moved on to other tasks/projects, and it will be difficult to bring them back. Plus, people forget, and it might be difficult for them to determine the nature of a mistake and to correct it.

In all projects, requirements are ideally firmed up as early as possible; paradoxically, the best way to do that, especially when the requirements are uncertain, is *to learn* from information based on *discoveries made later*—in the Test, Integration, and Launch stages. Small batches permit this: if someone in the Integration stage determines a requirement must be changed, she can communicate that back to the

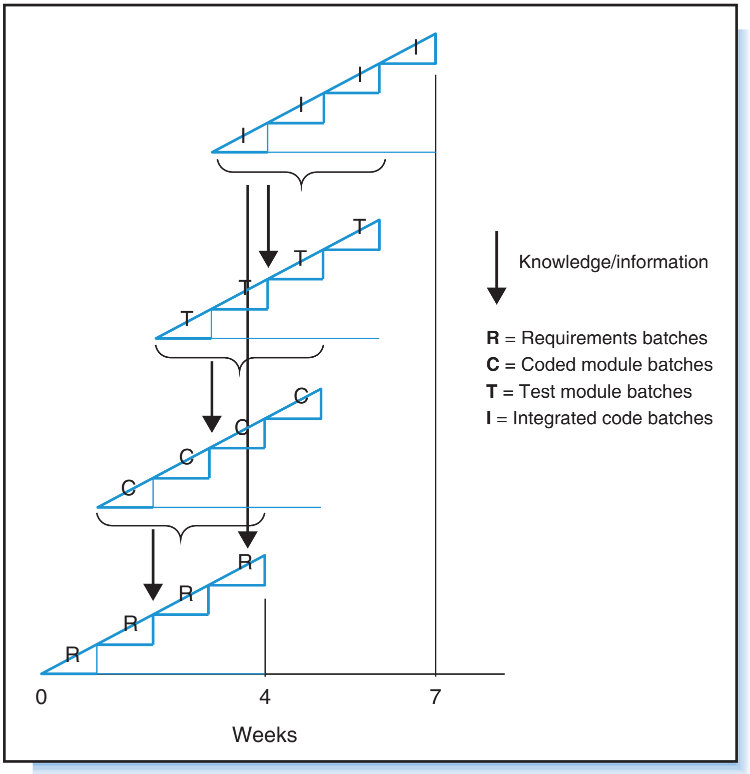


Figure 14.11
Feedback: sharing knowledge and information gained in later stages with earlier stages.

people working in Requirements, which is still underway (Figure 14.11). If someone in Test determines the code must be changed, she can communicate that to Code, which is also still underway. Frequent feedback enables decisions to be revised based on the latest information. This is what happens in APM.

Efficiency

Suppose the Code stage created programs from a batch of 40 requirements, but then it was discovered that all 40 requirements were based on an initial incorrect assumption. This will require that all 40 requirements, and the code based upon them, be reviewed and corrected. If, instead, the Code stage had received only the first 10 requirements, identified the incorrect assumption and informed those creating the requirements, the next 30 requirements would not include that assumption, and only the first 10 requirements and associated code would have to be redone. And redoing them will take relatively less time because everything is still fresh in everyone's minds. In general, when people get quick feedback they are to fix things quickly; when people get late feedback, they waste time trying to figure out what they did wrong.

Workload variability

Large batches between stages impose an up-down workload on project resources. An engineer who can readily test 2 items a day will be overloaded by the arrival of 40 items. As large batches move through a project, resources at each stage are stretched. Says Reinertsen, it's like watching "an elephant move through a boa constrictor," progressively overloading stages of the system along the way.[22] Smaller batch transfers result in smaller workload variability and a more uniform workload for project resources.

Urgency and motivation

A programmer who must deliver written code for testing *tomorrow* is motivated and puts the code at the top of her to-do list. She won't feel so motivated if the code has to be delivered 30 days from now as part of a batch that will include a big pile of code from many programmers.

Overhead cost

The larger the batch, the more items that have to be checked and reported on. If software is tested in a large batch, there might be many bugs to identify and rectify—so-called "open bugs."[23] If there are 100 open bugs and 1 more is discovered, all 100 will have to be reviewed to see if the new one is unique or duplicates any of the others. If there are only ten open bugs, each new one will have to be checked against only nine others. Status reports would address 10 bugs instead of 100. And, since 10 bugs will be resolved much sooner than 100, they will not have to be reported on for nearly as long.

Risk

Much of the risk in development projects comes from the threats of changing customer needs and wants, preemption by competitors, and emerging new technology. Smaller batches enable quicker feedback about all of these, and they enable the project to finish quicker and thus be vulnerable to the risks for a shorter time.

There is, of course, an argument for larger batches: lower cost for batch setup and transport and transfer. Usually, work on a batch must be preceded by preparation, and the batch must be transferred after it is completed. Thus, concomitant with smaller-sized batches are overall higher setup and transfer costs. In projects, however, such costs are often low or negligible (what is the cost to transfer a batch of information?), and the comparative advantages of small batches win out.

Batch size versus iteration

Batch size and iteration are related concepts. TPM is large batch, single iteration: do each stage once and complete everything before moving to the next stage. APM is small batch, many iteration: repeat stages iteratively, and in each iteration, address only a portion of the solution/end-item and take advantage of feedback from prior iterations. Scrum is iterations within iterations: do a little of everything each day to build a small piece of the system; combine the pieces during each sprint to create a stand-alone, usable result; with the last sprint, combine the results to create a completed product.

In general, the size of the batch and iteration frequency should depend on the uncertainty: projects with greater uncertainty should use smaller-sized batches (shorter tasks) repeated more frequently to allow quicker feedback and quicker changes. APM projects handle uncertainty in this way, but so can TPM projects: give the design group requirements as soon as each requirement is created, give the modeling group drawings as soon as each drawing is created, and so on. This principle applies as long as the risk consequence of making an error or doing rework is less than the value of doing work quicker and getting feedback quicker.

Queue size and wait[24]

Queues—backlogs of work waiting to be done—are the project equivalent of inventory. In general, the longer the queue, the longer the waiting time (think of people waiting in line to get through a check-out counter; the longer the line, the longer the wait).

Queue length and batch size are related: the larger the batch arriving at a stage, the longer the queue. Figure 14.12, which is similar to Figure 14.9, shows the work queue size at each work transfer point. The shaded triangles represent growing queues as items are processed at each stage. The right-hand side of each triangle is the amount of work transferred to the next stage; think of it as a batch of items that have to wait in line at the next stage to be processed. Figure 14.13 shows what happens with smaller batches. Smaller triangles represent smaller queues and shorter waiting times.

In manufacturing systems, queues are easy to see—they are physical items—and when the queues get too large, managers try to shorten them. But in projects, queues are often invisible because they consist of information stored on computers; unaware of them, managers don't feel compelled to do anything. But long queues—even invisible ones—have the same drawbacks as large batches and the same benefits to reducing them. Two ways to reduce average queue size are to speed up the stage (move work through it faster) or reduce the batch size of items arriving at the stage. Whereas work at a stage often cannot simply be "sped up," usually the sizes of batches arriving at the stage can be reduced.

The "gating process" described in Chapters 4 and 19, whereby the project is halted at each stage for review and authorization, illustrates the large-batch, long-queue case in Figure 14.12. Despite its purported advantages, the gating process holds up work and information at each stage and does not release it until everything is approved. If speed-to-market is a goal of the project, gating is not the way to achieve it.

Cycle timing and standardization

Cycle time is the time to complete a job or produce a unit. In a project, it can be the time to build a model, code a module, complete a test, launch a new product, and so on. *Cycle timing* is the concept of

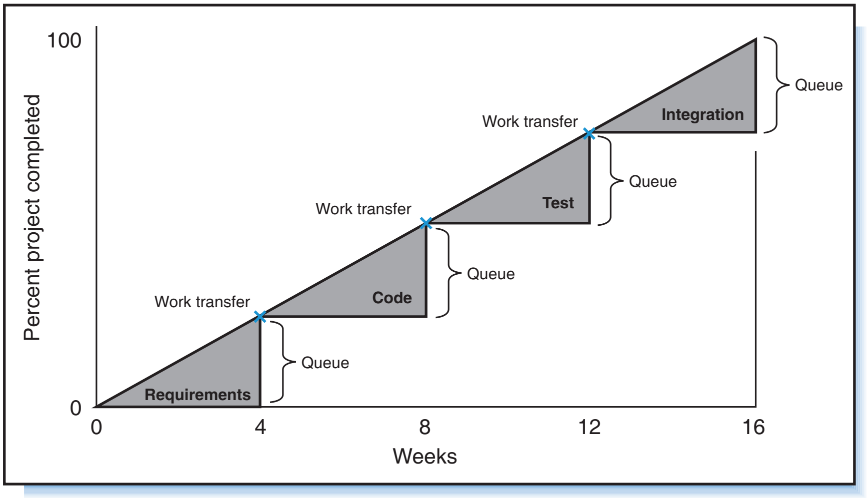


Figure 14.12
Queue length, work transferred monthly.

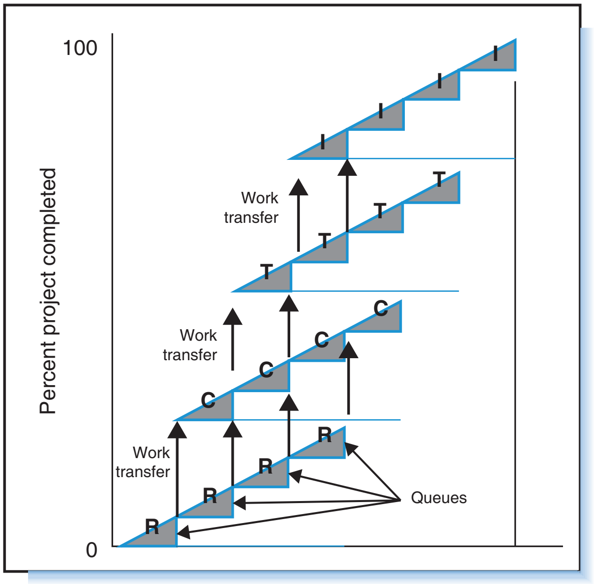


Figure 14.13
Queue length, work transferred weekly.

regularity or rhythm, and it means devoting roughly the same time to build every model, perform every test, launch every product, and so on. In terms of scheduling, it says, for example, "we will complete one coded module every day," "we will complete one test every week," or "we will release a new version of the product every month."

Cycle timing is related to the concept of *smooth flow*, or work that is performed uniformly to a beat, rhythm, or pace, without interruption. Such uniformity reduces uncertainty about workload variability and enables managers and workers to better meet work expectations; for example, each day, a programmer knows she is expected to complete one coded module. Smooth flow is achieved in part by moving work stage to stage on a periodic basis and in small batches. The work batch is sized small enough so it *can* be completed in the assigned cycle time.

In APM projects, work flows in this manner—the aforementioned concept of velocity. Consider, for example, a project that involves daily cycles of code-test-integrate. This means every day, programmers will complete and submit code that is ready to test, and every day testers will complete tests and submit tested code that is ready to integrate. If code is not ready to test or to integrate, it is not submitted, but because everyone knows what is expected each day, most often, they do it. Everyone receives, produces, and delivers known entities every day.

Cycle timing is aided by the principle of *standardization*, which refers to setting standards on processes, tasks, schedules, and so on so that everyone tends to do work in the same way, in the same amount of time, and use the same steps and resources. Standardization reduces uncertainty and variability regarding what must be done and the resources needed to do it. In lean organizations, the work standards are set by people most familiar with the work—those actually doing it; this is part of the self-management principle described later.

Meetings and reviews[25]

The applications and benefits of small batches and cycle timing apply broadly; a good example is meetings and reviews. Instead of scheduling infrequent, long meetings, use standard, frequent, short meetings—daily standups. Short, frequent meetings permit quicker feedback and attacking issues immediately and with urgency. The overall meeting time stays the same, since frequent short meetings require about the same time as infrequent long meetings.

Meeting schedules are standardized and cycle timed; that is, meetings are convened at the same time and place, every day or the same day every week, with the same durations. This reduces planning and coordination effort and decision delays: whereas an ad-hoc meeting might take several days to arrange and thus delay decisions by several days, daily meetings require no arrangements and delay decisions by at most 1 day.

The same standardized-cycle-timed concept applies to project status reviews: convene them at regular intervals, at the same time and same day every month, regardless of project progress or issues. Everyone knows the meeting dates in advance and can fit them into their schedules.

The benefits of short, regular, frequent meetings are seen everywhere. Reinertsen tells the story of Hewlett Packard, where every morning and afternoon the coffee cart came rolling through the departments.[26] Twice a day, engineers would gather around the cart, talk informally, and cross-pollinate ideas. When the coffee cart was terminated, engineers had to go to the cafeteria for coffee. Everyone went at different times; conversations and cross-pollinating dropped off significantly.

A similar standardized-cycle-timed rationale applies to resources that support multiple projects: make them available to each project at a scheduled time every day or week. For example, make the manufacturing representative available to the project team 9 a.m. to 10 a.m. each morning. That way, anyone who needs to work with the representative will have an hour during which the rep is fully available. If someone has an important issue at other times, she can request the representative's assistance; otherwise, she waits until the next day. The time the resource is available can be adjusted depending on demand or the stage of the project.

Self-management, minimal hand-offs, visual management, and Kanban

Lean production philosophy recognizes that problems and opportunities in a process are often first identified by workers in the process and, given appropriate skills, those workers are the people best suited to make decisions and take action. This is the lean principle of *self-management*, which refers to empowering worker teams and providing them with the skills and information necessary to take action without direction from supervisors or managers.

In a self-managed project team, everyone is able to assist everyone else, and each person is able to do a little of everything, regardless of her specialty. Reinertsen calls these "T-shaped resources," people deep in one skill area but broad in many—Jack-of-all trades, master of one. T-shaped resources are developed by hiring "I-shaped resources" (deep skill in one area) and giving them assignments to expand their skill set. In a project, this starts by giving workers assignments in "adjacent" stages of the project—stages that ordinarily provide inputs to or receive outputs from the worker. For example, analysts are cross-trained to do programming, and programmers are cross-trained to do analysis and testing. When the programming queue gets too long (perhaps as indicated on a white board), analysts stop doing analysis and start doing programming; when the testing queue gets too long, programmers stop coding and begin testing. The same goes for everyone.

In many projects, team members commonly work in different departments, buildings, or wherever they are needed. For a self-managed team, however, it is best to physically co-locate everyone—this is a maxim for APM projects but applies also to concurrent engineering in TPM projects. Co-location maximizes information exchange, feedback, and cooperation. Team members share information constantly—and in small batches. They learn about each other's interests, backgrounds, and families, which builds team cohesion.

Also, co-location eliminates a main source of inefficiency in projects—*handoffs*, which refers to the transfer of tasks or work items between project workers, departments, and contractors. Handoffs are wasteful: information transferred is inadequate or incorrect, and jobs are held up. Co-location minimizes this waste because everyone already knows about everything that's going on.

Self-managed teams are aided with *visual management*, which are *visual* cues all around them that provide information to enable them to decide what, when, and how much to do and when and where problems are occurring. On a production line, for example, each worker observes other workers at stages before and after her. If she sees those stages are being underutilized or overloaded, she accelerates or decelerates her own work or walks over to assist those other stages. A self-managed project team acts in similar fashion. It tracks and controls workflow using daily standup meetings and burn down charts. Sticky notes on white boards show jobs or user stories at each stage of the process: as jobs move from stage to stage, notes are moved from section to section, which enables everyone to see the stage of the project for every job and which stages are underloaded or overloaded.

To prevent overloading, the team can use a white board to *restrict* the number of jobs (queue size) in a stage; this prevents downstream (later) stages from being overloaded by work coming from upstream (prior) stages. The concept of regulating and smoothing the work flow by restricting the work volume at each stage originated in manufacturing with the lean production concept of *Kanban*. With Kanban, no stage is permitted to transfer work to the next until it receives a signal that the next stage is ready to receive it. For example, each stage on the white board in Figure 14.6 can hold a maximum of three jobs (sticky notes). The signal that a stage is ready to receive another job is simply when the number of jobs at the stage drops below three. The team is able to use this simple visual method to monitor progress and control work to keep jobs flowing at a uniform pace.

14.6 Summary

Traditional project management methodology applies to projects where the problem/goal and solution/end-item are well understood and can be well defined. The project phases/stages are largely completed in sequence. In incremental TPM, a variation of TPM, the end-item is implemented in stages or pieces, which enables portions of it to be put into use sooner.

Agile project management applies to projects where the solution/end-item is somewhat or largely uncertain. It accommodates this uncertainty through a learn-as-you-go process of iterative steps in the execution phase, where each iteration leads to the release of an end-item "increment" and a better understanding of the ultimate end-item.

In the spiral model form of APM, the end-item is released through a series of multiple cycles, where each cycle consists of the stages of analysis, design, develop, test, and so on and results in a prototype. With each cycle, the customer provides feedback to the developer, who creates an improved version of the prototype and, ultimately, a final product.

Scrum, another form of APM, is commonly applied to software development. The Scrum process starts with the product owner listing customer/user needs and wants on the product backlog, and the team addresses these through a series of sprints. Each sprint focuses on a subset of items in the backlog and results in the release of "something of value" to the customer—a potentially shippable product. The team receives feedback on the release as input to subsequent sprints.

Lean production implies performing work for the least time, resources, and effort without diminishing work quality or output. It emphasizes smooth flow—that anything going through a multistage process should move unhindered. APM is sometimes called "lean project management," but lean practices apply to TPM projects as well.

One lean concept is use of small batches. By decreasing the batch size, project stages can be overlapped: the project finishes sooner, mistakes are detected earlier, and the team gets quicker feedback from later stages and from the customer. Batch size and iteration are related concepts. APM is small batch, many iteration: stages are repeated iteratively; each iteration addresses only a portion of the solution/

end-item and takes advantage of feedback from prior iterations. Batch size and queue length are also related. The smaller the batch arriving at a stage, the shorter the work queue and the time to move work through each stage.

Lean philosophy recognizes that the problems and opportunities in a process are often first identified by workers in the process; given the right skills and information, they are often the best suited to make decisions and take action. This is the concept of self-management—empowering worker teams to make decisions and take action aided by visual management—providing teams visual information to enable them to decide what, when, and how much to do.

The preceding sections of the book described how project managers, organizations, and teams plan, organize, and guide projects, though little was said about the project managers, organizations, or teams *themselves*. The following section addresses project *organizational behavior*; it focuses on managers and teams and the topics of organization structure, leadership, participation, and teamwork.

Review Questions

1. What is the main characteristic of projects for which TPM (*waterfall approach*) applies?
2. How are changes in requirements handled with TPM?
3. How does incremental TPM differ from TPM? What is "incremental" about it?
4. For what kinds of projects is TPM inappropriate or poorly suited?
5. Describe how APM can be described as a "learn-as-you go" approach.
6. What happens during each iteration in APM? What are the expected outcomes of an iteration? How long are the iterations?
7. Describe the planning process in APM.
8. How is APM different than incremental TPM?
9. Describe how the spiral model works and the outcomes of each cycle. In what ways does the spiral model differ from Scrum?
10. Can you imagine projects where both APM and TPM would apply? Describe them.
11. Define each of the following: product backlog, user stories and epics, sprint backlog, sprint, time-box, conditions of satisfaction, potentially shippable product.
12. Define the roles and responsibilities of the Scrum master and product owner.
13. Describe significant features of a Scrum team—roles, structure, size, responsibilities of team members.
14. How are the results of "sprint increments" turned into production or operational product versions?
15. What happens during the following: sprint planning meetings, daily Scrum meetings, and review/retrospective meetings?
16. Describe how a white board is used for tracking jobs/tasks.
17. Describe how a burn down chart is used for tracking work progress.
18. If a three-person team is to work 6 hours a day for a 15-day sprint, what is the total number of labor hours available in the sprint? What will the hours of effort remaining be at the start of the sprint?
19. On day 7, Helena starts and completes Task A, which was estimated to take 4 hours. She also starts Task B, estimated to take 5 hours, but at the end of the day, she guesses that the task is about 60 percent complete. For day 7, by how many hours has Helena reduced the hours of effort remaining?
20. As of day 7, the sprint has 59 hours of effort remaining. The sprint started out with 120 hours of effort remaining and was timeboxed to 15 days. What is the velocity? Will the project finish within the timebox?

21. If a sprint is falling behind, why not work the team overtime to complete the backlog?
22. Why is application of APM methods limited to certain kinds of projects? Why might it be difficult to apply APM to construction, large-scale infrastructure, and hardware-product development projects?
23. What does "lean" in lean production refer to?
24. What does "flow" refer to in projects? What is it that is flowing?
25. What are the "batches" in projects? What is small batch flow?
26. Explain how small batches: reduce project duration; improve quality; increase feedback, efficiency, and motivation; and decrease workload variability, overhead cost, and risk.
27. There are drawbacks to small batches (hence benefits to large batches). What are they?
28. Describe the connection between batch size and iteration in projects.
29. Describe the connection between batch size, queue size, and waiting time.
30. Where are the queues in a project, and *what*, exactly, is waiting in the queues?
31. Is the gating process large batch or small batch?
32. What is cycle timing? How does it apply to projects, and what are the benefits?
33. What does standardization mean in a project context? Give some examples.
34. Describe self-managed teams. Are they the same or different than the teams in APM?
35. How do self-managed teams reduce the problem of handoffs?
36. What is visual management? Give examples.
37. What is Kanban? How does it apply to project management?

Questions About the Study Project

Do you think or know as a fact that incremental, iterative, agile, or lean practices were used in the project? If so, answer the following questions.

1. Was the project performed in iterations? If so, why? What aspects of the project (phases or stages) were iterated?
2. If the project was performed in iterations, what were the outcomes of each? Would you say they were "increments"?
3. If the spiral model was used, how was it similar or different than the model described in the chapter? If the Scrum approach was used, how was it similar or different? In answering this, refer to the terms mentioned in question 11 previously.
4. Were there a Scrum master and a product owner? What were their roles?
5. Was there a project manager? What was her role?
6. Describe the project team, roles of team members, responsibilities, and how the team functioned.
7. Who were the other stakeholders and what were their roles?
8. How was the project planned? How was it tracked and controlled? Were white boards, burn down charts, or other methods used?
9. Is the project manager aware of "lean methods"? Does she apply them to project management?
10. Would you say work in this project moved in small batches or large batches? (What are the "batches" made of?) If large, explain how/where the project might have benefitted from small batches.
11. Did you observe work tasks waiting or being delayed that could have benefitted from smaller batch transfers?
12. Did you observe cycle timing or task standardization in the project?
13. Were visual management methods or the Kanban concept applied in the project?
14. Was the team self-managed? If yes, discuss in what ways it managed itself.

CASE 14.1 GRAND ENTRY FOR ACCENT, INC.

The goal of the Grand Entry project was to provide a new web portal for employees of Accent, Inc., to replace the existing portal, which employees found cluttered and difficult to use. The project's mission statement was to "Create an improved user experience by developing a simple and intuitive system that allows users to navigate and access the desired contents quickly and efficiently." Among its objectives were "innovative design, simple and intuitive interfaces, features to encourage users to return to the site, and use of an agile process to develop the site."

The CIO had heard about agile methodology and thought Grand Entry would be a good place to try it out. He assigned the project to Theodora Lamar, a software project manager with much experience, although none in agile. Senior management provided no budget but told Theodora to hold costs to "between $400,000 and $600,000" (to cover salaries of workers assigned to the project) and shoot for completion in 16 months. She was to conduct the project in "agile fashion" wherein each sprint was to deliver "additional functionality" that would be reviewed and approved by "stakeholders."

Theodora read some articles on agile and Scrum, appointed herself Scrum master, and selected two analysts for the Grand Entry (GE) team. Their first action was to form a focus group through which portal users could vocalize their dissatisfaction with the current system. The team selected for the focus group two Accent employees, recently hired and not yet assigned to specific work. Although new to the company, they had recent experience with the portal and would know its limitations. Their role was twofold: (1) talk to as many fellow employees as possible to learn the problems of the current portal and get ideas for improvement and (2) use the deliverables from each sprint and make suggestions. Initially, they would devote all of their time to the project; later, they would split their time between the project and other work assignments.

Theodora and the analysts first interviewed the two employees and then three senior managers, including the CIO. Their comments and suggestions formed the basis for the original list of "user requirements" for Grand Entry. Theodora reviewed the list and chose the ones she thought would be the most realistic to implement. She then selected three more people from different departments to join the GE team—an architect, a developer, and a support resource. None of them had worked together, but Theodora knew them all and felt they were technically "the best." Besides the GE team, the other technical party involved in the project was Metasoft, the developer of the browser platform upon which the portal resided. Metasoft would handle all project issues relating to the browser.

The GE team identified itself, the focus group, Metasoft, and the three senior managers as the project "stakeholders." It did not include or communicate with the group charged with maintaining and updating the existing portal and, as a result, was not aware of problems that that group had already discovered. This resulted in some duplication of effort, as both the GE team and the maintenance group worked on the same problems; the GE team even tried using features that the maintenance group had already found unsuccessful. When the maintenance group eventually learned of the project, they initially resisted the GE team's requests for assistance. Only several weeks later did they start to cooperate.

Theodora planned the project in a 4-month, rolling-wave fashion; that is, she prepared a plan to address the requirements in an upcoming 4-month period and intended to repeat this four times during the 16-month project. The plan did not specify the expected number of sprints or their durations. Each sprint was to last 2–3 weeks, depending on Theodora's estimate of how long it would take to complete the requirements she had selected. Some sprints originally planned for 2 weeks stretched to 3 weeks when the work took longer than anticipated.

During the project, the browser shut down twice and halted the project. The GE team was at the mercy of Metasoft, which had assigned no special priority to the project and took several days to fix each shutdown.

Each sprint resulted in a beta version that the GE team demonstrated to the focus group. The focus group's typical response consisted of suggested improvements beyond what the team was capable of addressing in the next few sprints. This created a backlog of new requirements and open issues, from which Theodora could select only a few as focal points of the next sprint. Since so many previously identified issues had not been addressed, the focus group kept re-identifying them; thus, instead of identifying new, more pressing issues, the group kept pointing out issues the GE team was aware of but hadn't had time to fix.

A few months into the project, additional senior managers started to sit in on the beta demonstrations and add their own suggestions for improvements. Consequently, issues intended to be resolved or functionalities to be added in upcoming sprints were superseded by new requirements. The list of stakeholders grew as more managers learned about the project and attended the demos.

Theodora's response to the growing list of requirements was to impose more work on the team. She had tried to avoid overtime, but not ever being completely aware of what the team was working on, she simply requested them to do more. They never said no, and only after several weeks of the team working overtime—with a noticeable decline in morale and increase in mistakes—did Theodora realize she was asking too much. The reason she didn't know exactly what the team was doing was because her tracking method was entirely verbal. She had told team members they should inform each other about when they had completed or were stalled on a task. Team members had different perceptions about work progress, and only Theodora's constant checking prevented work from falling through the cracks.

The project was completed within 16 months and the target dollar range. The most significant requirements as identified by the focus group and senior managers were incorporated into the portal, but opinions about the portal's effectiveness from the broader employee population are still pending. The operation and future upgrade and repair of Grand Entry will be handled by the maintenance group, which, said the group, might prove challenging since the GE team's "agile process" had produced little documentation—so little that code for portions of the site was hard to comprehend. The GE team, following *The Agile Manifesto* creed of "value-added work over documentation" had done practically nothing to document its work or the system it had created.

QUESTIONS

1. Prepare a "lessons learned" section for the Grand Entry Project closeout report. Consider at least the following points:
    a. The customer and customer representation
    b. Requirements definition and prioritization
    c. Tasks selected for each sprint
    d. Participation of Metasoft
    e. Theodora's project planning and sprint planning
    f. Sprint duration and overtime
    g. Project tracking and control
    h. Documentation.
2. Describe how the case illustrates the benefits and pitfalls of agile. Which of the mistakes made resulted specifically from the agile method, and which might have been made with a more traditional approach as well?

CASE 14.2 TECHNOLOGY TO TRACK STOLEN VEHICLES[27]

Track & Found, Inc. (TFI), a leading vehicle tracking and recovery company, had grown significantly over the past 10 years due to high demand for its systems. The company was aware that its entire product offering was reliant on information and communication technology capabilities, so it restructured its IT department into a "DevOps" organization to promote DevOps software development methodology. The restructure split the IT department into two teams, one for development (50 employees) and one for operations (30 employees). The IT department's more experienced and better-qualified programmers and engineers were placed in the development team; its less-qualified emplyees and newly hired college grads were put in the operations team. Because the company was growing so quickly, the two teams had to be placed in different buildings located a considerable distance apart.

TFI executive management approached SoftTech Engineers, a reputable software engineering company with which it had had a longstanding relationship, to assist its own development team in developing a new tracking application (called "TFIApp") to be used by vehicle response teams in conjunction with TFI's existing tracking solution to recover stolen vehicles more quickly and accurately. SoftTech was included in the project because it possessed development skills and knowledge that TFI did not, plus it had agile project management experience that TFI management felt could benefit the project. TFI's development team had no such experience and expected SoftTech would provide guidance.

In the TFIApp project, SoftTech would create software for the GPS-based tracking application, the TFI team would create hardware to add functionality to the vehicle receiver unit, and SoftTech would integrate the hardware and software. SoftTech was capable of also developing hardware, but in the interest of the DevOp methodology, TFI management gave the task to its own development team to encourage a close working relationship with the operations team.

SoftTech divided work for both hardware and software components of the system into a series of two-week sprints. Completion of each sprint would be followed by a demonstration to TFI management. In dividing up the work, the TFIApp project manager, who worked for SoftTech, made sure that virtually all of his own team's work could be done independently of the development team's work (he had learned from prior experience that TFI's IT department could not be expected to stick to plans). The teams would not have to work together until integration at the end of the project.

The SoftTech team's work progressed smoothly, and it completed the intended deliverables of every sprint for the software on time, on budget, and according to specifications. Unfortunately, however, the TFI development team completed its deliverables for the first sprint only. Thereafter it slipped farther and farther behind, because it needed input from the operations team, which, being understaffed and less experienced, was in constant fire-fighting mode and had no time to meet with the development team. As one consequence of "splitting the work," the development team had received no training and little guidance in agile. And the fact that the team was not demonstrating deliverables every 2 weeks was apparently overlooked by the SoftTech project manager and TFI management. Neither had shown much interest in the development team until SoftTech completed its software application and was preparing for integration with the development team's hardware. Upon hearing from SoftTech that the hardware was not ready, TFI's IT executive raced to the development team and demanded an explanation.

QUESTIONS

1. What is DevOps? List characteristics of the DevOps software development methodology.
2. What might the SoftTech project manager have done differently to ensure a more successful outcome for the entire project?
3. What parts of the agile project went well, and what parts of the project did not adhere to agile methodology?
4. What should TFI's management have done differently? What advice do you have for them to manage their IT resources better?[28]

Notes

1. Fowler M. and Highsmith J. *The Agile Manifesto*; August 2001, www.pmp-projects.org/Agile-Manifesto.pdf.
2. Nicholas J. *Lean Production for Competitive Advantage*, 2nd edn. Boca Raton, FL: CRC/Productivity Press; 2018.
3. For basic principles, see Dennis P. *Lean Production Simplified*, 2nd edn. New York: Productivity Press; 2007. For applications to project management, see Blackburn J. *Time-Based Competition*. Homewood, IL: Business One Irwin; 1991; Reinertsen D. *Managing the Design Factory*, New York: Free Press; 1997; Leach L. *Lean Project Management: Eight Principles for Success*. Boise, ID: Advanced Projects; 2005.
4. For thorough coverage of APM and its variants, see Wysocki R. *Effective Project Management: Traditional, Agile, Extreme*, 6th edn. New York: Wiley; 2012. Much of the following discussion is adapted from that book, particularly from pp. 44–47, 380–445.
5. The spiral model was introduced in Boehm B.A. Spiral model of software development and enhancement. *ACM SIGSOFT Software Engineering Notes, ACM*, 11(4); August 1986: 14–24.
6. The problem of managing hardware—software integration and simultaneous waterfall-spiral methodologies—is addressed in Maier M. and Eberhardt R. *The Art of Systems Architecting*, 3rd edn. Boca Raton, FL: CRC Press; 2009, pp. 96–98.
7. Much of this section is adapted from Cohn M. *Succeeding with Agile: Software Development Using Scrum*. Upper Saddle River, NJ: Addison Wesley; 2010.
8. Ibid., pp. 117–140.
9. Ibid., p. 202.
10. Ibid., pp. 355–388. For discussion on scaling agile, see Gower B. and Rally Software. *Agile Business: A Leader's Guide to Harnessing Complexity*. Boulder, CO: Rally Software; 2013.
11. Adapted from Ries E. *The Lean Startup*. New York: Crown Business; 2011. pp. 138–140.
12. See Schwaber K. and Beedle M. *Agile Software Development with Scrum*. Upper Saddle River, NJ: Pearson; 2001.
13. Lohnes P. and Wilson C. Can agile and traditional project management be partners? Integrating agile methods with project management best practices, http://pppm.mclmg.com/docs/AgileVsCBPwhitePaperFinalB.pdf, accessed September 10, 2014.
14. See Wils A., Van Baelen S., Holvoet T. and De Vlaminck K. *Agility in the Avionics Software World*. Leuven: K.U. Leuven DistriNet, Department of Computer Science, https://distrinet.cs.kuleuven.be/legacy/publications/42148.pdf, accessed September 17, 2014.
15. Lohnes and Wilson. Can agile and traditional project management be partners? (Most APM methods originated from and are used in software development projects, but one, adaptive project framework, purportedly can be used in all kinds of projects; see Wysocki. *Effective Project Management*, pp. 408–437.)
16. See Weaver P. Agile is not a project management methodology! *Blog Posted*; April 2, 2012, http://network.projectmanagers.net/profiles/blogs/agile-is-not-a-project-management-methodology/ accessed September 10, 2014.
17. From Denning S. How Agile can transform manufacturing: the case of Wikispeed. *Strategy & Leadership* 40(6); 2012: 22–28, accessed June 25, 2019.
18. Nicholas. *Lean Production for Competitive Advantage*, p. 66.

19. Lean concepts applied to construction projects, see: Ballard G. The last planner. In *Northern California Construction Institute Spring Conference*. Monterey, CS: Lean Construction Institute; April 1994; Koskela L., Howell G., Ballard G. and Tommelein I. Foundations of Lean Construction. In Best R. and de Valence G. (eds). *Design and Construction: Building in Value*. Oxford, UK: Butterworth-Heinemann; 2002.
20. Lean concepts applied to product development, see: Smith P. *Flexible Product Development: Agile Hardware Development to Liberate Innovation*, 2nd ed. Preston G. Smith, 2018; Reinertsen D. *Managing the Design Factory*; and Reinertsen D. *The Principles of Product Development Flow: Second Generation Lean Product Development*. Redondo Beach, CA: Celebras, 2009. The following sections draw from the last, especially Chapters 5 and 7.
21. There are two kinds of batches: production and transfer. Production is the volume of work done in a stage without interruption; transfer is the volume of work moved from stage to stage. Our discussion of batches focuses solely on transfer batch size. For further discussion of production vs. transfer batch, see Nicholas. *Lean Production for Competitive Advantage*, pp. 123, 128.
22. Reinertsen. *The Principles of Product Development Flow*, p. 112.
23. Ibid., p. 112.
24. Ibid., p. 115
25. Ibid., pp. 111–120.
26. Ibid., pp. 180–185.
27. Ibid., pp. 155–156.
28. Bond-Barnard T. University of Pretoria.

Part IV

Organizational behavior

Projects are organizations of individuals and groups created for the purpose of delivering results or end-items, and project success depends in part on how those organizations are structured and how well the people within them work together as teams.

The three chapters in this section focus on organizational and behavioral issues inherent to projects. They describe the ways that projects are organized and integrated, leadership styles of project managers, roles and responsibilities of project team members, and ways teams are managed to maximize teamwork and minimize the negative personal consequences of working in projects.

Chapter 15

Project organizational structure and integration

Organizations are systems of human and physical elements created to achieve goals. As with all systems, they are partly described by their structure—the form of relationships that bond their elements. In all organizations, two kinds of structures coexist. One is the *formal structure*, the *published* one that describes normative superior–subordinate relationships, chains of command, and subdivisions and groupings of elements. The other is the *informal structure*, the unpublished one that consists of relationships that *evolve* through the interactions of people. Whereas the formal organization prescribes how people are supposed to relate, the informal organization is how they actually do relate. This chapter deals primarily with the formal organizational structure of projects and how project organizations are structured, depending on project goals and available resources.

The chapter also deals with project integration, which is the way that individual functional groups, subunits, project phases, and work tasks are interlinked and coordinated to achieve project goals. The discussion covers various means of project integration and the special case of integration within large-scale development projects.

Important to note is that occasionally projects are conducted without any formal project organization, per se. In other words, a manager and people are tasked with doing a project, but no project group or organization is explicitly recognized. Lack of an identified project organization makes everything more difficult to manage because of uncertainty over reporting relationships and who, exactly, is on the project. Also noteworthy is that most project organizations are "superimposed" on the existing organizational structure; although this better enables them to achieve project goals, those in the formal organization sometimes view the project organization as disruptive to their business as usual.

15.1 Formal organizational structure

Concepts of organizational structure apply to all kinds of organizations—companies, institutions, agencies—and to their subunits—divisions, departments, projects, and teams. The formal organization structure is often publicized in a chart such as the one for NASA in Figure 15.1. A quick glance at it reveals both the organizational hierarchy and groupings for specialized tasks. The chart in Figure 15.1 shows, for example:

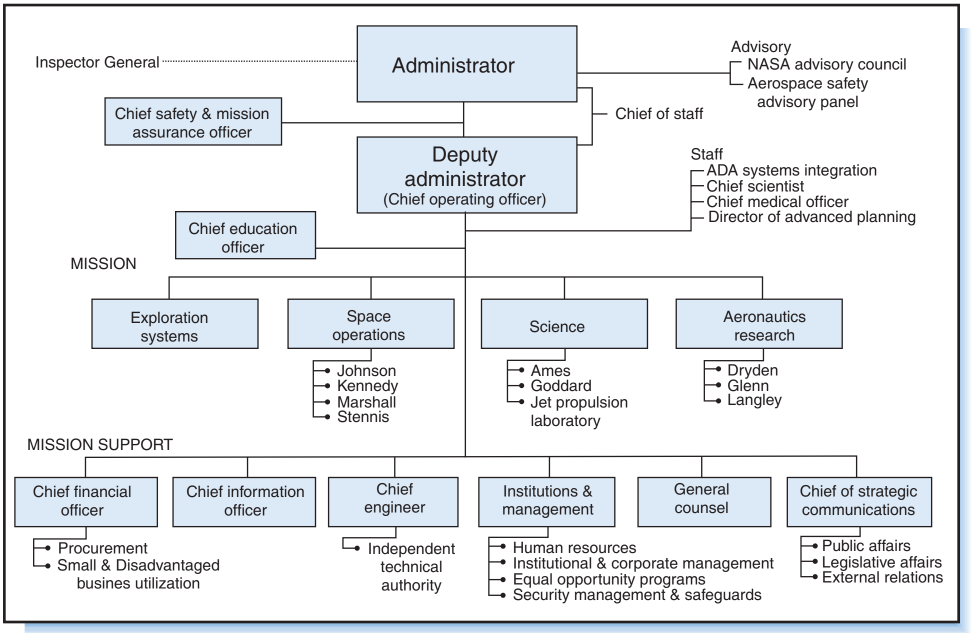


Figure 15.1
NASA organization and program chart.
Source: NASA.

1. The range of activities in which the organization is involved and the major subdivisions of the organization (exploration, space operations, science, aeronautics research).
2. The management hierarchy and reporting relationships (under "Mission," e.g. directors at Ames, Goddard, and Jet Propulsion Laboratory research centers all report to the administrator for science).
3. The type of work and responsibility of the subdivisions (e.g. projects at the research centers focus on specific disciplines or goals such as space exploration and space operations).
4. The official lines of authority and communication (the administrator is the highest authority, the deputy administrator is next highest, and so on; communication moves vertically along the lines from one box to the next).

There are things the chart does not show, for instance, personal contacts. For example, workers at Jet Propulsion Lab communicate directly with workers at Dryden via email and telephone, not (as the chart implies) via the directors of these centers. Nonetheless, the chart provides a useful overview of the organization's departments and roles and formal relationships among them.

15.2 Organizational design by differentiation and integration

There is no "best" kind of organization structure. The most appropriate structure depends on the organization's goals, type of work, available resources, and environment. Organization structures typically develop through a combination of planned and evolutionary responses to ongoing problems. To deal with certain classes of situations and problems, organizations create specialized subdivisions and groupings, each with the necessary expertise and resources. As they grow or the environment changes, organizations add new subdivisions and groupings to handle new situations and emerging problems. For example, when a company expands its product line, it may subdivide its manufacturing unit into product-oriented divisions to better address problems specific to each line. As a company expands its sales territory, it may subdivide its marketing force geographically to better handle unique problems of regional origin. Subdividing an organization like this into specialized areas is called *differentiation*.

Ordinarily the subunits of an organization do not act independently but interact and support each other—at least in theory. The degree to which they interact and coordinate their actions to fulfill organizational goals is called *integration*.

Traditional forms of organization

There are six ways that organizations differentiate into subunits: functional, geographic, product, customer, process, and project. We will start by looking at the first five forms and then delve more deeply into the project form.

Functional differentiation

Functional differentiation is so called because the organization is divided into functional subunits such as marketing, finance, production, and human resources; the structure of the Iron Butterfly Co. in Figure 15.2 is an example. Most of the integration between subunits is handled by rules, procedures, coordinated plans, and budgets. When problems occur that cannot be handled by these measures, the managers of the affected subunits must work together to resolve them.

Functional differentiation works well in repetitive, stable environments because there is little change, and the rather low level of integration afforded by rules, procedures, and chain of command gets the job done. The functionally differentiated organization has a long history, going back to the Roman army and the Catholic Church, and remains today the most prevalent form of organization.

Geographic differentiation

Most organizations have more than one basis for differentiation. The Roman army was also geographically differentiated; that is, it was subdivided into legions that oversaw different locations. Organizations

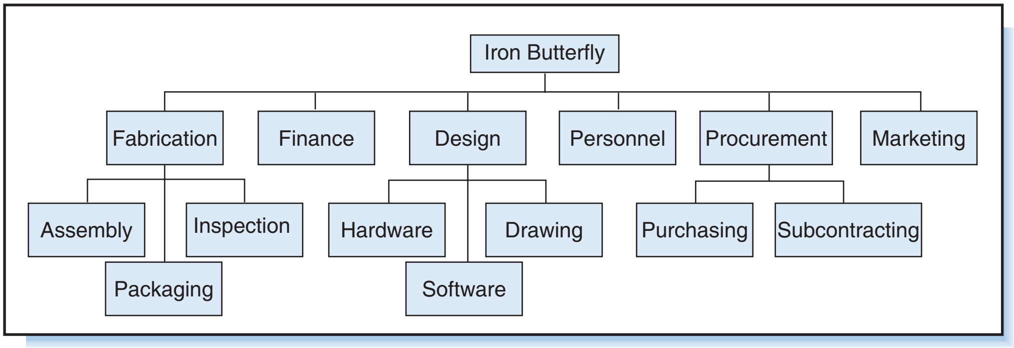


Figure 15.2
Functional differentiation in organization structure for Iron Butterfly Company.

subdivide this way (e.g. Atlantic branch, European division, Far East command, etc.) to adapt themselves to the unique requirements of local customers, markets, suppliers, adversaries, and so on. Within each geographic subunit, functional differentiation is often retained (e.g. marketing department of the Mexican branch). Regional subunits may operate relatively autonomously and be integrated through standardized financial and reporting rules and procedures.

Product differentiation

Firms with a variety of product lines use product-based differentiation. Corporations such as General Motors, General Foods, and General Electric are split into subdivisions wherein each designs, manufactures, and markets its own product line. Within each subdivision is a functional, geographic, or other form of breakdown. As with geographically differentiated organizations, integration between product subunits tends to be limited to standardized financial and reporting rules and procedures.

Customer differentiation

Organizations may also differentiate by customer type. For example, companies with both military and commercial sales often establish a separate military division because federal requirements for proposals, contracting, and product specifications differ substantially from those for commercial customers. The level of integration between divisions depends on the interdependency of the product lines; typically, however, there is little integration.

Process differentiation

Organizations also differentiate according to process or sequence of steps. This is illustrated in Figure 15.2 for the Fabrication division of Iron Butterfly Co., which includes departments for assembly, inspection, and packaging, which are three steps in the fabrication process. These subunits require high-level integration because they are sequentially interrelated and problems in one unit directly affect the others. The subunits are integrated through coordinated plans, schedules, and task forces and teams, discussed later.

Drawbacks of traditional forms of organization

By their very design, traditional forms of organization can address only certain anticipated, classifiable kinds of problems. As the environment changes and new kinds of problems arise, they react by further differentiating subunits and adding more rules, procedures, and levels of management; in other words, they add more bureaucracy and pay the price of less flexibility and greater difficulty in integrating the subunits.

Traditional forms of organization work on the assumption that problems and tasks can be neatly classified and resolved within specialized units that can work somewhat independently. But what happens when a problem arises that doesn't fit any of the subunits? There may be no place for it, and such problems fall through the cracks.

The usual way to handle new, previously unanticipated, or unclassifiable problems is to redesign the organization and add new subunits. However, the process of redesigning an organization to suit unique problems is slow and expensive. An alternative is to bump problems up the chain of command and involve managers of the functional units best suited to resolve them. This works as long as it is not done too often, since it sometimes overwhelms the chain of command and encourages hiring more managers (and increasing the size of the bureaucracy). In short, traditional organizational forms are not well suited for situations with frequent change, unique problems, and high uncertainty. Nonetheless, most projects are conducted within or use resources provided by organizations with traditional forms of structure.

15.3 Requirements of project organizations

Project environments are characterized by frequent change, distinctive problems, and uncertainty, and they typically require the resources and coordinated work effort of multiple subunits and organizations. Each project is a new undertaking, somewhat unique, aimed at a new goal; because of that, risk and uncertainty are inherent. Changes, mistakes, or delays in one subunit have consequences to all others, and because of that, the subunits must be able to work together—they must be integrated. Project organizations are created around projects and, ideally, their structure and composition is whatever best suits the project. And, like projects, they are temporary. When the project ends, the project organization is disbanded.

Projects in software development, pharmaceuticals, biomedicine, space exploration, product development, and even construction routinely encounter unexpected changes in goals, customer needs, environmental demands, and resources. Consequently, the project organizations must be adaptable; they must be both highly differentiated *and* highly integrated to accommodate a variety of problems and situations. To achieve this, project organizations share two properties:

- Subunits are differentiated to suit the unique requirements of the project and the environment.
- Subunits are integrated using horizontal relations.

These properties are discussed next.

15.4 Integration of subunits in projects[1]

Traditional organizations are characterized by their "verticalness" or reliance upon up-and-down patterns of authority and communication. This makes them slow and ineffective in dealing with uncertainty or quickly changing situations. In contrast, project organizations are characterized by their *horizontalness* or use of direct communication between the parties involved in a problem. Horizontalness means cutting across formal lines of authority and moving decision-making to the level of the parties affected.

All organizations have elements of horizontalness, mostly in the form of personal contacts, informal relationships, and friendships. Horizontalness helps expedite communication and resolve problems between subunits. For example, whenever the assembly department in Figure 15.2 experiences a minor parts shortage, George, the assembly foreman, phones Helen in the purchasing department for a "rush order" favor. The informal call bypasses the formal structure (involving George's and Helen's respective managers) and speeds up the order.

A drawback with informal processes is that they do not ensure everyone who should be involved is. For example, Helen must charge all purchases to an account; if George isn't privy to the dollar amount in the account, his informal requests might deplete the account before additional funds can be credited, which involves someone in the finance/accounting department who isn't aware of George's requests. Further, if George does not tell anyone about the parts shortages, then the reasons for the shortages—pilferage, defective parts, or underordering—never get resolved. In short, informal processes sometimes work, but they are, in many regards, inadequate.

Project organizations improve upon informal processes by building horizontalness into the formal organization structure through the use of functions called *integrators*. Integrators are people or groups who facilitate communication between the subunits working on a common task. Integrators bypass the traditional lines of authority and speed up communication, but they also ensure that everyone affected by a problem is involved and has the necessary information.

Several kinds of integrators are used in projects. In the following they are listed in order of increasing authority, importance, and cost; in the list, the latter kinds take on all the authority and responsibility of the former:[2]

- Liaison roles
- Task forces and teams
- Project expeditors and coordinators
- Pure project managers
- Matrix managers
- Integrating contractors.

15.5 Liaison roles, task forces, and teams

The *liaison* role is a specialized person or group that links two or more organization subunits. In Figure 15.3, the dotted line represents the liaison role of "inventory controller." This person performs duties in the assembly department but also notifies the purchasing department of impending shortages and keeps track of orders placed. The role relieves the assembly foreman of this responsibility and, by legitimizing the process, ensures that orders get placed, funded, and documented.

But the liaison role is not always effective. Although the inventory controller expedites parts ordering, the reason for part shortages still goes unresolved. To unravel that problem, it might be necessary to involve people from elsewhere in the company. This is where the next kind of integrative role, a *multifunctional task force* or *team*, comes into play.

A *task force* is a temporary group with representatives from several subunits (multifunctional) that is formed to address a need or solve a problem. When the group begins addressing the problem, it is, in fact, conducting a project. For example, to address the shortage problem, the assembly foreman might call together representatives from the areas of inspection, finance, and purchasing. The task force meets as often and as long as necessary to solve the problem, and then it disbands. The most effective task forces have ten or fewer members, a team leader or coordinator, and are short lived.[3]

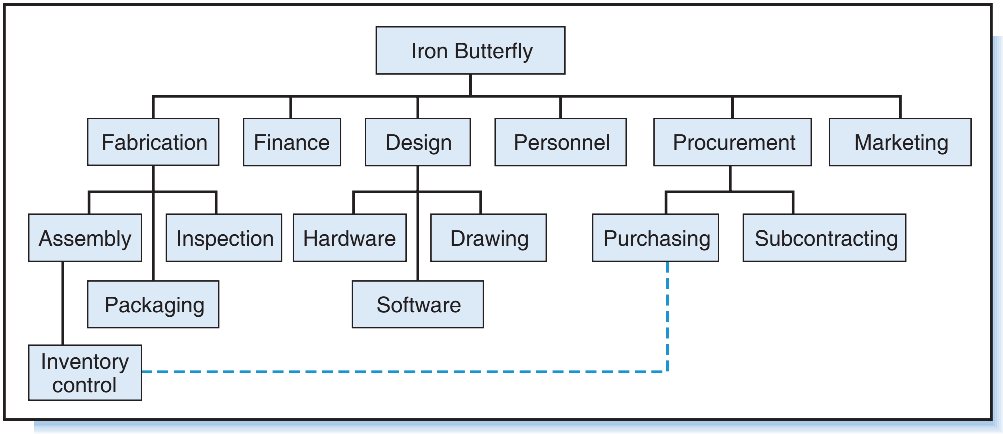


Figure 15.3
Liaison role linking Assembly and Purchasing departments.

Both the team leader and members are selected by (and the leader reports to) whoever initiated or sponsored the project—a functional manager, vice president, or CEO. Team leaders are responsible for expediting and coordinating the efforts of the team, and they may have authority to direct tasks and to contract out work. Usually, though, they have little formal authority over team members, who, often, divide time between the task force and their "usual" work. Task forces undertake an unlimited variety of projects and special assignments, including the following:

- Company reorganizations
- Mergers, acquisitions, or divestitures
- Special studies, surveys, or evaluations
- Major audits
- Efficiency, modernization, and cost reduction efforts
- Geographic or marketing expansions
- Facility relocations or changes in facility layout
- Management and organization development programs
- New equipment or procedures installation.

Ideally, the task force members have access to information relevant to the project plus authority to make commitments for their functional areas. Lacking information, the group cannot make good decisions; lacking authority, the group will not be able to act on its decisions.

For problems that are novel but need *continuous* attention, *permanent teams* are formed. These teams have the same characteristics as task forces except that they convene periodically on a regular basis, indefinitely. For example, if Iron Butterfly Company makes products that require design changes throughout the year in response to changing markets and competition, then representatives from design, fabrication, procurement, and other areas will need to meet face to face on a regular basis to make decisions regarding these changes. Members work on the team either part-time or full-time.

Most projects involve several kinds of teams; some convene during a single phase of the project life cycle, others for the entire project. An example of the latter is the *change control board* discussed in Chapter 13, a multifunctional team that meets periodically to discuss and approve project changes.

See Chapter 13

Sometimes it is difficult to find people with the requisite knowledge, authority, and inclination to serve on multifunctional tasks forces and teams. People develop attitudes and goals oriented toward their specialization, and although this helps them be effective in their own areas of work, it limits their ability to work with people from other areas. For multifunctional projects, the team-building methods described in Chapter 17 help break down barriers and forge bonds between project team members.

15.6 Project expeditors and coordinators

The simplest kind of project organization is a single, small group of people, a task force or team formed on a full- or part-time basis to perform an assignment. Such a group can exist inside one functional area or span across multiple functional areas.

Projects within one functional area

It makes sense that a project that affects or requires expertise from only one functional area should be located in that area. For example, a project to survey customer attitudes about a new product would ordinarily be placed entirely within the marketing department, as indicated in Figure 15.4, because all the necessary resources and expertise are there. The team does everything—prepare the survey instrument, obtain mailing lists, distribute the survey, and process the results. A project team like this is managed by a *project*

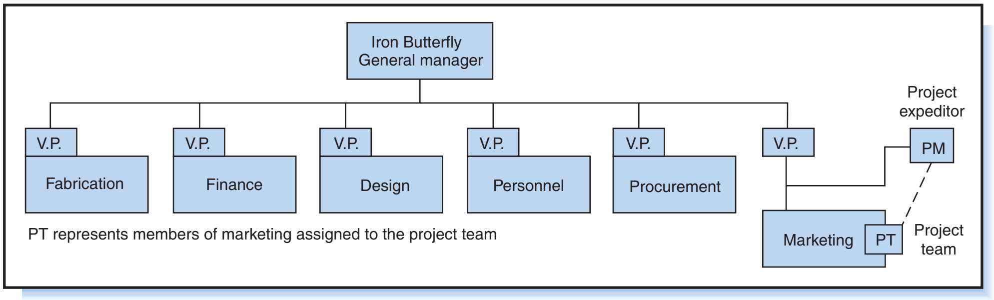


Figure 15.4
Project expeditor within a single functional area.

expeditor,[4] someone selected by the manager of the area wherein the project lies. The expeditor coordinates decisions, creates and monitors schedules, and keeps the project moving and the manager updated about progress. The expeditor, however, typically has no authority over team members and so must rely on persuasion, personal knowledge, and information about the project to influence team members. A large organization might have over 100 such projects being conducted in its functional departments at any given time.

Multifunctional project teams

An example of a project that might use a *multifunctional team* is one to develop an enterprise resource planning (ERP) system, which is a companywide system that connects information about forecasting, sales, scheduling, order entry, purchasing, and inventory. The team, which might be called the "ERP Task Force," would include representatives from all the departments that must provide inputs to the system or would utilize its outputs, such as accounting, inventory control, purchasing, manufacturing, engineering, and IT. Representatives from suppliers and customers might also be on the team. The team is responsible for defining the system requirements and overseeing the development and installation of the system.

Multifunctional project teams are not associated with any one particular functional area (they are multifunctional), and they report to a higher-level manager, as shown in Figure 15.5, which imputes

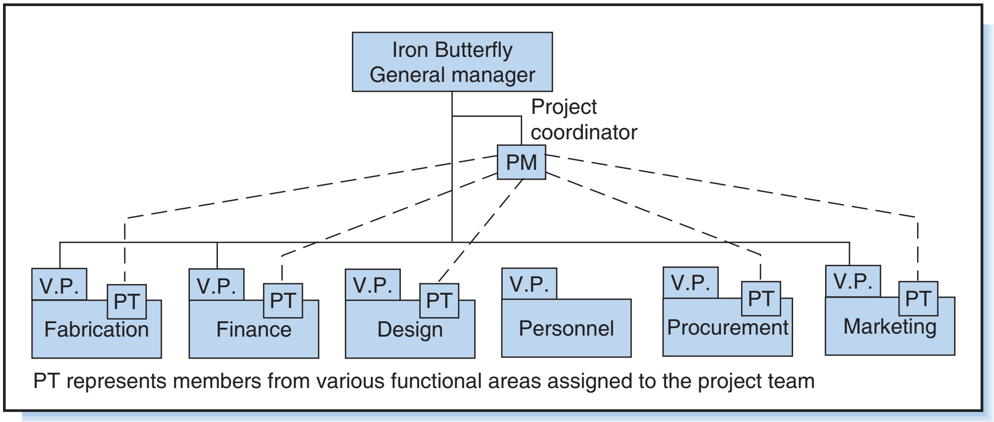


Figure 15.5
Multifunctional project team.

greater importance to the project. The person managing such a project is designated the project *coordinator*. The coordinator has no line of authority over team members but does have authority to make and execute decisions about project budgets, schedules, and work performance. The coordinator's influence originates in his reporting to a high-level general manager and, like that of the expeditor, his knowledge of and central position in the project.

Multifunctional teams are commonplace in product development. By forming closely knit teams of engineers, designers, assemblers, marketers, suppliers, dealers, and customers, phases of the systems development cycle can be done simultaneously instead of sequentially. This approach, called *concurrent engineering*, eliminates cross-functional barriers and can result in higher quality and lower cost. Concurrent engineering is discussed later in this chapter.

15.7 Pure project organizations

Projects that involve much complexity, major resource commitments, and high stakes require a *pure project* or *projectized* form of organization. A pure project is a separate organization, sometimes its own company, created especially for and singularly devoted to achievement of the project goal. Whatever is needed to accomplish project goals—all necessary human and physical resources—is incorporated into the pure project organization. Often, within the pure project organization are liaisons, task forces, and teams.

Heading the pure object organization is the *pure project manager*. Unlike a coordinator or expeditor, the pure project manager has formal authority over all people and physical resources assigned to the project and thus maximum control. The project manager can bring in resources from internal functional areas as well as contract out with external subcontractors and suppliers. The pure project manager is involved in the project from start to finish: during proposal preparation, she requests and reconciles plans from functional areas and prepares preliminary budget and schedule estimates; after project acceptance, she hires personnel; during project execution, she allocates resources and approves changes to requirements and the project plan. When personnel must be "borrowed" from functional areas, she negotiates to obtain them.

When external resources are required, the project manager heads selection of and negotiations with subcontractors. She oversees and coordinates their work with other areas of the project. The project managers in the Delamir Roofing, disaster recovery, and NASA examples in Chapter 1 are pure project managers.

See Chapter 1

Besides providing for project focus and control, the potential advantages of pure projects organization include higher team spirit, speed of execution, fast decision-making, flexibility, and autonomy (less subject to bureaucracy).

Pure project variations

Three common variations of the pure project structure are the *project center*, the *partial project*, and the *stand-alone project*.

In the *project center*, the structure of the parent organization remains the same, except for the addition of a separate "project arm" and project manager. This form is shown in Figure 15.6 for the Iron Butterfly Company, which has two pure-project arms, LOGON and SPECTOR. (Organizations, unlike people, can have any number of such arms, one for each of however many projects they have.) Resources and personnel are borrowed from functional and staff areas to work in the project center for as long as needed. General Motors used a project center when it chose 1,200 key people from various divisions for the task of downsizing vehicles in all of its automotive lines. The project center developed suggestions, turned them over to the automotive divisions for implementation, and then disbanded. In another corporation, a project center was used to oversee the relocation of the corporate offices.

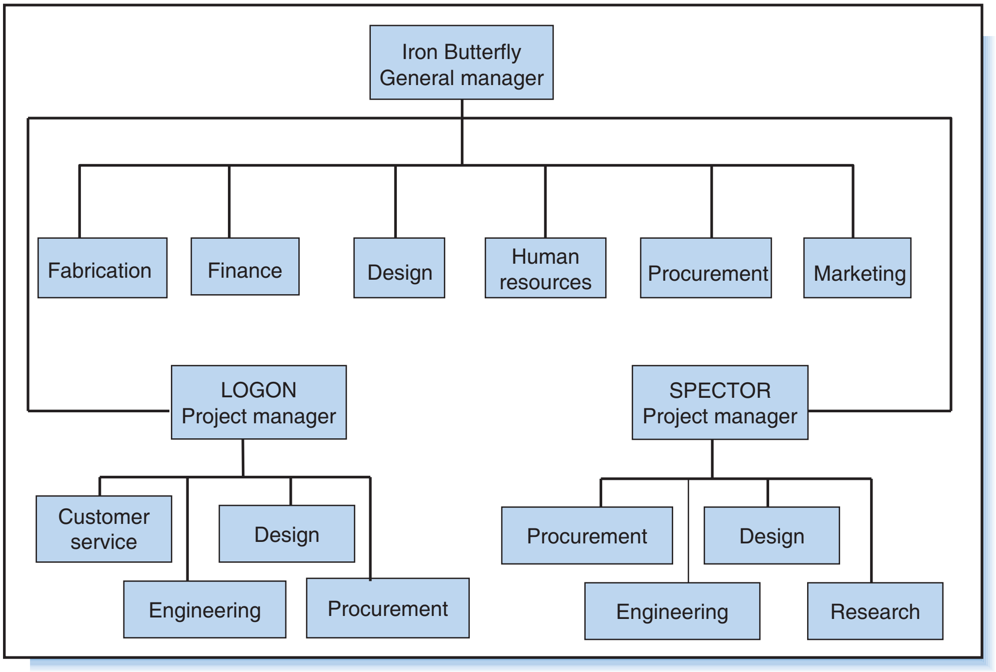


Figure 15.6
Pure projects as “arms” to the functional organization.

The project center worked full-time to address the tricky problems of relocation, while the rest of the organization continued to work as usual.

In a *partial project*, the functions critical to the project (such as construction or engineering) are assigned to the project manager, while other, support-oriented functions (such as procurement and accounting) remain within functional areas of the parent organization. The manager of a partial project directly controls all major project tasks but receives assistance from functional areas in the parent company providing support. In Figure 15.6, for example, the LOGON project manager might fully control design and procurement but rely on the functional areas of finance, human resources, and marketing for support.

The *stand-alone project* is an entire organization created especially for the purpose of accomplishing the project. It is typically used for large-scale government, public works, or development and installation projects that involve one or more prime contractors, dozens of subcontractors, and numerous supporting organizations, suppliers, and consultants. The International Space Station development program, Quebec’s La Grande hydroelectric complex, the Channel Tunnel, China’s Three Gorges Dam, and Boston’s Big Dig are examples. When the project is completed, all that might remain of the organization is a function to operate the system; the rest of it dissolves. Stand-alone projects are discussed later in this chapter in the section on concurrent engineering.

Disadvantages

The chief disadvantage of the pure project organization is its *cost*. Because each pure project is a completely or partially independent organization, it must be completely or substantially staffed. Each project becomes a self-contained empire, and there is often little sharing or cross-utilization of resources with other projects. Companies conducting multiple pure projects may incur considerable duplication of effort and facilities and high overheads. In Figure 15.6, for example, the LOGON and SPECTOR projects each has its own design and procurement functions, and those are in addition to the design and procurement functions of the company.

To ensure that resources will be available when needed, pure project organizations must begin acquiring them in advance of the project. One of the authors was among numerous engineers hired in anticipation of a large government contract to ensure the project could begin as soon as the contract was signed. But the company didn't win the contract, and everyone assigned to the project had to be transferred elsewhere or laid off. The payroll loss alone amounted to many hundreds of man-months.

In most organizations, the functional manager is the driving force behind workers developing their technical competencies. Most functional managers encourage their professional workers to expand their capabilities, and they back it up with raises and promotions. But in a pure project organization, there might be no functional managers and hence no one to emphasize competency development. The usual tactic of the project manager is, lacking suitable in-house technical competency, to contract out the work. While this suits the project's needs, it represents a missed opportunity for the organization to develop its own in-house expertise. Further, those workers that do have considerable competency often resign after completing what they consider the interesting part of the project because they cannot foresee what they'll be doing next in the project—or even what the next project will be.

This suggests still another cost: outplacement. Whenever there is no follow-up work, the pure project organization faces the problem of what to do with its workforce after the project ends. Personnel who have worked on long-term projects often become so specialized that they cannot be placed in projects requiring more generalized or up-to-date skills.

Pure project organizations are strictly temporary; as the project draws to a close, uncertainty about the fate of the team grows, and morale and enthusiasm decline. A project manager may become so preoccupied with generating new contracts or finding a job for himself and his team that he becomes neglectful of his closeout responsibilities for the current project.

15.8 Matrix organizations

The pure project form often provides the only way to do large-scale, one-time projects; however, its disadvantages make it impractical for industries that *continually* operate on a project basis. Such industries include: architecture and construction, where every building, bridge, or highway is a project; product development, where every product design, manufacture, and promotion is a project; IT, where every hardware and software installation is a project; law and accounting, where every litigation and audit is a project; and aerospace, where every new aircraft and space system is a project. Most of these projects are too large, too complex, and have too much at stake to be handled by task forces. In addition, businesses in these industries are involved in many projects at a time—they are *multiproject* organizations—and they need the capability to create large project teams quickly without the personnel and cost disadvantages associated with pure project organizations.

To achieve this capability, the *matrix* form of organization evolved. First adopted in the aerospace industry by firms such as Boeing and Lockheed-Martin, the *matrix*, illustrated in Figure 15.7, is a grid-like structure of authority and reporting relationships created by the overlay of a project organization onto a traditional, functional organization.[5] This overlay gives the matrix four unique capabilities.

First, the functional part provides the pool of technical expertise and physical resources needed by projects. Each project manager creates a project team by negotiating with functional managers to "borrow" the skilled workers and physical resources needed for her project. Each project is composed of workers who are on loan to work on the team during the course of the project. This sharing of the same workforce across several projects reduces duplication of effort.

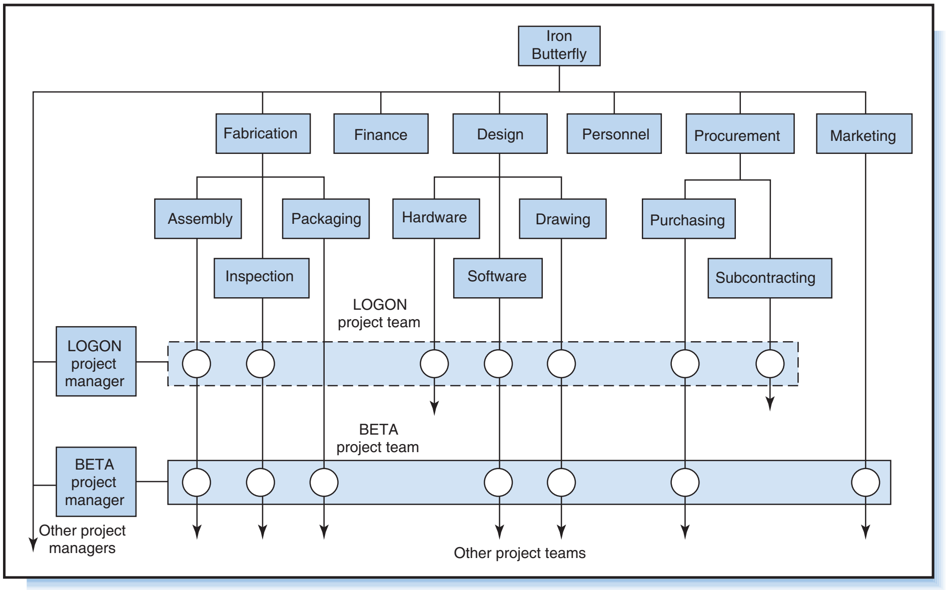


Figure 15.7
Matrix form of project organization.

Second, while in their "functional homes," workers associate with colleagues in their fields of specialization; this not only keeps them current in their profession or trade but makes them more assignable to new projects. Each functional area has, at a given time, many individuals working on different projects, sharing ideas, and exchanging points of view. This makes all of them more effective in their respective projects.

Third, when their assignments are fulfilled or their projects are completed, workers return to their functional areas for new assignments. This eliminates anxiety and reduces fluctuations in workforce levels and worker morale.

Finally, while managers of functional areas provide resources and technical support to each project, one person, the project manager (or *matrix manager*) oversees the resources and unifies and integrates their efforts to achieve project goals.

Although the matrix structure shares the virtue with pure-project organizations of having dedicated resources and a project manager to give the project direction, the project manager's range of authority within the matrix can vary considerably. The Project Management Institute distinguishes matrix organizations as "strong," "weak," or "balanced." In a strong matrix, project managers have substantial authority; they control project funds and other resources and devote most or all of their time to managing each project. In a weak matrix, project managers are actually coordinators or expeditors who, as explained before, are not quite fully fledged project managers and must fit the role into their other, usually non-project, work. They coordinate project work being performed by the contributing functional areas but have little authority, no budget responsibility, and no ability to command resources on their own; project work within the functions is overseen by the functional managers. In the balanced matrix, the managers are fully fledged project managers, but their level of authority and control over budgets and resources is less than in a strong matrix and is shared with functional managers.

In a strong matrix organization, prioritizing and balancing the resources shared by the different projects is the responsibility of the *manager of projects* or the *PMO director* (the "vice president of projects" in Figure 15.8). The manager of projects attempts to meet the requirements of current and upcoming

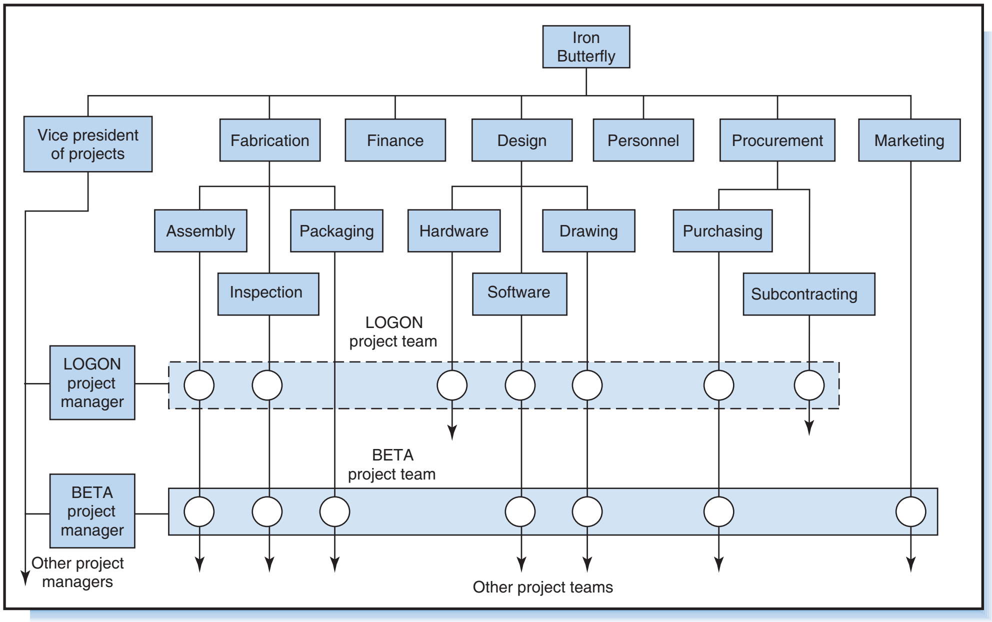


Figure 15.8
Location of the vice president of projects in a strong matrix organization.

projects, resolves resource conflicts between projects, and relieves top management of project operations responsibility. The PMO is discussed later.

Problems with matrix organizations

The main benefit of the matrix organization—its combined vertical-horizontal structure—is also the main source of its problems.[6] The matrix is not just a structure but a whole different way of doing things. Most organizations are accustomed to hierarchical decision-making and vertical information flow. With its emphasis on horizontal relations, lateral information flow, and decentralized decision-making, the matrix is clearly contrary. It superimposes a horizontal team system on a vertical functional system, and companies that adopt the structure must add horizontal information processing systems to existing vertical accounting and command systems. It can be done, but it tends to be difficult and expensive.

In human terms, the drawback of the matrix is that it induces conflict. Theoretically, the matrix promotes coordinated decision-making among functional areas and enables tradeoff decision-making for the benefit of the projects. It assumes, however, that a balance of power exists between functional and project managers. Often, however, authority in the matrix is unclear, and functional and project managers jockey to control one another. In multiproject organizations, functional managers control project resources, so conflict arises over which project gets priority and which project managers get the best resources.

The matrix structure attempts to be the best of both worlds—functional and projectized—but it falls short. Its main problem is rooted in something few people like to admit—fear and power: functional managers fear that project managers (who are sometimes perceived as having the more interesting and challenging work) might take control of "their" resources and reduce their roles to mere "support/staff" functions. They become even more worried when the vice president of projects controls project funding and threatens to outsource work normally provided by their areas. Project managers get frustrated, too, because, unlike functional managers, they have little or no control over workers because they have no say over worker incentives such as promotions, salaries, and bonuses.

There are no easy solutions to these problems, but as a start, everyone must understand their roles: the project manager should have a say over *what* must be done, and the functional managers should have a say over *how* it must be done (and, to a large extent, *who* within the function should do it).

Here is another problem: each project worker in the matrix has at least two bosses, a functional manager *and* a project-matrix manager; this violates a major principle of management: single chain of command. The project manager directs the worker on a project, but the functional manager evaluates the worker's performance. The inevitable result is role conflict and confusion: to whom should the worker give allegiance, the project manager or the functional manager?

To avoid conflict and confusion in the matrix, everyone—managers and workers—must be clear about their roles, and the organization must establish clear priorities. Boeing, for example, which has used the matrix successfully for years, sets priorities day to day: people operate *either* in a project team *or* in a functional area, and they put priority on whichever area they are in.[7]

The matrix can lead to still other dilemmas, explained next.

Example 15.1: Two-Hat Problem

The matrix structure requires *a lot* of managers, yet in many organizations, managers are scarce. One solution is for managers to wear two hats—one as project manager, the other as functional manager. While wearing the functional hat, the manager allocates resources to different projects; the problem is, while wearing the project hat, it is hard to convince other project managers that he hasn't grabbed the best resources for the projects that *he* is managing. Also, to people from his department who are working on his projects, the "project hat" is invisible. All they see is that "functional hat," ever mindful of the fact that he controls their wages and promotions; as a result, they *always* prioritize his projects over others they might be working on.

Any attempt to adopt a matrix structure must be accompanied by both attitudinal and cultural changes, which are difficult to achieve. In many companies, conflicts over priorities and resource allocation are eliminated or reduced by the PMO, which sets the priorities and assigns resources. Even with a PMO, however, anxiety and conflict remain common maladies of the matrix structure.

15.9 Selecting an organizational form for projects

Project managers are seldom involved in designing the organizational structures of the projects they lead, yet they can offer suggestions to the managers who do. It is impossible to state which organization form is always best, but general criteria help specify which form is most appropriate for a given project. Figure 15.9 shows the approximate applicability of different project organizational forms based upon four criteria:

- Frequency of new projects (how often, or to what degree, the parent company is involved in project-related activity).
- Duration of projects (how long a typical project lasts).

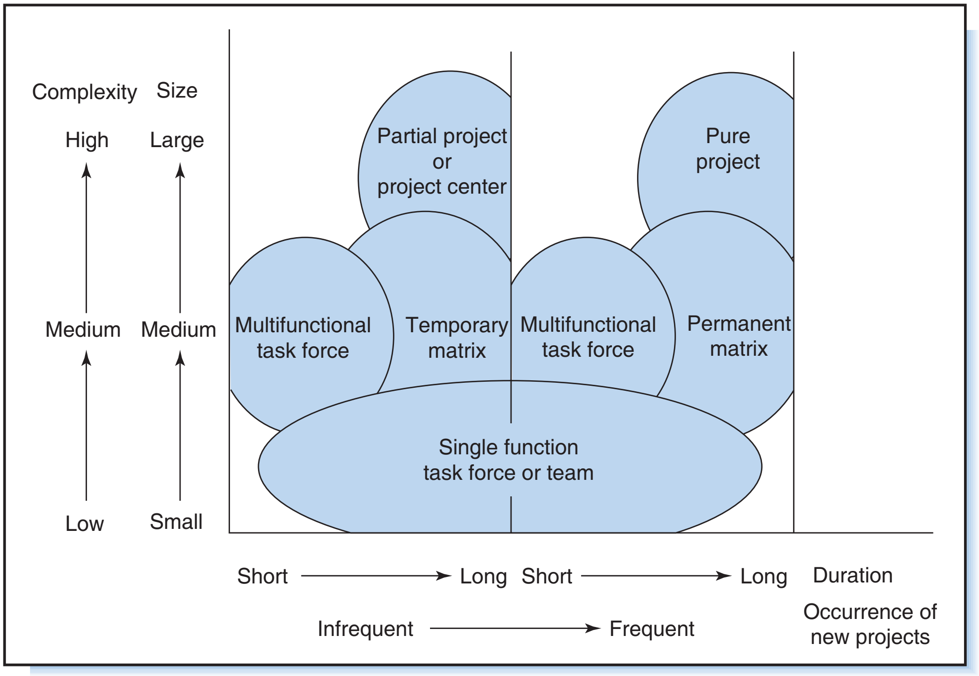


Figure 15.9
Criteria for selecting the appropriate project organizational form.

- Size of projects (level of human, capital, or other resources in relation to other activities of the company).
- Complexity of relationships (number of functional areas involved in the project and degree of interdependency).

Matrix and pure project forms are applicable to projects of medium and higher complexity and of medium or larger size and in companies that are always doing projects. These kinds of projects require large amounts of resources and information and need project managers and integrators with strong authority. In particular, the matrix works best where a variety of different projects are being done concurrently and all can share functional resources on a part-time basis. In contrast, when there is less variety between projects, when specialists must be devoted full-time, and when high-level project authority is desired, then the pure project form is better. Both forms are applicable where projects are the organization's "way of life."

For smaller projects that involve several functional areas, task forces and cross-functional teams are more appropriate. Part-time task forces managed by expeditors can effectively handle short-duration projects involving one or a few functional areas. When several areas are involved, a multifunctional task force led by a coordinator who reports to the general manager is more suitable. Projects of longer duration but small scope are best handled by full-time project teams with coordinators. When the team size needed to accomplish the task becomes large and the interrelationships complex, then a temporary matrix or partial project should be set up. Teams, task forces, and project centers are appropriate when the existing structure and work flow of the organization cannot be disrupted.

In selecting a project form, consider the relative importance of the following criteria: the stake of the project, the degree of technological uncertainty, the criticalness of time and cost goals, and the uniqueness of the project.[8] For example, task forces and teams are generally appropriate when the project task is highly certain and involves little risk and when time and cost are not major factors. When risk and uncertainty are great, when time and cost goals are critical, or when much is at stake, matrix and pure project forms better afford the obligatory high level of integration and control. When a project differs greatly from the normal business of the firm, it should use a partial or full pure project form.

These considerations all relate to the project itself, which, in fact, is sometimes less important than attributes and experiences of the parent company. For example, matrix and pure project forms are seldom found in small organizations, which usually don't have sufficient resources and managers to commit. Top management's attitudes about the appropriate level of responsibility and authority for the project manager also matter. The most important factor is the company's experience with projects and management's perception of which project forms work best. Firms with little project experience avoid the matrix because it is difficult to adopt. Faced with a complex project, they adopt a partial or project center approach.

Most organizations are involved in a variety of projects and use a variety of different project forms, whatever best suits each project. In a given organization, much or most of the work might be done by matrix teams, but a few high-visibility projects will be set up as pure projects. Meantime, within functional departments, innumerable small, single-function projects are being conducted, and scattered elsewhere are project task forces. Within a given project, a *composite* structure might be created, that is, a structure that combines features of a functional, matrix, and pure-project forms, depending on the scope and kinds of work in the project. At Microsoft Corporation, for example, the organizational structure of development projects mirrors the products they produce.

Example 15.2: Product Development Organization at Microsoft[9]

A software product-development project at Microsoft might involve 300 to 400 people, including specialists in product specification, development, testing, user education, and planning. Program managers and developers divide the product into "features," where each feature is a relatively independent building block that will be apparent to customers (e.g. printing, adding a column of numbers, or interfacing with a particular brand of hardware). They then divide the project organization into development teams, where each concentrates on one or some of these features. In essence, the project is divided into small, feature-driven projects that mirror the structure of the overall product. Through this feature-driven organization, product functionality can be increased simply by adding more development teams: the more features desired in the product, the more teams assigned to the project.

Each team consists of three to eight developers, one of whom is the "lead." The lead reports to the project's development manager, who has a broad view of the product and interconnections among its features. A recent version of Excel had ten feature teams: eight worked on the basic Excel product, one on a graph product, and one on a query tool product. Paired with each feature development team are parallel teams responsible for feature testing and user education.

Each feature team has considerable autonomy, though it must follow rules so its work stays coordinated with the other teams. Each team is expected to "build" and have checked a certain amount of code each day. This forces the teams to synchronize their work at the pace of the overall project.

Microsoft's philosophy for organizing projects is that a product tends to mirror the organization that created it. A big, slow organization will create a big, slow software product. A small, nimble group in which everyone gets along well will create pieces of code that work together well, which is why Microsoft uses small, flexible teams.

15.10 Project office and project management office

The term *project office* has dual meaning: it can refer to a support staff group that assists in project management and reports to the project manager, and it can be a physical place where the project team meets. Our discussion here will focus on the *project support staff*.

The purpose of the project office is to *coordinate* work efforts and advise the different functional areas and subcontractors on *what* they should do in the project (but not *how* they should do it). The office is responsible for planning, directing, and controlling project activities and for linking the project teams, users, and top management. When projects are small and procedures are well established, the office might consist of just one person, the project manager. When the office must coordinate multiple projects, the staff is larger and comprises what is called the *office of projects* or, more commonly, the *project management office*. The PMO is a support office that develops project management policy and methodology, offers training, and provides various services to project managers, as described in Chapter 18.

See Chapter 18

Functions of the project office

The functions and composition of the project office depend on the authority of the project manager and the size, importance, and goal of the project. The project office shown in Figure 15.10 is for a large-scale engineering development project. Among the functions shown is planning and control. During the conception and definition phases, this function prepares the WBS, schedules, and budgets. During execution, it monitors work, forecasts trends, updates schedules and budgets, and distributes reports to functional, upper-level, and customer management.

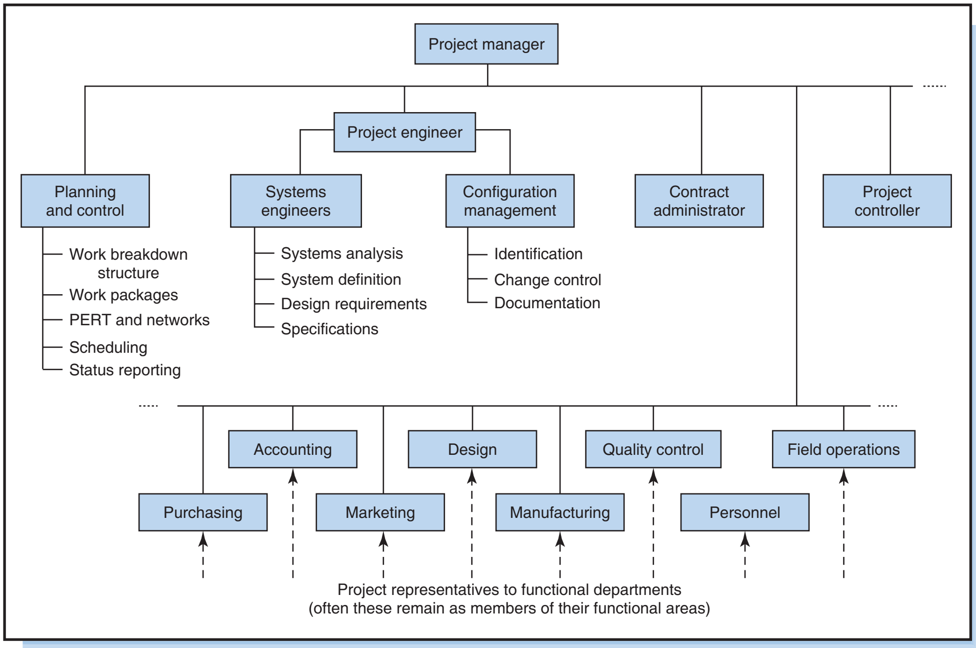


Figure 15.10
Project office for a large development project.

See Chapters 4, 10, and 13

Also shown are functions for systems engineering and configuration management, both headed by the project engineer. The systems engineering function oversees systems analysis, requirements definitions, and end-item specifications (discussed in Appendix A to Chapter 4) and furnishes inputs for planning and control. Configuration management (discussed in Chapters 10 and 13) defines the initial product configuration and controls changes in product and system requirements and project plans. As shown, the project office also handles contracting and financial control.

Integrating the functions within a project is achieved by structuring the project office to mirror the functional areas the project office must integrate.[10] This happens by including in the office a representative from each functional area working in the project (in Figure 15.10, purchasing, accounting, etc.). Although each representative is a specialist in a functional discipline, while in the project office, his primary role is to integrate that discipline with the others. As a result, through *coordinating and integrating the functional representatives* in the project office, the work of the functional areas in the project is coordinated and integrated. Usually members of the project staff are co-located in the same physical office where they can intermingle face-to-face. In smaller projects, the size of the project office can be reduced by allowing some or most of the functional representatives to remain in their functional areas.

Office of projects, project management office, and program office

Multiproject organizations also have an *office of projects* (not to be confused with the project office), PMO, or program office. This was shown in Figure 15.8 as the "vice president of projects." In pure project organizations, the office is located at a level between senior management and project managers (in Figure 15.6, it would be located below the general manager and on the line connected to the LOGON and SPECTOR projects). When projects are small, the office of projects substitutes for individual project offices and handles proposals, contracting, scheduling, cost control, and report preparation for every project. When projects are large or overlap, the office of projects or PMO is used in *addition* to project offices and coordinates the combined requirements of all the projects.[11]

See Chapter 18

When projects are part of a program, *a program office* is established to ensure that the projects supplement one another and "add up" to overall program goals. The program office (discussed in Chapter 18) handles interfaces and integration between projects and with external resources for each project, maintains customer enthusiasm and support, and keeps project managers informed of potential problems. The NASA program office described in Chapter 1 is an example. When programs are very large, the integration work of the program office is supplemented by outside "integration contractors," discussed next.

15.11 Integration in large-scale projects

In a large-scale project (LSP) or *mega project*, numerous parties—sponsors, prime contractors, subcontractors, consultants, and suppliers—all contribute to one effort. Figure 15.11 shows the principal contributors and relationships in an LSP. Relationships are complex, and lines of authority connecting the parties are often weak, sometimes based entirely on contracts and purchase orders. If Figure 15.11 appears somewhat confusing, well, that simply reflects the fact that relationships in LSPs *can be* confusing. Examples of LSPs include space systems (e.g. the International Space Station), construction projects (Canada's La Grande hydroelectric venture, Holland's Delta flood control project, the Channel Tunnel, China's Three Gorges Dam), company relocations (involving the client, movers, construction companies, recruiters, consultants, and suppliers), and corporate mergers (dual sets of clients, consultants, and attorneys).

Notice in Figure 15.11 the direct relationships, both horizontal and hierarchical, among different contributors' managers as well as between their functional areas. Such relationships between, for instance, design groups from the sponsor and its contractors and subcontractors, helps speed up decision-making and tighten integration. The relationships between contributors are facilitated by project managers, coordinators, expeditors, liaisons, and task forces.

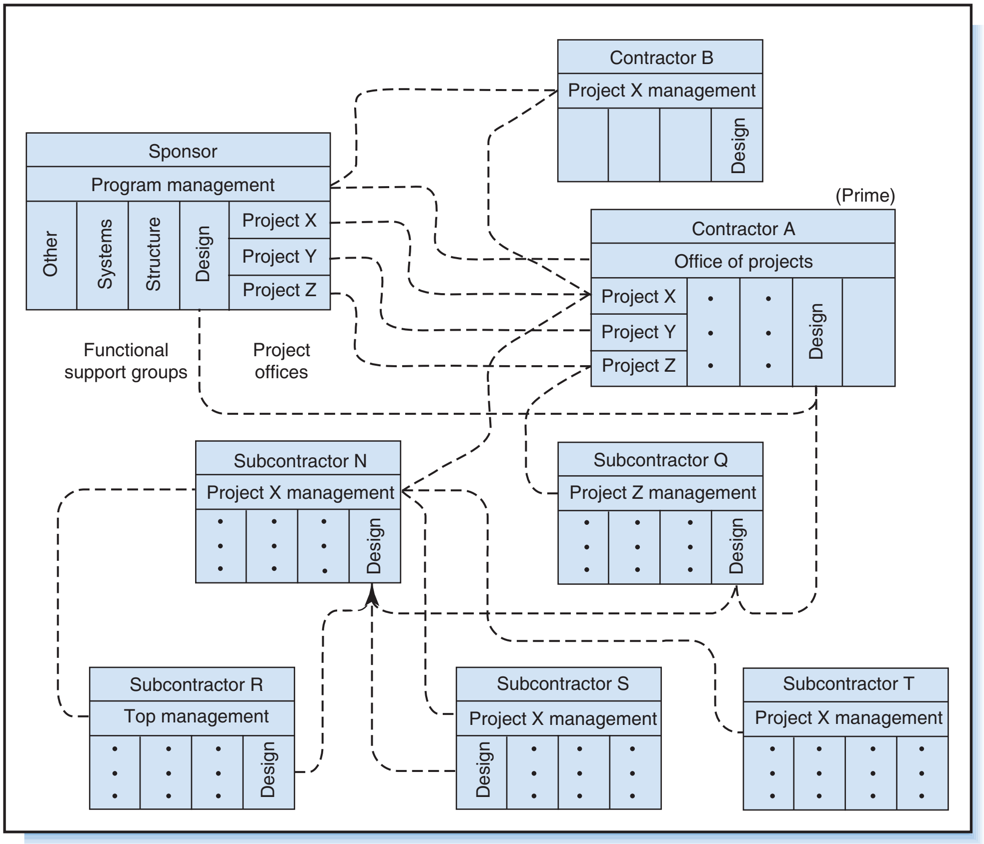


Figure 15.11
Integration relationships in a large-scale project.

Most LSPs are devoted to development and/or construction of complex systems. The total effort is subdivided among a number of contributors, each responsible for a specific subsystem or component that must be integrated with others to form the overall system. Figure 15.12, for example, shows the major components in the International Space Station. The figure is simplified and does not show major elements of the program such as launch vehicles to place the components into Earth's orbit; ground support systems; and the numerous organizations that work to develop, produce, integrate, and operate the components (prime contractors, subcontractors, and suppliers).

Oversight and integration contractors

In public works and government projects, integration is usually the responsibility of the sponsoring agency. Sometimes, however, the engineering and management tasks are quite difficult or extensive, and outside help is required.

Among the first LSPs to experience the integration problems inherent to large systems were weapons system development projects during World War II.[12] For instance, separate offices within the Army Air Corps purchased the components that made up a bomber aircraft, and these components—airframe, engines, and electronics—were then furnished to and assembled by the aircraft manufacturer. As systems grew more complex, this approach no longer worked. Sometimes the component interfaces

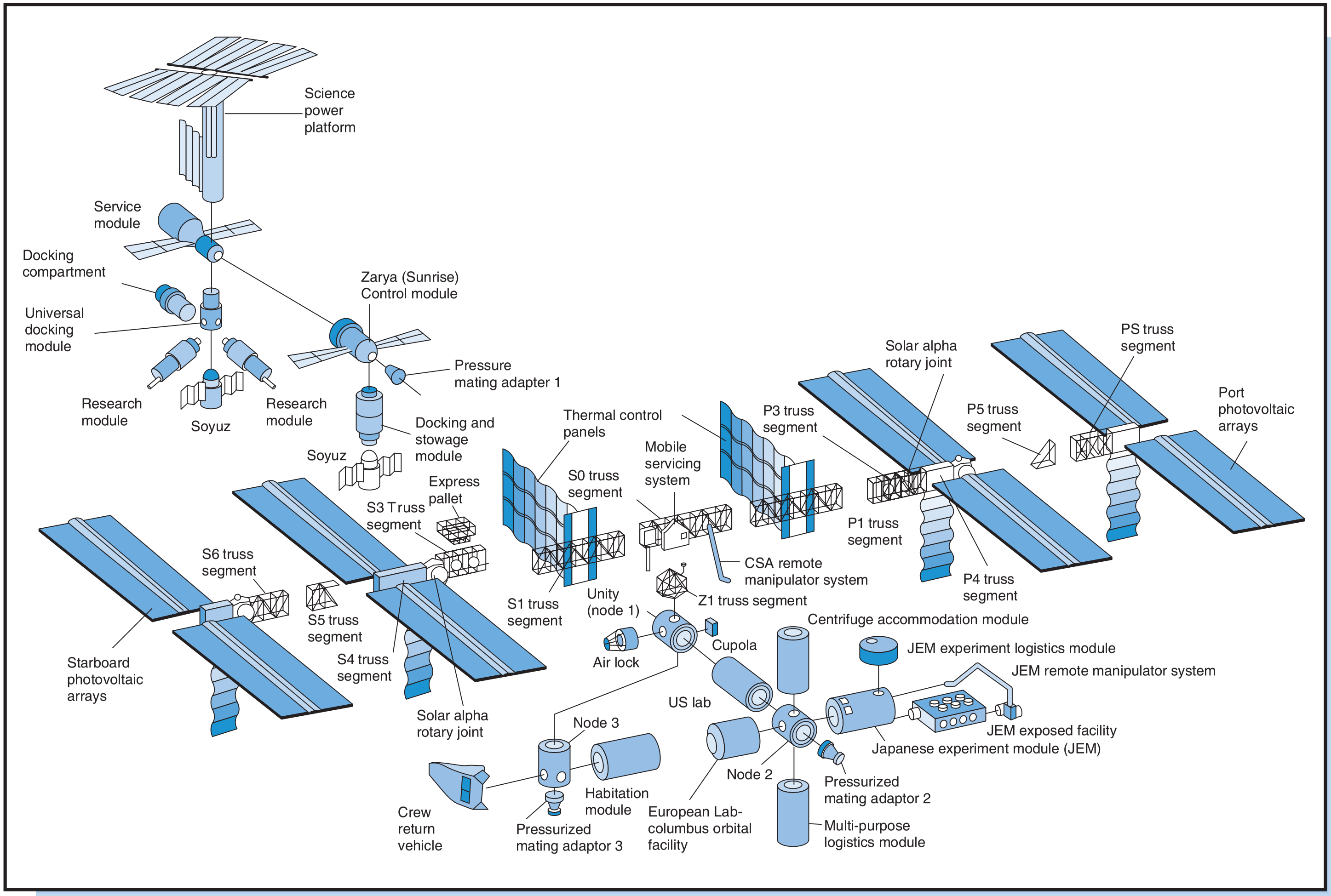


Figure 15.12
Major components in the hardware and assembly of the international space station.

(connections) were different, so plugs and fasteners would not fit together, or the sizes of the components were different than planned and the entire system had to be redesigned to accommodate them. To overcome these difficulties, the military formed technical groups to coordinate component interfaces, but this resulted in massive red tape and only worsened matters, as explained by Livingston:[13]

> A contractor wanted to change the clock in an airplane cockpit from a 1-day to an 8-day mechanism. It wrote a request and gave it to the military representative, who forwarded it to the military technical group. The tech group reviewed the request and asked the contractor for a more detailed request. The contractor revised the request and resubmitted it. The tech group approved the request and sent it to the change committee. The change committee reviewed and accepted the change, then sent written authorization back to the representative, who forwarded it to the contractor. In all, this simple change request took *3 months* to approve.

Today, integration is expedited by giving integration responsibility to a single "oversight" body, usually the *lead* or *prime* contractor (the "prime"), a role similar to that of a wedding consultant or general contractor but on a larger scale. The project sponsor is still responsible for contracting with *associate* contractors (subsystem producers), making major decisions, and resolving conflicts between the prime and associates. The associates become subcontractors ("subs") to the prime contractor, take orders from the prime, and are subject to its surveillance and approval. Figure 15.13 shows the relationships among the sponsor, prime, and subs for an urban transit project.[14]

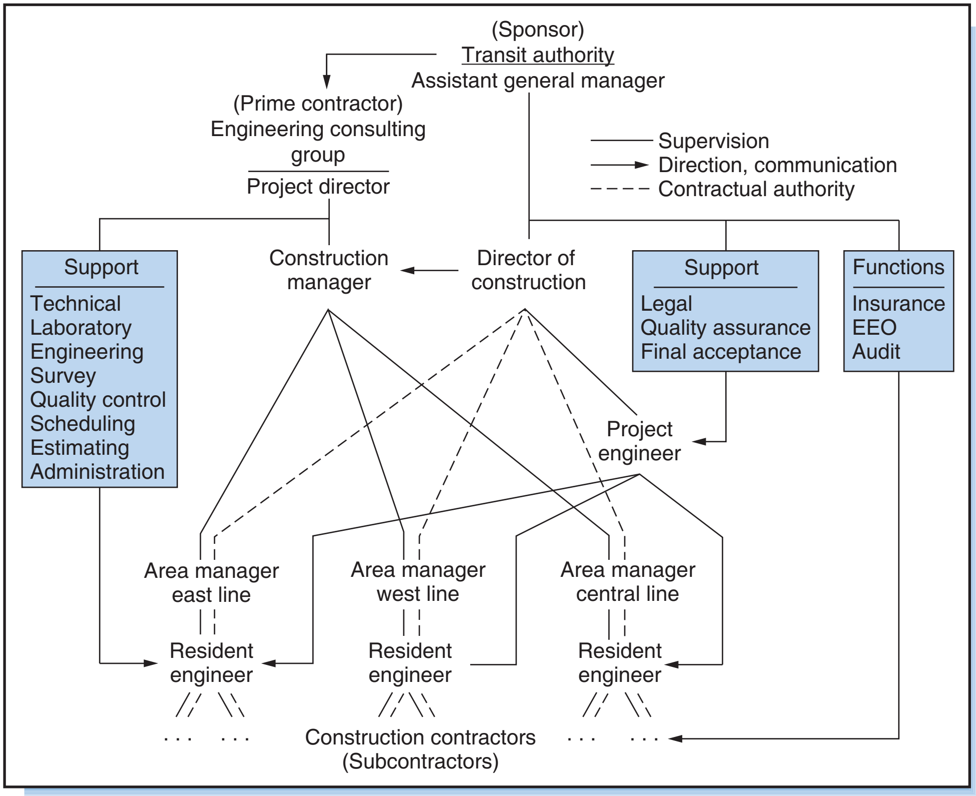


Figure 15.13
Management and authority relationships in a large construction project.

Sometimes the prime is conferred even greater responsibility, such as assisting the sponsor in selecting associates, pricing of subsystems, and allocating project funds. This situation poses a problem when the prime and the subs are competitors, since, understandably, subs are hesitant to divulge innovative design concepts or subsystem details, even though the prime needs to know those things to integrate the subsystems.

Sometimes even the largest prime contractors aren't big enough. At such times, they form teams ("joint ventures") and submit joint proposals where one company serves as leader and takes on responsibility for systems engineering and management of the others. This appeals to small- and medium-sized firms that ordinarily would not have the resources to contract independently. With this approach, however, unless the lead company is strong, there could still be interface problems. But no company is likely to have all the best ideas, and the sponsor may require the lead firm to open up development of subsystems to competitors and, if necessary, change the companies of the team.

When the prime contractor lacks the capability to perform all the integrating work, a separate consulting firm or *integration contractor* is engaged entirely to provide integration and engineering advice.[15] These contractors, which sometimes employ thousands of workers, are able to quickly pull together all the necessary resources. The problem is that they often operate in the same business as the contractors they are responsible for integrating, which puts them in the awkward position of managing their competitors and being able to learn their secrets.

Example 15.3: Corporate Merger—Large-Scale Non-Technical Project[16]

Special integration management is necessary not only for technical projects but any *large, complex* project. When one of the United States' largest pharmaceutical firms acquired one of Europe's largest pharmaceutical firms for $6.9 billion, an acquisition that involved 10,000 people, 18 manufacturing locations, and 30 international affiliates, it engaged a well-known global consulting firm to oversee the integration effort. The consulting firm established a program management office and a global acquisition integration management (AIM) team with 18 full-time director-level individuals from the US corporation. The AIM team's purpose was to plan, manage, and execute the integration of all divisions and functional areas of the corporation. This team went on to create other teams, eventually numbering 24 and including more than 500 people from both companies. The consulting firm formed the teams, structured the work of the teams, participated in their major decisions, monitored critical path activities, and consulted with the European firm's managers and functional areas. By engaging the consulting firm as integration contractor, the project benefited from the best practices and lessons learned through the consultant's many years of merger and acquisition experience—experience that the two pharmaceutical giants lacked. The project structure, consisting of the consulting firm, AIM teams, and other teams, was a pure-project organization devoted entirely to the corporate merger.

15.12 Integration in systems development projects

Project integration can be conceptualized in two ways: integration of the functional *areas* of the project organization and integration of the *phases* of the project. The former, and the subject of the chapter thus far, is called *horizontal integration;* the latter is called *vertical integration* (Figure 15.14). The two ways are interrelated because integration of the project phases also usually requires integration of the functional areas working within the phases.

Large-scale product and software development projects require the integrated efforts of many functional units throughout conception, definition, design, testing, production, and installation. Achieving the necessary high-level integration can be difficult and does not always happen.

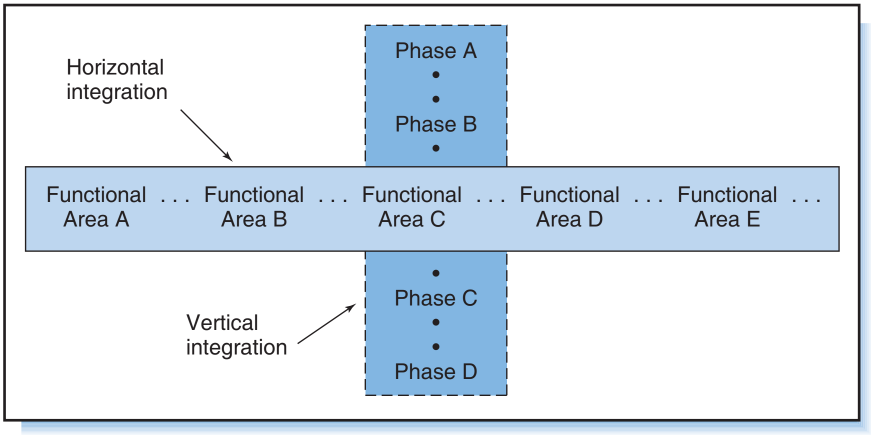


Figure 15.14
Horizontal and vertical integration in systems development projects.

Nonintegrated (serial) systems development

In a traditional development project, a different functional group is responsible for each project stage. For example, the marketing group specifies the initial concept and user requirements, the design group then defines the technical specifications and creates the system design, the manufacturing group then determines how it will make the product, and so on. Even with a project manager to oversee the process, work in each stage remains largely centered in one functional area and minimally involves the other areas. The project is a series of "hand-offs" where one functional group hands off its work to the next. At each stage, a new functional group takes over, "inheriting" and being forced to accommodate the output of previous areas. As a result, the design group must create a product design that conforms to the requirements it inherited from marketing; in turn, the manufacturing group must develop a production process that conforms to the design it inherited from the design group. In this serial development process, illustrated in Figure 15.15, there is little interaction and knowledge sharing between the participating groups.

In this process, since the different functional groups work somewhat independently, their decisions are often incomplete or incorrect because they do not address the needs and requirements of other functional areas involved in the project. As a result, for example, the marketing group specifies a requirement that is not really necessary, but the design group inherits and must incorporate it into the product design. Each functional group entering the process must struggle to accommodate commitments made by earlier groups. When it encounters a prior commitment (about a requirement, design, procedure, etc.) that is wrong or difficult to implement, it must request a modification to the commitment from the other groups. This back-and-forth exchange between groups results in numerous *change requests*, which delay progress and increase costs. The problem is lack of horizontal and vertical integration—a failure of groups involved early in the process to address the complete life cycle of the system and the needs of functional groups that will later inherit and have to live with the consequences of their decisions.

One integrated approach to systems development is *concurrent engineering*.

15.13 Concurrent engineering

Concurrent engineering is implemented with a cross-functional team structured as a matrix team or pure-project organization. Every group, department, or contractor responsible for or influenced by some

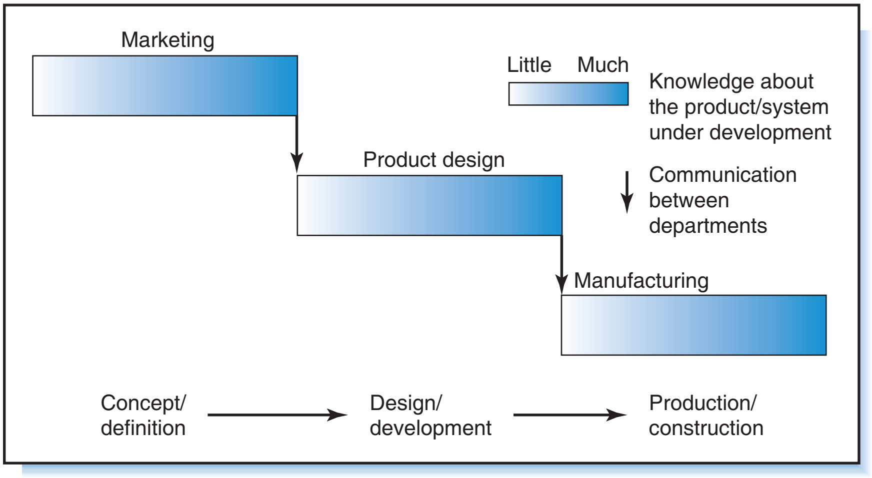


Figure 15.15
Traditional interaction between functional areas during phases of systems development project.

Source: Adapted from Wheelwright S and Clark K. *Revolutionizing Product Development*. New York, NY: Free Press; 1992. P. 178.

piece of the project has the opportunity to participate *early* in the project and to contribute to key decisions long before they actually begin to design, produce, test, or operate the system (Figure 15.16). Unlike serial systems development, hand-offs are nonexistent because all parties have a hand in everything. Horizontal integration and vertical integration are achieved in one fell swoop.

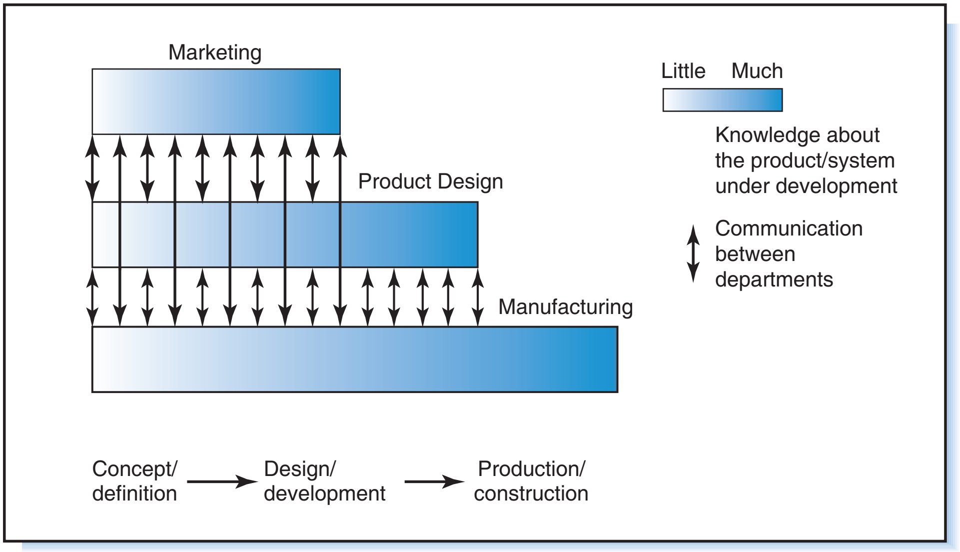


Figure 15.16
Concurrent interaction between functional areas in systems development.

Source: Adapted from Wheelwright S and Clark K. *Revolutionizing Product Development*. New York, NY: Free Press; 1992. P. 178.

In concurrent engineering, decisions about design, development, production, and operation overlap, which greatly reduces the project duration. For example, the process of making dies for stamping automobile body-panels, which is expensive and time consuming, does not usually occur until near product launch. The body-design group doesn't talk to the die-producing group until the last minute. With concurrent engineering, however, the groups work together so the dies are designed and produced soon after the body panels have been designed, which happens months before launch and allows ample time to work out bugs in the dies and make changes if needed. Concurrent design of the panels and dies alone can reduce the production preparation time for a new automobile by more than a year.

Concurrent engineering also improves tradeoffs between product features and production capabilities. Working together, product and process designers can discover subtle changes to product design features that are transparent to the customer but that take advantage of existing production capabilities. The result: lower production costs from fewer production bugs and rework and fewer customer usage problems and warranty claims.

Team organization

A concurrent engineering team is organized to maximize team member communication and control over design decisions. This is achieved by:[17]

- Autonomy. Members of a concurrent engineering team are relieved of unrelated obligations and commit fully to the development effort.
- Full-time, full-duration participation. Ideally, members are involved in *all* decisions throughout the *entire* systems development process. That's what "concurrent" means.
- Co-located. Team members work in close proximity and share one office, which encourages frequent, spontaneous informal chats. Periodic formal weekly meetings are largely replaced with continual informal meetings and standups.
- Small size. The team is small enough to allow open communication and encourage team commitment, yet large enough to represent all the affected functional areas, customers, and key suppliers. About six team members is optimal, although as many as 10 to 20 can be effective. If the size exceeds 20, smaller subteams are formed and coordinated by an interteam steering group.
- Team of doers. Each member is a specialist in some area (design engineering, manufacturing, marketing, purchasing, etc.) yet is expected to take on a wide range of responsibilities and obligations. Members are "can-do" folks, willing to visit customers and suppliers; work on design; and do modeling, assembly work, and whatever else needs to be done.

These features mirror those of the sprint teams in Scrum, described in the previous chapter.

But concurrent engineering is more than just organizing people into a team. It is taking people normally involved in only one stage of the system development process and engaging them in the other stages. Product designers wander the factory to see how their designs are manufactured and what features of the design make it hard or easy to produce. At the same time, production engineers and assembly workers talk to designers to understand why a design feature is important and has to be retained. Some auto manufacturers require their designers to spend a full day every few months on the assembly line producing the portion of the car they helped design.

There are other ways in which organizations organize teams to achieve vertical and horizontal integration. Example 15.4 describes two.

Example 15.4: Systems Development at Motorola and Lockheed-Martin[18]

Motorola's systems development cycle includes the phases of product definition, contract development, product development, and program wrap-up. The process emphasizes integration of functions to develop innovative products and effective resource utilization for speedy product development. Projects are conducted by a core cross-functional team responsible for most development decisions and detailed design work, as well as for specifying resource requirements and setting performance targets. Functional units provide support to the core team.

The core team approach is used when speed is critical, such as in projects to create systems with entirely new architectures or in markets that quickly change. For a project to develop a new phone product, the team consisted of a project manager and eight members from industrial engineering, robotics, process engineering, procurement, product design, manufacturing, human resources, and accounting/finance, plus a member from Hewlett Packard, the vendor for a crucial component in the system. To encourage outsiders to "look in" on the team and offer suggestions, they worked in a glass-enclosed office located in the middle of a manufacturing facility. The team created the work plan for the project and, after gaining senior management approval, took responsibility for performing the bulk of the project. The project was completed in 18 months (half the usual time for a project of that size), met the cost objective (which was much lower than normal), and yielded a product of high quality and reliability.

Lockheed-Martin's advanced development division, called "Skunk Works," has a reputation for developing radical designs and breakthrough aircraft and space vehicles.[19] The term "Skunk Works" is trademarked by Lockheed but in common usage refers to an autonomous project team working on advanced technology that can achieve results more quickly and at a lower cost than traditional development projects. For each development effort, Skunk Works handpicks the project manager and cross-functional team. Unlike the core teams at Motorola, which rely on functional areas for resources and support, each Skunk Works team is fully autonomous and controls virtually all the resources it needs. The team is similar to a separate business unit: it works on its own and has the authority to requisition resources and subcontract work. Emphasis in Skunk Works teams is on technical excellence and speed. Although projects tend to broadly follow the familiar phases of conception, definition, and so on, the team is free to create procedures and standards that best suit a project's goals. Team members are selected for high competency, broad skills, strong commitment, and ability to think on their feet. They are co-located, usually at an isolated site to increase motivation and teamwork and to maintain secrecy. Aside from budgets and general procedures, the team gets minimal direction from senior management. Since its inception in World War II, Skunk Works has become a model for creating highly innovative, leading-edge aircraft and space vehicles quickly and on budget.

An example is the F117 Stealth fighter project mentioned in Chapter 11.[20] The Air Force wanted a relatively low-cost production aircraft that would be difficult to spot on radar (stealth). The Skunk Works team created a radical design that used new materials but minimized costs by using an engine, computers, flight controls, and other parts from pre-existing aircraft (off-the-shelf). The project was completed in record time—31 months. The cost for research, development, and production of 59 airplanes was $6.6 billion, considered low at a time when other aircraft programs were running $1 billion over budget. Efficiency and low cost were partly attributed to the small-sized development team (a few hundred people in the design phase), which minimized red tape and maximized communication and project control.

Heavyweight teams

The Motorola teams described in Example 15.4 are what Wheelwright and Clark[21] call "heavyweight" teams; they are the systems development equivalent to the pure project organizations described before. The project managers are heavyweights, too, because they are minimally on the same level as functional managers and have the organizational clout to exert strong influence over everyone involved in the development project. The Lockheed-Martin Skunk Works teams are fully autonomous and even "heavier" in that they control all of whatever resources they need to get the job done. Being autonomous, of course, the team has only itself to blame if the project fails.

Cross-functionality and autonomy for core teams provide for strong emphasis on the project goal, discipline in coping with complexity, and consistency between design details. The teams define and bring into focus the customer requirements and translate them into terms everyone on the team can understand. Steps of the development process and details of the system are handled in a coherent fashion, minimizing inconsistencies and changes later on.

A disadvantage of heavyweight teams is that individual components or elements of the end-item system might not reach the same high-level technical excellence as they would if they had received attention from a traditional functional area. Although a cross-functional team might design a component that meets requirements and integrates with the entire system, the component might contain flaws that only a functional team of specialists could have prevented. A way around that problem is to involve specialists in formal reviews, as mentioned in Chapter 10.

See Chapter 10

15.14 Summary

Structure refers to the way organizations attempt to achieve goals and respond to problems in the environment. Two key features of structure are differentiation and integration; the former is the way organizations subdivide into specialized subunits; the latter is how they link the subunits to coordinate their actions. Organizations traditionally differentiate subunits along functional, geographic, customer, and process lines and integrate the subunits with rules, procedures, coordinated plans, and chains of command. These means are effective when the environment is stable and tasks are certain but less so when goals and tasks involve frequent change, high complexity, and uncertainty—the case with many projects.

Each project organization is uniquely structured to suit the project's goals and environment. It is formed to include all the functions needed and to integrate those functions through management roles that emphasize horizontal relations. When the project goal involves just one specialty, the project team is composed of staff from one functional area. More common is when it requires multiple functions, and the team is composed of members drawn from all the functional subunits involved or impacted by the project; this form of organization, called a task force or cross-functional team, is managed by a project expeditor or coordinator. Expeditors and coordinators direct project work but lack authority to command resources or strongly influence the behavior of team members.

For projects that have much at stake and require sizeable resource commitment, the appropriate form of organization is the pure project. This form gives the project goal the highest priority and the project manager greater ability to command and control whatever resources are needed, although it tends to be costly in terms of duplication of effort and project startup and shut down.

The matrix organization form creates project teams by sharing members and resources from across functional subunits. It is effective for a creating a continuous stream of project teams; however, it can be difficult to implement and induces organizational conflict.

Many companies use a *composite* of multiple forms—the matrix and pure project for large projects, cross-functional teams and task forces for smaller ones. Most project organizations are hybrids and combine combinations of the task force, pure project, and matrix forms.[22]

The project manager of a large project is often assisted by specialists and functional representatives in the project office. This project office handles contracting, planning, scheduling, and control, but its major role is integrating functional units. In a large-scale project that involves multiple companies, integration of all their efforts is sometimes taken on by the project sponsor. For a large, technically complex project, responsibility is usually handled by the prime contractor or a special integration contractor. In companies that undertake multiple, simultaneous projects, oversight and integration of the projects is handled by the office of projects, PMO, or program office.

Project integration involves coordinating both the efforts of multiple units (horizontal integration) and the phases of the project (vertical integration). In system development projects, this integration is achieved by combining representatives from all parties affected by the end-item system into a single team for the duration of the project, a practice called concurrent engineering. The team is formed early in the project and has the resources and authority to make decisions that affect the project and the full life cycle of the end-item product or system.

Review Questions

1. What do the terms "differentiation" and "integration" mean?
2. What are five traditional forms of differentiation? List some companies that presently use each.
3. List the various forms of integrators. Give examples of each.
4. What are the advantages of functional organizations? What are the disadvantages?
5. What distinguishes project forms from other forms of organization?
6. Describe the responsibility and authority for each of the following:
   - Project expeditor
   - Project coordinator
   - Project leader in a pure project
   - Project leader in a matrix.
7. Describe the applications, advantages, and disadvantages for each of the following:
   - Project task force
   - Project team
   - Pure project and project center
   - Matrix.
8. Give some examples of organizations where each of these project forms has been used.
9. What is the project office? Describe its purpose. Who is in the project office? How should members be selected for the project office?
10. What is meant by the informal organization? Give some examples. How does it help or hinder the formal organization? How can its beneficial aspects be influenced by the project manager?
11. Describe the role of the prime contractor and integration contractor in large-scale projects.
12. One form of integration contractor is the wedding consultant; another is the consultant who organizes high school reunions. For each:
    - List the various groups, organizations, and individual parties that are involved and must be integrated.
    - Describe the relationship among these parties and how the consultant coordinates their efforts, both prior to and during the wedding or reunion.

13. What parties should or might be included in a concurrent engineering team? What are the contributions of each? How does their inclusion in the team improve (a) the systems development process and (b) the resulting, final product?
14. What do you think are some of the major difficulties in changing from a traditional nonintegrated development approach to a concurrent engineering approach?

Questions About the Study Project

1. In your project, how is the parent organization organized—for example, functionally or geographically? Show the organization chart, its overall breakdown, and relationships.
2. How does your project fit into the organization chart of the parent organization?
3. What form of project structure is used in your project? Show the project organization chart; indicate the key roles and the authority and communication links between them.
4. How did the project structure develop? Did it "evolve" during the project? Who designs or influences the project structure? What role did the project manager have in its design? Is the design similar to those used in other similar projects in the organization?
5. Critique the project design. Is it appropriate for the project goal, the parent organization, and the environment?
6. Is there a project office? Is there also an office of projects or a program office? In each case: (a) describe the office and how it is used; (b) describe the members of the project or program office staff—representatives, specialists, and so forth. What is the purpose of the project office staff? Describe the various tasks and functions handled by the project office. What is the members' participation in the project office (full-time, as needed, etc.)? What is the reporting relationship between the project manager and members of the project office?
7. How does the project manager integrate functional areas?
8. Are prime and associate contractors involved? If so, what is the function of the company you are studying (prime, subcontractor, or supplier), and how does it fit into the structure of all the organizations contributing to the project? If applicable, discuss the involvement of integration contractors or team leader contractors.
9. Did the project apply concurrent engineering? If so, discuss how it was applied.

CASE 15.1 ORGANIZATION FOR THE LOGON PROJECT

Iron Butterfly Company is a medium-sized engineering and manufacturing firm specializing in warehousing and materials handling systems. The company purchases most of the subsystems and components for its product systems and assembles them to meet customer requirements. Every IBC system is made to customer specification and most of the firm's work is in system design, assembly, installation, and checkout. The firm's 250 employees are roughly equally divided among five divisions: engineering, design, fabrication, customer service, and marketing. Recently, competition has forced the firm to expand into computerized-drone warehousing systems despite its rather limited experience and expertise in that field.

IBC has been awarded a large contract for a drone system for placement, storage, retrieval, and routing of shipping containers for truck and rail by the Midwest Parcel Distribution Company.

This system, called the Logistical Online System, LOGON, is to be developed and installed at Midwest's main distribution center in Chicago. The contract is fixed price at $14.5 million and includes design, fabrication, and installation at the center. IBC was awarded the contract because it was the lowest bidder and has an outstanding record for quality and customer service. A clause in the contract imposes a penalty of $1,000 daily for failure to meet the specified delivery date.

At various times throughout the estimated 47-week project, personnel from the functional divisions of design, fabrication, procurement, and customer service will be involved, most on a full-time basis for between 4 and 18 weeks. In the past, the company has set up ad hoc project teams composed of a project coordinator and members from the functional areas. These teams are then responsible for planning, scheduling, and budgeting the actual work to be done by the functional departments. Team members serve primarily as liaisons to the functional areas and work part-time on the teams.

The LOGON contract differs from other IBC systems, both in its heavy usage of computerized, real-time operation via drones and in its size. Although IBC has some prior experience with real-time warehousing systems, the technology involved is continuously evolving. IBC recently hired people with the backgrounds needed for the project. In addition, it has signed contracts with CRC and Creative Robotics to provide the computer software and drone hardware and assistance with system design, installation, and checkout.

The LOGON contract is among the largest IBC has ever undertaken. The company is presently in the middle of two other projects that absorb roughly three-fourths of its labor capacity, is winding down on a third that involves only the customer service division, and has two outstanding proposals for small projects under review.

Discuss how you would organize the LOGON project if you were the president of IBC. Discuss the alternatives available for the LOGON project and the relative advantages and disadvantages of each. What assumptions must be made?

CASE 15.2 PINHOLE CAMERA AND OPTICS, INC.: WHY DO WE NEED A PROJECT MANAGER?

Beverly is the newly appointed vice president of strategy for Pinhole Camera and Optics, Inc. (motto: "See the World Through a Pinhole"), a medium-sized, privately owned manufacturing firm. Until recently, the 14-year-old company had experienced rapid growth through developing new products and optical manufacturing processes. Beverly believes that the company's market position has slipped because Pinhole has not been able to react quickly enough to changing market requirements and increased competition. The company is divided into the traditional functional departments of research, marketing, sales, production, and so on. New product-development projects are managed by handing off responsibility between managers of the departments. Beverly believes this is the greatest contributor to Pinhole's inability to identify and respond to market opportunities, and she would like to create a new position, manager of new products, for the purpose of integrating departments during product development projects. This position would be the project manager of new product development.

The owner of the company, Ovid Pinoli, disagrees. He contends that the managers of the functional departments, most of whom have been with the company since it started, are excellent managers, really know their specialties, and usually are able to work together. He feels there is no need to create the position, although he wonders where such a person would come from.

Mr. Pinoli instead suggests that for each new project, one of the department managers be picked to coordinate the efforts of all the departments. The manager would be selected from the department that has the biggest role in the project; in other words, according to whether the project primarily involves research, marketing, or production.

Beverly is convinced that Mr. Pinoli's idea won't improve the situation. She decides to prepare a formal written report that will address the pros and cons of Mr. Pinoli's suggestions and persuade him that the new position of manager of new products must be filled by someone other than a functional department manager. She also wants to describe how Pinhole's new development projects could be better organized and staffed.

If you were Beverly, why would you disagree with Mr. Pinoli's suggestion that the existing departmental managers serve as the project manager? What would you say in the report to argue for the position of manager of new products?

CASE 15.3 IMPLEMENTING A MATRIX STRUCTURE IN AN R&D LABORATORY[23]

The R&D laboratory of a large Dutch multinational corporation served two roles, split roughly 50/50: product/process development (PPD) and support service to product/process development, production, marketing, and other areas of the corporation. The lab's employees were grouped into 13 departments, 7 (with 85 employees) devoted to PPD, 6 (with 84 employees) providing support services.

The decision was made to restructure the lab to operate as a matrix, and a policy committee was appointed to draft a proposal for the restructure. After a year of discussion, a "balanced matrix" was introduced, and five project managers, recruited from the lab, were appointed to coordinate PPD projects. The functional managers of the restructured R&D departments (who were excluded from strategic decision-making) felt uneasy about the balanced matrix and suggested instead a "weak matrix," but they were overruled. Functional managers responsible for PPD complained about loss of operational authority. Those responsible for support services had a different grievance: in the past, their work supporting stakeholders outside the R&D lab (e.g. production and marketing) always took precedence over PPD activities, which they performed in whatever time remained. The matrix now changed that, with priority going to PPD activities with enforced due dates.

The functional managers, who "didn't feel called upon to cooperate much," rebelled and ceased making constructive contributions to the projects their departments were involved in. This forced the project managers to attempt to manage the projects single handedly, which resulted in serious work overloads. Trying to speed up project work, they stealthily bypassed functional managers whenever they visited the functional departments. Further contributing to the rift was the fact that project managers received higher salaries and nicer company cars than the functional managers.

Twice the functional managers requested that some projects in the project portfolio be delegated to their departments. The first time, they created a list of 22 big and 26 small projects ("small" defined as requiring less than 1,000 labor hours per half-year, many that involved only one or two departments), and they proposed that the small ones be delegated to their departments. The policy committee (under the leadership of one of the project managers) countered this by cancelling some small projects and integrating others into the big projects. Six months later, the functional managers noted that some of the biggest projects involved seven to eight departments, and coordinating work among them was difficult. They proposed that big projects be divided into subprojects with responsibility delegated to subproject managers within their functional departments. This proposal was opposed by the project managers and rejected.

The project managers, frustrated that personnel were often shifted between projects by the functional managers who supplied the personnel, proposed that personnel on larger projects be assigned to projects "semi-permanently," for a period of, say, 6 months, during which they would not be reassigned. After a year of deliberation, the proposal was approved despite the opposition of managers of the service support departments because it compromised their ability to give highest priority to service requests. The managers of production and marketing, who wanted quick response to their requests for services, supported these objections.

Initially, service support tasks that required more than 300 hours were handled by project managers, and those requiring less were handled by functional managers; later, the 300-hour threshold was lowered to 100 hours. All service requests were sent directly to the departments for subsequent assignment to project or functional managers, but the project managers suspected that functional managers manipulated the rule by creating service projects such that they required less than 100 hours. They proposed that service requests be sent directly to them, but this was rejected.

Three years after initiating the matrix structure, the caustic behavior slowly decreased; disagreements still existed, but the atmosphere improved. Managers of the support-oriented departments admitted that the matrix structure improved objective-setting and project control, but they still favored a weaker form of matrix over the balanced matrix. Managers of the PPD-oriented departments came to accept the balanced matrix, although the general manager remained unsatisfied and suggested that all departments should split their staff into two groups, one for product-process development and the other for support work.

QUESTIONS

1. What would the roles and responsibilities of functional managers have been prior to implementation of a matrix structure? How did the change in roles contribute to conflict after implementation of the matrix?
2. Comment on the complaint of functional managers of support-orientated departments about due dates being enforced for product development work. What possible solutions do you suggest?
3. Many of the projects required the involvement of only one or two departments. Comment on how this fact should have been taken into account in the design of the organizational structure.
4. Why would it make sense for smaller projects to be handled by functional managers?
5. Why would the proposal for subproject managers in functional departments for the biggest projects make sense?
6. Sometimes reasonable proposals get "politicized." What role do you think mutual suspicion plays in this? How could this have been prevented in this case? Comment on the idea that project managers should display "integrative leadership."
7. In this case, it took a year of discussions prior to implementing the matrix structure and another 3 years before it started to work reasonably well. Comment on the time you think it should take to implement a matrix structure. What factors must be considered?

Notes

1. Discussion of the organization structure and integrating mechanisms in high-technology environments is given by Galbraith J. Environmental and technological determinants of organizational design. In: Lorsch J.W. and Lawrence P.R. (eds), *Studies in Organization Design*. Homewood, IL: Irwin-Dorsey; 1970, pp. 113–139.
2. See Galbraith J. *Designing Complex Organizations*. Reading, MA: Addison-Wesley; 1973.
3. Peters T. and Waterman R. *In Search of Excellence*. New York: Warner Communications; 1984, pp. 127–130.
4. See Davis K. The role of project management in scientific manufacturing. *IEEE Transactions of Engineering Management* 9(3); 1962: 109–113.
5. The matrix organization and its applications and implementation are described in Davis S. and Lawrence P. *Matrix*. Reading, MA: Addison-Wesley; 1977.
6. McCann J. and Galbraith J. Interdepartmental relations. In: Nystrom P. and Starbuck W. (eds), *Handbook of Organizational Design II*, no. 61. New York: Oxford University Press; 1981.
7. Peters and Waterman. *In Search of Excellence*, pp. 307–308.
8. See Thomas R., Keating J. and Bluedorn A. Authority structures for project management. *Journal of Construction Engineering and Management* 109(4); 1983: 406–422.
9. Cusumano M. and Selby R. *Microsoft Secrets*. New York: Free Press; 1995, pp. 74, 235–236, 248–249.
10. Burns J. Effective management of programs. In: Lorsch J. and Lawrence P. (eds), *Studies in Organizational Design*. Homewood, IL: Irwin-Dorsey; 1970, pp. 140–152.
11. Archibald R. *Managing High-Technology Programs and Projects*. New York: John Wiley & Sons; 1976, Chapter 4.
12. This discussion is based on Livingston J. Weapons system contracting. *Harvard Business Review*; July–August 1959: 83–92.
13. Ibid., p. 85.
14. Adapted from Lammie J. and Shah D. Construction management: MARTA in retrospect. *Journal of Construction Engineering and Management* 110(4); 1984: 459–475.
15. Complete discussion of integration contractors provided by Sayles L. and Chandler M. *Managing Large Systems: Organizations for the Future*. New York: Harper & Row; 1971, pp. 253–271.
16. Arndt D., Clampett L., Fedder W., Foxx K., Lorenz C., Ward N. and Worthington J. *Analysis of the Role of the AIM Team in the Integration of Knoll Pharmaceuticals into Abbott Laboratories*. Loyola University Chicago; July 13, 2002.
17. From Nicholas J. Concurrent engineering: Overcoming obstacles to teamwork. *Production and Inventory Management Journal* 35(3); 1994: 18–22.
18. Portions adapted from Wheelwright S. and Clark K. *Revolutionizing Product Development*. New York: The Free Press; 1992, pp. 159–162, 200–203.
19. Its SR-71, a high-performance reconnaissance aircraft developed in the 1960s, still holds the world's speed record five decades later. See Rich B. and Janos L. *Skunk Works*. Boston: Little, Brown & Company; 1994.
20. See Aronstein D. and Piccirillo A. *Have Blue and the F-117A: Evolution of the "Stealth Fighter."* Reston, VA: American Institute of Aeronautics and Astronautics; 1997; Stroud M. How the F-117A flew on budget, on time. *Investor's Daily*; February 1, 1991.
21. Wheelwright and Clark. *Revolutionizing Product Development*, pp. 194–196, 202–112.
22. Strengths and weaknesses of different project forms are described in Bannerman P. Risk implications of software project organization structures. *20th Australian Software Engineering Conference*, IEEE Computer Society, April 14–17 2009, Gold Cost, Australia.
23. Adapted from De Laat P. Matrix management of projects and power struggles: A case study of an R&D laboratory. *IEEE Engineering Management Review*; Winter 1995.

Chapter 16

Project roles and stakeholders

All the world's a stage,
And all the men and women merely players.

—William Shakespeare
As You Like It

When an organization undertakes a project, it forms a project team, but unless the team is a pure-project form of organization, most people on the team are "borrowed"—they come from functional departments or contractors and work on the project for only as long they are needed. Project management "gets work done through outsiders"[1]—people from various functional and specialist groups scattered throughout the parent company and outside subcontractors. As Sayles and Chandler describe,

> "Project management is dealing laterally but not in the informal-group, informal-organization sense. It requires a capacity on the part of the manager to put together an organizational mechanism within which timely and relevant decisions are likely to be reached, [as well as] a conceptual scheme for 'working' interfaces . . . [It is a] dynamic, interactive, iterative, and intellectually challenging concept of the managerial role."[2]

Part of being a project manager is the ability to influence people without giving orders or making decisions in the same way as other managers. Most project managers have a great deal of responsibility but not much formal authority, so they need a different skill set and leadership style than traditional managers.

Of course, the project manager is just one of numerous individuals and groups who are involved in, influence, or are influenced by a project—collectively referred to as *project stakeholders*. This chapter discusses the project manager's role, project stakeholders, and the project manager's role in managing stakeholder expectations.

16.1 The project manager

Project manager's role

The project manager is the centerpiece of project management; she is the glue that holds the project together and the mover and shaker that spurs it onward. Being a project manager requires wearing different hats, some at the same time; these hats are those of an integrator, communicator, decision-maker, motivator, evangelist, and entrepreneur.

As the central figure in the project, the project manager's prime role is to *integrate everything* and *everybody* to accomplish project goals. The project manager has been called the organizational "metronome," the person who keeps the project's diverse elements responsive to a single, central beat.[3]

The project manager is the *communication hub*, the funnel through which most reports, requests, memoranda, and complaints flow. She receives inputs from more sources and directs information to more receivers than anyone else in the project. Between sources and receivers, she refines, summarizes, and translates information to keep all key stakeholders well informed about project plans, progress, and changes. Many project managers say they spend 90 percent of their time communicating; not all project managers agree with that figure, but virtually all will say they spend most of their time communicating.

Being the communication hub, the project manager is also the central *decision-maker* for setting project scope and direction, allocating resources, and balancing schedule, cost, and performance criteria. Even when lacking authority to make high-level decisions, she is often the best situated to influence others who do make those decisions.

The prime *motivational factor* in any diverse group is strong commitment to a central goal. The successful project manager is able to foster enthusiasm, team spirit, confidence, and drive the team forward, even when the work becomes stressful and frustrating.

You could say the project manager is a sort of *evangelist* who builds faith in the project and its value and workability. During the conception phase, she is often the only person who sees the big picture, and whether the project gets funded often depends on her ability to gain the endorsement of influential stakeholders.

Also, the project manager is like an *entrepreneur* of sorts, driven to procure the funds, facilities, and people needed to get the project off the ground and keep it flying. Early on, she must win over reluctant stakeholders who question supporting or assigning resources to the project. After the project is underway, she must continue to champion the project and sometimes fight for its existence. In the end, whether the project succeeds or fails, the project manager is the one who is ultimately held accountable.

Example 16.1: Gutzon Borglum: Project Manager and Sculptor[4]

If you are familiar with the carvings pictured in Figure 16.1, then you know the handiwork of Gutzon Borglum. More than two million people a year visit Mount Rushmore National Memorial. Most of them who hear the name Gutzon Borglum think that it was he who *sculpted* the faces. He was, of course, the sculptor, though not of the actual faces on the mountain. The contract for the project specified that the memorial was "to be carved by and/or under the direction of Gutzon Borglum" and that Borglum was to enjoy "full, final, and complete freedom of authority in the execution of the monument's design." He did carve the faces, but on a miniature model 1/12 the size of the ones on the mountain to serve as a guide for workers who did the actual "sculpting," much of which consisted of removing huge quantities of granite using dynamite, heavy drills, and pneumatic jackhammers.

Projects of such grandiose size are never the work of just one person, although in the case of Mount Rushmore, if anyone should get credit, it would have to be Gutzon Borglum. Many others contributed to the project in important ways, but it was Borglum's tireless efforts that yielded much of the project funding and his genius and dedication that made it happen. He picked the site; he wrote letters and spoke personally to businessmen, wealthy industrialists, senators, congressmen, and US presidents; he determined that the faces would be of Washington, Jefferson, Roosevelt, and Lincoln; he hired and directed the work crew; he created the innovative means for transferring the design from the

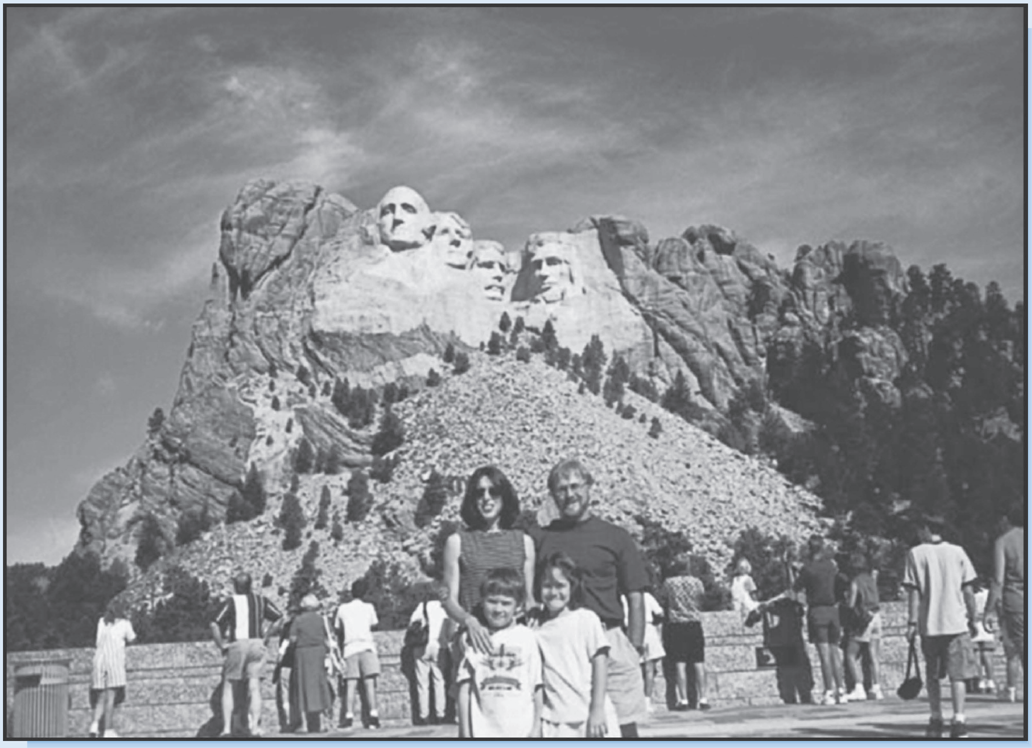


Figure 16.1
Gutzon Borglum's most famous work attracts millions of visitors a year.
Source: Photo courtesy of John Nicholas.

model to the mountain; and, *in addition*, he attended to myriad details, from designing the scaffolding, work platforms, tramway, hoists, and grounds buildings to orchestrating the pageants for the initial dedication and final unveiling ceremonies. People wondered when he ever rested or slept. Of course, he was by no means perfect; he did not always have project problems under control, and his efforts in the early years were criticized for being unorganized. When the project began in 1927, Borglum wasn't completely sure what the monument was going to look like. People familiar with Borglum were impressed with his artistic talent, but they were even more impressed with his "capacity for affection, wrath, generosity, stinginess, nobility, pettiness, charm, and sheer obnoxiousness."[5] He was short on modesty and humility and long on "mulish stubbornness." He thought big, dreamed big, talked big, and was not afraid to tackle any undertaking. His enthusiasm was contagious.

The project work crew consisted of 22 men. Most of the sculpting they did using 80-pound drills and jackhammers while dangling on the side of a cliff. They sat in harnesses designed by Borglum that were lowered down the mountain face with hand winches. Imagine their feelings, as described by biographer Rex Smith:

> You do your drilling while hanging on the side of a stone wall. . . . From where you sit you can look down upon mountains and plains that stretch farther than the eye can see. Surrounded by these vast spaces, suspended against a stone cliff, you feel dwarfed and insignificant . . . and uneasy.[6]

Borglum was a stickler for safety, so despite the dangers, there were few accidents and no fatalities throughout 14 years of work. Borglum was never chummy with his crew, but he cared and looked out for them, and, in return, they were loyal to him and to each other.

Seeing the monument today, we realize that its construction must have posed great challenges but that, obviously, those challenges were overcome. Borglum, however, was never sure they would be overcome. Although he had selected the mountain, he knew there was the risk that it might contain some disastrous hidden flaws—cracks or bad rock—that could not be worked around. In fact, besides funding, it was the shape of the mountain and its deep fissures that determined that the number of presidential busts had to be just four. Time and again obstacles arose, funds ran out, and the project had to be stopped. But Borglum and other supporters persevered so that the project would again be revived. In the end, the carving was abandoned and the monument left uncompleted because the nation was about to become embroiled in World War II and would no longer support the effort. Just months before the project was canceled, Borglum died. He had been the project's prominent driving force, and you have to ask: Had he lived, how much more of the monument would he have completed? Borglum was a sculptor, but when it came to turning a mountain into a monument, he was the ultimate project manager.

Job responsibilities

The project manager's principal responsibility is to deliver the project end-item in accordance with requirements and contract terms and, when specified, in fulfillment of profit objectives. Other specific responsibilities vary depending on the size and nature of the project, the stage of the project, and the responsibilities delegated by upper management, which range at the low end from the rather limited influence of a project expeditor up to the centralized, almost autocratic control of a pure project manager.

Though responsibilities vary, they usually include:[7]

- Planning project tasks and end results; creating the WBS, schedule, and budget; coordinating tasks; and allocating resources.
- Selecting and organizing the project team.
- Working and negotiating with influential stakeholders (customers, functional managers, contractors, supporters, and top management) and managing their expectations.
- Monitoring project status and communicating status to stakeholders.
- Identifying technical and functional problems.
- Solving problems directly or knowing where to find help.
- Dealing with crises and resolving conflicts.
- Anticipating risks and working to mitigate them.

Most managers of medium- and large-sized projects report in a line capacity to a senior-level executive. They are expected to monitor and narrate the technical and financial status of the project and to report current and anticipated errors, problems, or overruns.

Domain competency and orientation

Project managers work at the *interfaces* between top management, the customer, subject-matter specialists, and contractors, so they must have managerial ability, technical competency, and other broad qualifications. They must feel as much at home in an office talking with executives and customers about policies, schedules, and budgets as in the plant, shop, or on-site talking to subject-matter experts and supervisors about technical matters.

Broad background is also essential. The more differentiated the functional areas, the more prone the areas are to conflict. To effectively integrate multiple, diverse functional areas, the project manager needs to understand each of the areas—the jargon, techniques, and procedures used—and the contributions of the areas to the project. Referred to as *domain competency*, the project manager must have a good understanding of *all areas* within the project domain. Another way of saying this is that the project manager's technical and administrative competency must cover the full scope of the project, that is, all areas within the project scope statement and tasks at the first or second level of the WBS. Although most project managers cannot be experts in all areas of the project, they must be sufficiently familiar with those areas to be "credible"—to intelligently discuss issues, ponder ideas offered by specialists, and evaluate and make appropriate, balanced decisions. Along the same lines, to deal effectively with top management and the customer, they must be familiar with the workings and businesses of the parent and customer organizations. Overall, they should know more about the project than anyone.

But project managers cannot know everything. When they are responsible for areas about which they are ignorant, they admit it and seek input and advice from people who are competent and whom they trust. As a rule of thumb, a project manager tries never to bluff, since doing so risks losing all credibility with stakeholders.

Studies indicate that the most effective project managers adopt goals, time, and interpersonal orientations *intermediate* to the functional units they integrate. In other words, they take a balanced outlook.[8] For instance, to integrate the efforts of a production department and a research department, the project manager adopts a time perspective intermediate between the production group's short-term, weekly outlook and the research group's long-term, futuristic outlook.

As far as the relative importance of technical ability versus managerial competency, that depends on the project. Project managers in most research and engineering projects need some or much technical competency, because the problems and orientation of the project team are technical. In non-technical projects, however, project managers can get by with little or no technical competency. But to manage projects that involve multiple, diverse functional areas, the project manager needs some knowledge of all those areas, plus the managerial ability to integrate them. In general, project managers must be sufficiently technical to be able to understand project issues, but not so technical as to neglect their managerial role. There is no substitute for strong managerial competency in the role of the project manager.

16.2 Project management authority

Authority refers to a manager's power to command others to act or not to act. There are different kinds of authority; the most familiar is that conferred by the organization and written in the manager's job description, called *legal authority*. Given legal authority, people in higher organizational positions are viewed as having the "right" to control the actions of people below them. Associated with legal authority is *reward power*, the power to evaluate and reward subordinates.

Another kind of authority, *charismatic authority*, stems from the power one gains through personal characteristics such as charm, personality, and appearance. People both inside and outside the formal organization can increase their authority by being charismatic.

Traditional authority

Management theory says that authority is always greater at higher levels in the organization and is delegated downward. This is presumed to be the way it ought to be because managers at higher levels are assumed to "know more" and therefore are able to make decisions and "command" workers at lower levels. This point has been challenged on the grounds that managers, particularly in technology-based organizations, cannot possibly know everything needed to make complex decisions. They often lack technical expertise and so, increasingly, must rely upon subordinate specialists for advice. Even managers who are technically skilled cannot always manage alone; they rely upon staff groups for personnel and budgetary assistance. Especially in projects, this aspect of "participatory management" (described in Chapter 17) is commonplace.

See Chapter 17

Influence

It is important to distinguish legal authority from the *ability to influence*. Managers with legal authority influence subordinates by giving orders and controlling salaries and promotions. Generally, however, the most effective managers are able to exert influence *without* giving orders or making an issue of their superior–subordinate relationship. This is especially true when subordinates are well educated or highly experienced. In fact, managers who rely solely on legal authority are often relatively unsuccessful. Effective managers tend to rely instead on two other sources of influence: *knowledge* and *personality*.[9] The first source, called *expert power*, refers to a person's special level of knowledge or competency, plus the belief by others that the knowledge and competency are important and that they themselves do not possess it. Simply, the expert power holder is viewed as being right because he knows more, and others readily defer to his requests.

The other, called *referent power*, derives from rapport, personal attraction, friendship, alliances, and reciprocal favors. The subordinate in some way identifies with the power holder and defers to his requests.

Given expert power and referent power, a person can influence others irrespective of the formal hierarchy. These forms of power can even subtly reverse the authority relationship. A subordinate may exert considerable influence over her superior if the superior comes to rely upon the subordinate for information or advice, or if a bond of trust, respect, or affection develops between them. Everyone has seen this, and history is replete with examples of people of "lower" social or organizational stature controlling people of higher stature: Alexandria was empress of Russia; Rasputin was a lowly priest.

Authority in projects

Functional managers tend to rely on different forms of influence—knowledge, expertise, persuasion, and personal relationships; when these fail, however, they are able to fall back on their legal authority. But seldom are project managers able to do this. Except in the case of the pure project manager, the typical project manager *lacks any form of legal authority*.

In traditional organizations, influence and authority flow vertically, but in projects, they flow horizontally and diagonally. The project manager exists *outside* the traditional hierarchy. His role is temporary, superimposed on the existing structure, so, consequently, he is not afforded the leverage inherent to a hierarchical position. Project managers work across functional and organizational lines and, except perhaps for members of the project office, have no subordinates reporting to them in a direct line capacity. The issue is further complicated in matrix organizations, wherein project managers must share authority with functional managers.

Thus, despite the heavy responsibility they carry, most project managers lack a comparable level of formal authority. Instead they have what is called *project authority*, meaning they have authority to make decisions about project objectives, policies, schedules, and budgets but no authority to give orders backing up those decisions.

The disparity between high formal responsibility and low formal authority has been referred to as the *authority gap*.[10] The gap implies that project managers must strive to develop other forms of influence in the absence of legal authority. "How to make friends and influence people" is not an academic issue for project managers.

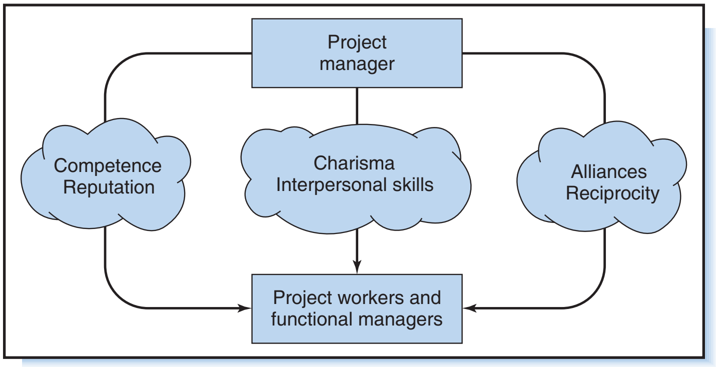


Figure 16.2
Project manager's sources of influence.

Project manager's authority

Most project managers handle the authority gap in similar ways: having no legal authority, their recourse is to rely on influence derived from expert power and referent power. They have to do this also because no matter the project, they depend on others to get the job done. Numerous decisions must be made, many for which they have neither the time nor expertise. Even in the rare case of a project manager having legal authority, she seldom uses it, because unilateral decisions and orders are inconsistent with the need for reciprocity and tradeoffs in projects. Project managers know that not all project information should be channeled through them, and they encourage direct informal contact between the individuals involved.

Project managers also gain influence through networks of alliances and informal connections they build with managers and other stakeholders. The strength and breadth of these networks increase with the project manager's perceived competency, reputation from prior project accomplishments, and charisma. The final feature, charisma, refers to the project manager's personal appeal—something about the project manager's demeanor, behavior, or personality that people *like*. Why should this matter? Well, project stakeholders are more likely to associate with, assist, or do what a project manager requests if they like her than if they do not; it's as simple as that. If the project gets into trouble, a project manager that people like will have alliances and friends to call upon for help.

In summary, project managers tend to rely upon knowledge, experience, personal relationships, and personality to influence others (Figure 16.2). To build expert-based power, they must be perceived as technically and administratively competent. To build referent-based power, they must develop effective interpersonal, persuasion, and negotiation skills. The different ways that project managers employ these sources of influence are illustrated in Example 16.2.

Example 16.2: Effective Project Managers, Contrast in Styles[11]

Two examples of how different project managers uniquely influence people are Kelly Johnson and Ben Rich, both former head managers of the advanced projects division of Lockheed-Martin Company, the "Skunk Works."

Kelly Johnson was a living legend, not only at the company but also throughout the entire aerospace industry. With the help of a highly cohesive team of engineers and shop workers, he created over 40 airplanes, including the fastest, highest-flying ones in the world. Yet, he was strictly business, without humor, hot tempered, and reputed to "eat young engineers for between-meal snacks." He made the bureaucrats and engineers with whom he had dealings sweat—particularly excuse makers and faultfinders, so he had as many detractors as friends. Nonetheless, when management needed someone to head up the most difficult and challenging projects, they repeatedly selected Kelly. Why? Beneath his bad temper and somewhat unkempt appearance was a sure-fire genius. He knew everything, it seemed, and his ability to make accurate, on-the-spot deductions amazed everyone. For a new engine inlet, Kelly simply glanced at the initial design and pronounced it wrong, about "20 percent too big." His engineers worked a full day to re-compute the design only to discover that, sure enough, the engine inlet was 18 percent too big. Another time, he looked at a design and said "the load here is 6.3 psi." After an hour of complicated calculations, his people measured it as 6.2 psi. When he retired, Kelly Johnson was recognized as the pre-eminent aerodynamicist of his time.

Kelly chose as his successor Ben Rich. Ben was the first to acknowledge that he didn't possess Kelly's genius and therefore would rely on his teams for most decisions. His first move was to loosen the reins and allow the teams latitude to make most calls on their own. Ben was decisive in telling a team what he wanted, but he then let them decide which methods to apply. Ben used a non-threatening approach. He stuck to schmoozing and cheerleading through an endless supply of one-liners. As one employee said, "Whereas Kelly ruled by his bad temper, Ben ruled by his bad jokes." Whereas he didn't shirk from scolding deserving individuals, he preferred complimenting people and boosting morale. Said a colleague, he was the perfect manager—there to make the tough calls, defend and protect his project teams, obtain more money and new projects, and convince the government and senior management of the value of his teams' work.

Johnson and Rich led using different styles, yet both have been acknowledged by the industry as exemplary project managers. Kelly Johnson accomplished great things, despite his temperament, and most engineers considered it an honor to have worked with him. Competency and reputation were his strengths; people tolerated his personality. Ben Rich, although no technical slouch, acknowledged that he had some smarter people working for him. Unlike Kelly, he had charisma and many personal friends, and with that he, too, was able to accomplish great things at the Skunk Works.

The balance of power

Typically, project managers and functional managers share authority, but in the best-performing projects, that authority is clearly differentiated.[12] Project managers have authority to decide *what* work must be done, procure resources, coordinate work, and mediate conflicts; in contrast, functional managers have authority to decide *how* the work must be done (the technology to use) and to resolve technical problems.

Although a project manager rarely has any form of reward power, workers tend to be more responsive if they *perceive* the project manager has some influence over salaries and promotions.

16.3 Project manager qualifications

The qualifications of successful project managers fall into four categories: personal characteristics, interpersonal skills, general business skills, and technical skills.

Personal characteristics

Archibald lists the following personal characteristics as essential for project managers:[13]

- Flexible and adaptable
- Preference for initiative and leadership
- Confidence, persuasiveness, verbal fluency
- Effective communicator and integrator
- Able to balance technical solutions with time, cost, and human factors
- Well-organized and disciplined
- Generalist rather than specialist.

These characteristics make sense given the project environment and the responsibilities and restrictions placed on the project manager role. Obviously, project managers must also be able to handle the pressure of constant deadlines; great uncertainty; startups and close outs; and constant changes in goals, tasks, people, and relationships.

The typical project manager likes to be out and about, mingling with the project team on-site and elsewhere with stakeholders. In this way, she connects with people, stays informed, and builds morale.

Interpersonal skills

A project manager must possess strong interpersonal skills and the ability to "actively listen to" and "read" people.[14] Active listening means asking for clarification and paraphrasing to make sure you understand what people are saying; it means:

- Asking leading questions.
- Remaining quiet and allowing the other person sufficient time to talk.
- Reflecting on the person's answer and checking for correctness.
- Reflecting on the person's emotions.

The acronym for active listening is LEAR: listen, explore, acknowledge, respond.

Ability to read people is more difficult. It is the talent to know whether to trust a person's actions or words through non-verbal cues and instinct.

The project manager must be sensitive to the attitudes of project stakeholders. Specialists on the project team often disdain anything non-technical and resent schedule and budgetary constraints imposed on them. The project manager must be able to convince them why these matter.

The project manager must also be able to build trust, promote team spirit, and reward cooperation; often, she does this through the only form of reward she is able to give: praise and credit. A good project manager understands the personalities, attitudes, and strengths of her team members and knows how to utilize their talents, even when they do not measure up to her standards. She is sensitive to human frailties, needs, and greed and able to resolve conflict, manage stress, and coach and counsel team members. It is a tall order, but a good project manager can do all of that.

General business skills

The project manager is, after all, a *manager* and so must also have general business knowledge and skills that include:

- Understanding the organization and the business.
- Knowledge of *management*—marketing, accounting, contracting, purchasing, human resource administration, and business concepts.
- Ability to translate business requirements into project and system requirements.
- Strong, active, continuous interest in teaching, training, and developing subordinates.

Most project managers have cost responsibility, so they must understand the concepts of cost estimating, budgeting, cash flow, overheads, incentives, and cost sharing. They are involved in contract agreements, so they must know contract terms and implications. They are responsible for the phasing and scheduling of work to meet delivery dates, so they must be familiar with the work tasks, processes, and resources in executing the project. And they are responsible for enforcing schedules and hence must be knowledgeable about tools and techniques for planning, tracking, and control.

Technical skills

To be able to make informed decisions, project managers must have a strong grasp of the technical aspects of the project. As mentioned in Chapter 15, their "domain competency" must span the full scope of the project. In low-technology projects, this grasp can be developed through experience and informal training. In high-technology projects, technical qualifications are more rigorous and usually require a career molded in the technology environment and a degree in a science, technology, engineering, or math (STEM)-related field.[15]

See Chapter 15

Although project managers seldom do technical analysis, they must be qualified to integrate concepts from different disciplines to make technical judgments. Often, technically qualified people are not good at integrating concepts from different disciplines because undergraduate training in engineering and other technical fields tends to emphasize analysis and ignore integration.[16] The project manager must be able to understand and speak the technical languages of different subject-matter experts on the team, regardless of their specialty; this is minimally necessary for communicating with and integrating the work of those experts.

Selection and recruiting

The manager to head up a given project is selected from among the ranks of product and functional managers, subject-matter experts, and experienced project managers. The last source is the best, though not always feasible, since it might be difficult to find an experienced project manager who has the right mix of qualifications and is available for the new project. As a result, when an experienced project manager is needed, often he is recruited from the outside; this is readily observable in job listings online and in major newspapers (Figure 16.3 shows a sampling). The downside with hiring an outsider is that it takes time for the manager to build friendships and alliances and learn organizational policies. On the plus side, she is likely better suited to objectively take on the task (without political influence) and less likely to have any enemies—at least initially.

The project manager can also be selected from among functional managers, although functional managers sometimes have difficulty shifting to a project perspective, which requires overseeing and integrating the work of many areas rather than managing just one. And, without abundant well-rounded experience, everyone will likely perceive him as just another functional manager.

Project managers can also be "created" by promoting subject-matter experts (SMEs—engineers, scientists, system analysts, designers, etc.), although this has the same drawback as with promoting any non-manager into a managerial role: the person has to first learn how to manage. Being a good SME is

Architecture

Senior Project Manager

We need aggressive, innovative, top-flight professionals to manage large-scale, complex building design projects. Degree and registration, plus a minimum of 10 years solid U.S. experience in putting buildings together.

Complete management responsibilities for scheduling, resource planning, feasibility studies, design and design/build for multi-million dollar projects.

PROJECT ENGINEERS

5-6 years of project management experience in the design of electro-mechanical products. Your track record of managing projects from inception thru completion should include: project and material planning, costing and product testing. A BSME is required with exposure to electrical engineering preferred. Supervisory and decision making skills.

PROJECT COORDINATOR

Move into this key position with the company that moves America...

Here you will assist/support a project team which analyzes the work flow/efficiency of several departments. Position involves: Heavy utilization of a PC; analyzing and assembling reports; independent research; identifying information pertinent to various projects; maintenance and control of all files; designing and developing PC forms and reports. Candidate will also perform various other duties as needed.

Requirements include 3-5 years of equivalent project coordination experience, preferably within a corporate environment, highly developed PC, communication and organization skills

Engineering

PROJECT MANAGER

We are a rapidly growing ENR 400 firm with an outstanding opportunity for a Project Manager. Responsibilities relate to activities for environmental audits and site assessments.

The successful candidate should have project management capabilities and hazardous waste background. Business development experience is also desirable.

Banking

SYSTEMS PROJECT ANALYSTS/LEADERS

Federal Savings and Loan Association has excellent professional opportunities for experienced Systems Project Analysts/Leaders. Immediate opportunities are available in the areas of telecommunications, McCormack and Dodge financial systems, and savings and loan financial systems, including installment lending and mortgage banking applications.

Ideal candidates must possess a college degree in business administration, or computer science with a business administration background, and have at least 5 years of experience in systems project implementation, operations analysis, and finance/accounting. Direct exposure and/or experience in savings and loans, other financial institutions, or mortgage banks is desirable.

Specific systems experience should include structured project management experience, through implementation. Candidates must also possess project supervisory and excellent communication skills.

Data Processing

CORPORATE PROJECT MANAGER

National manufacturer of transportation equipment is seeking an experienced individual to assume responsibilities as their Corporate Project Manager.

Candidates must possess a Bachelor of Science degree including some programming training. Three to five years experience within Production or Engineering Management within the primary metal fabrication industry is desired with experience working with mini and micro computers. Additionally, the preferred candidate will be experienced in modern inventory control techniques within a heavy manufacturing environment. Initial responsibilities of this function will be the analysis and installation of systems within a manufacturing environment with the successful incumbent becoming a candidate for executive management responsibility.

PROJECT ENGINEER

[illegible], the nation's leading manufacturer of private label vitamins, over-the-counter drugs and beauty products has an immediate need for a Project Engineer.

RESPONSIBILITIES. This position will be responsible for managing a variety of specification, design, and implementation projects in our manufacturing process area, and will also include providing assistance to the maintenance group and other engineering departments as needed.

QUALIFICATIONS. A BS in Mechanical Engineering, Chemical Engineering or related degree will be required, as well as 5 years project experience, preferable in a processing manufacturing environment.

PROJECT MANAGER TECHNICAL SERVICES

Our client, a [illegible] organization located in Texas, has retained us to asist them in recruiting a top level ELECTRICAL ENGINEER to manage hardware and software projects which support the services provided by the company's operating units.

The successful candidate will report to corporate manager of Technical Services and must possess a BS degree in Electrical Engineering and a minimum of 5 years experience. Experience should include: electronic hardware design, assembly language programming,

Communications

Project Supervisor

Looking for a challenging career with the leader in the communications industry? An opportunity is currently available for the qualified professional with [illegible]

As a member of [illegible] Organization, the successful candidate will be involved in coordinating the installation of communications technology.

Strong interpersonal skills are essential as is the ability to work produtively in a fast-paced, unstructured environment. This position requires a background in coordinating project installations and/or the communications industry.

Social Service

PROGRAM DIRECTOR

A major social service agency in Chicago is seeking a Program Director for an adult day training program for persons who are blind & developmentally delayed. Responsibilities include planning, organizing and supervising the activities

Health Care

PROGRAM DIRECTOR

[illegible] is seeking a Program Director for an 85 bed inpatient chemical dependency treatment center. Doctoral level psychologist or MSW with extensive management experience in large inpatient facility required.

Figure 16.3

Advertisements for project management positions.

no assurance the person will be a good project manager. In addition, the specialist must learn how to remove herself from her area of specialty and become a generalist.

Ideally, the project management assignment will not conflict with existing lines of authority. It is a bad idea, for example, to promote a specialist to the position of project manager and give her authority over her former boss.

Training

Project management skills cannot be learned quickly, so organizations devote significant time and expense in preparing individuals for the role. Some sponsor internal training programs that focus on the special requirements of their organizations; others use external seminars and university programs. Recent years have witnessed a proliferation of both kinds of programs and a rise in training directed toward professional certifications such as the PMP, APMP, and ICB-IPMA. Often, a project support office or PMO assists with this training and professional development.

But there is no substitute for experience. Many organizations allow promising people who aspire to become project managers the benefit of on-the-job training.[17] As part of their career paths, they rotate assignments throughout all areas of the organization to develop sufficient domain competency to enable them to manage projects that involve those areas. Technical specialists work full- or part-time as assistants to experienced project managers, and while this exposes them to management, it also tests their aptitude and talent for being managers. Valued technical specialists with little managerial aptitude or ability are given other non-managerial career opportunities commensurate with their skills and interests.

Example 16.3: On-the-Job Training of Project Managers[18]

Microsoft Corporation's approach to preparing project managers (which they term "program managers") is typical. There is neither an official program for training program managers nor guidelines that spell out job requirements. People learn the job by "doing" it. Microsoft carefully selects and mentors the right people, then expects them to learn on the job. For about 90 percent of program managers, training happens by pairing a new program manager with an experienced, successful program manager; the other 10 percent receive formal training that includes a 3-week training session. Microsoft occasionally holds video-recorded luncheons where managers present their experiences and then circulates the videos.

Moving into the role

Project management responsibilities range from few and mundane on simple projects to extensive and challenging on complex projects. Regardless of the project manager's qualifications, the burden of the role is eased when the project manager:[19]

- Understands what has to be done.
- Understands his authority and its limits.
- Understands his relationship with others in the project.
- Knows the specific results that constitute a job well done.
- Knows what he is able to do well and where he falls short.
- Is aware of what can and should be done to correct a bad situation.
- Believes that his superiors have an interest and confidence in him and want to see him succeed.

In ideal cases, senior management provides all of these to the project manager; sometimes, however, the project manager must seek out, request, or demand these.

16.4 Filling the project management role

Organizations use various titles for the project manager role, including “project director,” “project leader,” and “task force chairman.” The titles “task force coordinator,” “project supervisor,” and “project engineer” are also used, though these usually imply more focused roles with less responsibility than other forms. When no one is available or competent enough to manage the project, the role is filled in other ways. For example, it may be filled by the general manager or plant manager, though these managers usually have neither the necessary time to devote to the project nor the flexibility to shift roles. Alternatively, the role may be assigned temporarily to a functional manager. Here, the manager must divide her time between the project and her department, and both may suffer. Also, this combination functional-project manager may have trouble gaining cooperation from other functional managers when they see him as a competitor for resources. This “two-hat” role has other problems, as mentioned in Chapter 15.

See Chapter 15

In long-term projects, responsibility may pass from one functional manager to the next as the project moves through stages. In that situation, however, there is no one to provide the managerial or technical continuity to integrate the stages. The project moves through a series of handoffs, and managers of later stages are forced to inherit problems created by managers of earlier stages.

Sometimes project management responsibilities are divided among two or more people, as in construction projects where the architect is responsible for technical matters, while the so-called project manager handles administrative “paperwork.” Two managers tend to complicate issues of coordination, communication, and authority because both share responsibility. Further, when the project manager becomes subservient to, say, the architect, his ability to manage the project is compromised. A similar split is common in the motion picture industry. The movie *producer* manages the resources, schedules, and budgets (in essence, the project manager), while the *director* oversees technical-artistic matters; only occasionally are they the same person. Because the shooting of a motion picture is an artistic pursuit, directors need flexibility in budgets and shooting schedules, but costs matter, too, and the producer faces the question of “At what price creativity?” It is no surprise that the two do not always have a happy relationship.[20] Nonetheless, the movie industry holds the role of project manager in high regard. When an Academy Award is given for “Best Picture,” it is awarded to the picture’s producer—the person who managed the resources, budgets, and schedules.

Some projects, especially large ones in the public sector, require exceptional presentation, negotiation, and political skills to deal with broad stakeholder constituencies and powerful public- and private-interest groups. In such projects it is also common to see two people heading up a project—one to deal with technical matters, the other with stakeholders.

Ideally, there is but one project manager, and any others also serving in a managerial or administrative capacity (engineers, architects, directors, etc.) report to her. The project manager becomes involved during proposal preparation and remains through project closeout.

Although ideally, the person filling the project management role devotes full time to managing the project, it is common for managers to oversee multiple projects. This is acceptable as long as the manager can adequately fulfill the responsibilities for all of them. In fact, managing multiple projects can be advantageous because it puts the project manager in a position to resolve resource and priority conflicts and to negotiate resources among all the projects he oversees.

16.5 Roles in the project team

Early in a project, the project manager and functional managers divide the overall project into work packages. This division determines skill requirements and serves as the basis for personnel selection and subcontracting. Those individuals in the project office and from functional support areas and contractors and the project office who will contribute to the project become part of the *project team*. This section describes roles in the team.

Members in the project office

An example project office (described in Chapter 15 and not to be confused with a project *management* office or PMO) for a large engineering-development project is shown in Figure 16.4. Typically, the office will include the following members:

See Chapter 15

The *project engineer* (a.k.a. systems engineer or systems designer) is responsible for coordinating the technical areas and ensuring integrated design of the end-item. Sometimes the title "project engineer" denotes a person having full project manager responsibilities, although more commonly it refers to the more limited role described here. When several functional areas or subcontractors are involved, the project engineer:[21]

1. Oversees product or system design and development.
2. Translates performance requirements into design requirements.
3. Coordinates and directs the work of the functional areas and subcontractors.
4. Plans, monitors, evaluates, and documents progress in the design and testing of subsystems and the overall system.
5. Oversees configuration management and the change control system.

The *contract administrator*[22] is responsible for project legal aspects such as authorization to begin work and subcontracting with outside firms. Other responsibilities, discussed more fully in Chapter 12, include preparing proposals, defining and negotiating contracts, integrating contract requirements into project plans, ensuring fulfillment of contractual obligations, and monitoring and communicating project changes to the customer. During closeout, he notifies the customer of fulfilled obligations, documents customer acceptance of the end-item, and initiates formal requests for payment. He is also responsible for collecting and storing RFPs, correspondence, legal documents, contract changes, bills, and payment vouchers.

See Chapter 12

The *project controller*[23] works with functional managers to define tasks on the WBS and to identify individuals responsible for controlling tasks. She maintains work package files and cost summaries, releases approved work authorization documents, monitors work progress, evaluates schedule and cost progress,

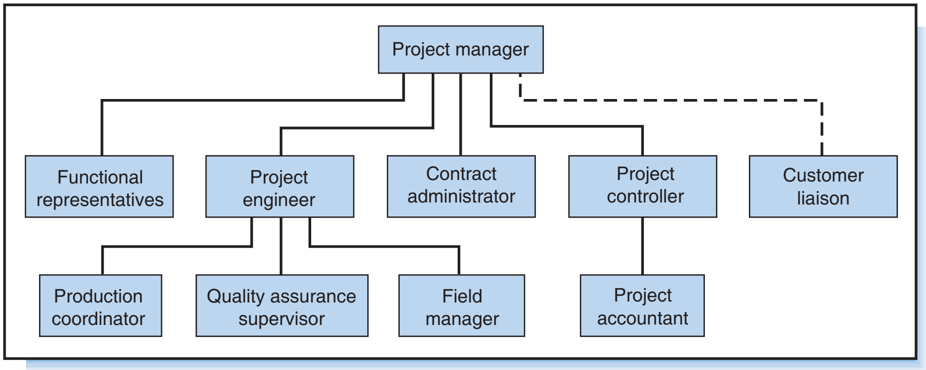


Figure 16.4
Members of the project office in a large engineering development project.

and revises estimates of time and cost to complete the project. She also prepares revisions to budgets, schedules, and work authorizations; drafts progress reports to users and management; and closes cost accounts upon project completion.

The *project accountant* provides accounting support to the project. He sets procedures for using the PMIS and PCAS, assists in identifying tasks to be controlled, establishes control accounts, prepares cost estimates, validates reported costs, and investigates financial problems.

The *customer liaison* maintains amicable contractor-customer relations. She participates in technical discussions and ongoing reviews (within the bounds of the contract) and helps expedite contract changes.

The *production coordinator* plans and coordinates production aspects of the project. Responsibilities include reviewing engineering documents released to production, developing requirements for equipment and parts, monitoring parts procurement and assembly processes for the end-item, monitoring production costs, scheduling production-related activities, and serving as the project manager's liaison to the production department.

The *field* or *site manager* oversees construction, installation, testing, and handover of the project end-item to the customer. Responsibilities include scheduling field operations, monitoring field operations costs, and supervising field personnel.

The *quality assurance supervisor* establishes and administers quality assurance procedures. His responsibilities are to raise quality awareness and institute means for improving work methods and producing zero defects.

The project office also has *representatives* from participating functional departments and subcontractors. These people work with the project manager and each other to coordinate the activities of their functional areas with the overall project. They work in and charge their time to the project office whenever they meet with the project manager and the other representatives, but they return to their functional departments as soon as their work has ended.

The number of staff in the project office should be as small as is practical. This makes the office simpler for the project manager to manage and minimize personnel costs and assignment problems. Members of the office staff contribute full- or part-time as needed and might be physically located in different places.

Functional managers

Often the glamorous work sits on the project side, and managers in functional departments feel their roles are diminished. But if earlier discussions have led you to believe that functional managers are somehow subservient to the project manager, be advised that that is rarely the case. Functional and project managers depend on one another to achieve project goals. Functional managers are responsible for maintaining technical competency and staffing and executing project tasks *within their disciplines and functional areas*. They work with the project manager to define the tasks and to plan, schedule, and budget them.

Personnel in matrix organizations shift from one project to another, and their only permanent "home" is their functional department. The functional manager is responsible not only for the hiring, performance reviews, and compensation of the people in his area but also their career development. Unlike project managers, who tend to solicit "human resources" solely in terms of what is best for their projects, functional managers are more likely to look out for the interests of the people being solicited.

In most project organizations, functional managers retain much the same authority and responsibility as in non-project environments. Nevertheless, some functional managers believe that the project manager role undercuts their authority and that they could handle each project better if it were exclusively within their domain. Project managers who try to undermine the authority of functional managers will have difficulty obtaining support and resources they need when they need them (see, for example, Case 15.3 in Chapter 15).

See Chapter 15

Before a project begins, the responsibilities and contributions to technical content for each functional manager should be clearly delineated.[24] This will ensure a continued strong technical base for all projects and alleviate potential animosity between functional and project managers.

Project functional leaders and work package supervisors

In some projects, each functional manager selects a *project functional leader* to serve as liaison between himself and the project manager. This person prepares his department's portion of the project plan and supervises project work performed by the department.

When a large amount of work is assigned to a given department, that work is divided into multiple work packages, and responsibility for each is delegated to a *work package supervisor*. The supervisor prepares the plan for the work package and supervises the work.

16.6 Roles outside the project team

This section discusses some individuals and groups outside the project team who contribute to managing the project (Figure 16.5).

Manager of projects or project management office director

The *manager of projects* (also called the PMO director, vice president of projects, or director of projects) is at the same level in the hierarchy as functional managers (see Figure 15.8 in Chapter 15). This manager oversees *multiple projects* and:[25]

See Chapter 15

- Directs and evaluates all the project managers.
- Ensures projects are consistent with the organization's resource limitations and strategic objectives.
- Works with functional heads to allocate resources and resolve priority conflicts between projects.

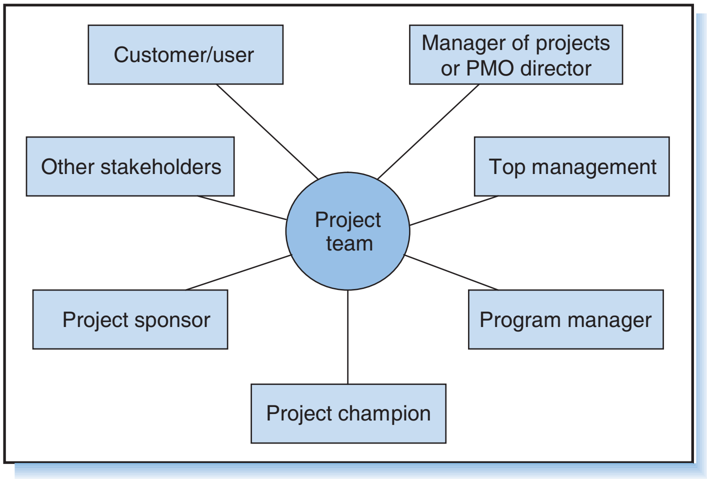


Figure 16.5
Project roles outside the project team.

- Assists in developing project management policies and techniques and systems for project planning and control.
- Ensures consistency among projects and that changes to one project's cost, schedule, or performance objectives are integrated with those of other projects.

See Chapter 18

Chapter 18 describes the role of the PMO more fully.

Top management

See Chapter 19

Top management makes all major decisions about project selection and prioritization. It approves the project feasibility study, selects the project manager, and authorizes project startup. In organizations that practice *project portfolio management* wherein projects are managed in groups for better alignment with organizational strategies and allocation of resources, responsibility is headed by the project portfolio manager, discussed in Chapter 19.

Top management establishes the rules and policies that govern the organization's project management. Directly or through the PMO, it:[26]

- Defines the project manager's responsibility and authority relative to other managers.
- Defines the scope and limitations on the project manager's responsibilities.
- Establishes policies for resolving project conflicts and setting priorities.
- Specifies criteria for evaluating the project manager's performance.
- Supports the project management methodology.

A project manager's authority is only as granted by the manager of projects and stated in the organization's charter or as agreed in the contract with the customer. In situations involving critical negotiations or irresolvable conflicts, top management may preempt the authority of the project manager.

Program manager

See Chapter 18

When the project is part of a larger effort called a *program*, the project manager works with the *program manager*, who is responsible for coordinating the project with other projects working to achieve program goals. The role of program manager is discussed in Chapter 18.

Project supporters: sponsor and champion

Every project ideally has the support of two key outsiders, the *project sponsor* and the *project champion*. The project sponsor is someone who works to ensure that the project gets the necessary priority, funding, and resources and thus has a disproportionately high impact on the project's success. This person has the formal authority necessary to clear roadblocks and the leadership ability to influence top management. As a consequence, the sponsor often holds a senior position in the customer organization. During project conception, the sponsor becomes the "owner" of the project business case; thereafter, the sponsor is responsible for realization of the expected benefits specified in the case.

Depending on the project, the sponsor might devote little time or much time to the role; in very big projects, the role requires a dedicated, full-time person. In all cases, the sponsor is the interface between the customer and project organizations and is available to assist the project manager, particularly for decisions and issues beyond the project manager's authority or control.

To be effective, the sponsor must be someone who is able to influence key decision-makers and who acts in the long-term interests of the customer organization. When the project is part of a program, the program manager sometimes serves as the project's sponsor.

The project champion is someone who firmly believes in the project and argues in its favor, both at its inception and thereafter. The main role of the champion is to *sell* the project, especially to external stakeholders—those not involved on the project but who will be affected by it. To most of these stakeholders, the champion is the project's most visible and outspoken spokesperson. The champion, like the sponsor, must be respected and the sort of person able to convince stakeholders of the project's value and benefits; unlike the sponsor, however, the champion often lacks the formal authority to remove barriers and command resources. When the project does not have a champion, the project manager might have to put on his "evangelist" hat and go scout for one.

Occasionally the champion and sponsor are the same person.

16.7 Project stakeholders[27]

The term "stakeholders" appears throughout this chapter and everywhere in the book. That's because stakeholders are key players in projects and perform critical roles in project management. By definition, a *project stakeholder* is any group or individual affected by, interested in, or potentially influential on the project. Among the most important stakeholders are project customers and users but also others that include prospective customers/users, partners, lenders, governments, the press, and trade groups. Recognizing that projects have widespread—even global—environmental impacts, we can also include as project stakeholders everyone concerned about or affected by the project's environmental impacts, including everyone in the larger community and society as whole. For that matter, we might include all of Earth's living organisms and ask, might the project contribute to species extinctions now or in the future, and what might be done to mitigate it? That's an existential question, but certainly one worth pondering as much by project managers as anyone.

Some stakeholders support the project and want it to succeed; others resist it and want it killed. The latter might include environmental or political interest groups or lobbies and anyone who competes with the project for resources or perceives the project as detrimental to their own or society's interests.

Stakeholder engagement

Most stakeholders are not aware of and don't care about other stakeholders. Before a project starts, the project manager needs to learn who the stakeholders are. In essence, he should prepare a list of all individuals, organizations, and groups influenced by or able to influence the project and try to determine possible relationships or lines of influence among them. This is part of *stakeholder engagement*, which includes learning who the key stakeholders are; understanding their interests, needs, and attitudes regarding the project; and preparing strategies to accommodate them. To do that usually requires talking directly to stakeholders to learn their views and opinions, what they hope for from the project (and the project manager), what they need (explicit requirements) and expect (unstated requirements), and how they might be influenced. Given limited resources, technical capability, or the demands of other stakeholders, not every need and expectation can be met, in which case the project manager does the best she can. Sometimes she does what she does simply because it is the "right" or ethical thing to do.

Example 16.4: Disgruntled Stakeholders

Chris is the project manager for a 54-story office tower rising next to the Chicago River. The tower overshadows a 12-story loft building next door; as it rises, it blocks stunning views the loft residents once had of the river and skyline—a common problem in cities wherever one building goes up next to another. To acknowledge their annoyance, Chris arranged every morning for coffee, rolls, and donuts from a popular coffee shop to be served in the loft-building lobby. When some residents complained they didn't like the coffee, he switched to another shop. One weekend after the lower floors of the new building had been erected and the site cleaned up, he organized a day-long picnic with activities for the loft residents and families. When one resident, Hilda, complained that her small unit would be in full view to anyone in the new building. Chris offered to buy her blinds and drapes, but she refused.

Early every morning, construction on the new building resumes and, with it, bright lights and cacophony. To remind him of her irritation, every morning Hilda leaves a message on Chris's cell, something like, "Here it is 5 am and I'm wide awake because of all the commotion you are causing." Several times a week, Chris calls her back. Ever courteous, he apologizes there isn't more he can do to make things better for her.

The list of stakeholders may be long, and the amount of communication with, information provided to, and interaction with each should depend on their interests in the project and power or ability to influence the project's outcomes. The table below shows appropriate strategies for dealing with stakeholders, depending on their level of interest and potential level of influence.

Stakeholder interest and influence	*Stakeholders with low influence on the project*	*Stakeholders with high influence on the project*
Stakeholders with high interest in project	Keep informed	Focus on these: keep informed and satisfied
Stakeholders with low interest in project	Possibly ignore; monitor for changes in interest/influence	Keep satisfied

For example, stakeholders with high influence but low interest need to be "kept satisfied," lest they become unsatisfied and then opposed to the project. The chosen strategy should address whether the stakeholder's "interest" is supportive, opposing, or neutral, how the project manager will engage the stakeholder throughout the project, and the stakeholder's communication preferences (face-to-face, phone, email, etc.).

For stakeholders opposing the project, the strategy should specify how to gain their support or, failing that, how to mitigate or accommodate their opposition. As Example 16.4 showed, the strategy might be to try to satisfy all high-interest stakeholders, even if they have low influence.

All of this can be included in a *stakeholder engagement plan* that lists the stakeholders and for each their interests and level of influence and strategies for communicating with, engaging, or otherwise dealing with them. The engagement plan should be reflected in the project communication plan and the project execution plan. Getting a project off the ground involves negotiating hoops and hurdles posed by stakeholders; the project manager is always mindful of those stakeholders and works to gain and retain their support in ways big and small.

Example 16.5: The Big Dig[28]

Boston's Central Artery/Tunnel Project (CAT)—known locally as the Big Dig—is an example of a complex project that must accommodate the interests of many stakeholders, including federal, state, and local governments; contractors; and many interest groups (Figure 16.6).[29]

The central artery portion of the project replaced the elevated interstate highway that ran through downtown Boston with a tunnel. The elevated highway (derisively called the "green snake") was an eyesore that separated Boston's North End and waterfront from the rest of downtown. Besides replacing the central artery, the CAT project included a tunnel under Boston Harbor to Logan Airport and new bridges across the Charles River to Cambridge—a total of 160 lane miles over 3.7 miles of tunnels, 2.3 miles of bridges, and 1.5 miles of surface streets. Celebrated as "the largest, most complex highway project ever undertaken in the US," its original price tag was $5 billion; the project eventually cost over four times that amount.

Project supporters faced daunting problems. The Massachusetts congressional delegation had to drive bills through the US Congress that would provide most of the funding; this required taking into account the interests of—and making promises to—a large host of ad hoc congressional allies. With funding authorization from the Federal Highway Administration (FHWA), supporters turned to the issue of who should oversee the project, the Massachusetts Bay Area Transportation Authority (MBTA) or the Massachusetts Department of Public Works (DPW). Although the MBTA had a better construction management reputation, the job was given instead to DPW on the rationale that MBTA is a transit, not highway, agency. To manage the project, DPW hired the experienced contractor team of Bechtel/Parsons Brinckerhoff, a joint venture formed by two of the world's largest consulting and management engineering firms—Bechtel Corporation and Parsons Brinckerhoff Quade & Douglas. The two (called Joint Venture) had partnered

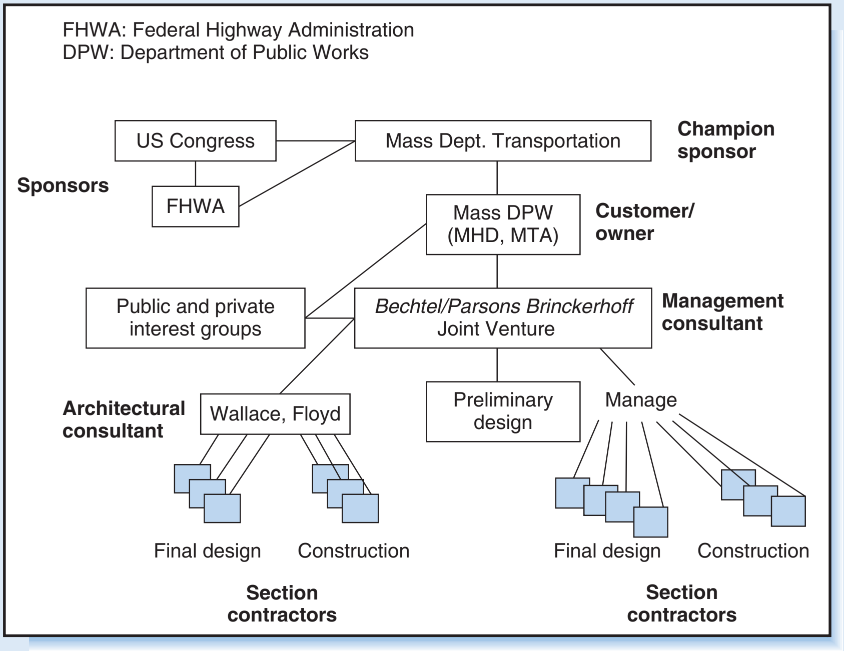


Figure 16.6
Key stakeholders in the Big Dig project prior to 1992.

before as contractors for the San Francisco BART System, and Bechtel had worked on the English Channel Tunnel and Disney's MGM theme park in Florida.

The CAT project was broken down into the phases of conceptual design, preliminary design, final design, and construction. Joint Venture created the preliminary design but hired contractors for final design and construction. Initially, the project consisted of 56 design and 132 construction work packages, each with a prime contractor. Managing the contractors responsible for the artery and tunnel design packages required especially close coordination, since these packages produced contiguous road and tunnel sections that had to dovetail.

In accordance with the law, Joint Venture placed a draft of the project in public libraries and provided public hearings. These resulted in DPW and Joint Venture engineers having to negotiate with hundreds of neighborhood, church, business, and environmental groups; developers; and individuals to mitigate countless issues regarding community and environmental impacts. These ultimately contributed to large escalations in project scope, costs, and schedules.

Example 16.6: McCormick Place West[30]

McCormick Place West is part of a major multiyear, multiphase project to expand Chicago's McCormick Place convention complex. The group of companies that teamed up to design and build the structure (another "joint venture") worked to establish relations with nearby residents and businesses. Project managers and staff visited local high schools to educate students about practices and careers in construction, engineering, and architecture. They offered a program to hire local workers, teach them trade skills through hands-on experience, and the opportunity to become union certified; about 20 people a year became certified in this way. The contractor donated old computers to local schools and cars for their shop classes. Copying a popular reality-TV series, the company remodeled the home of a local needy family. These and other charitable programs benefited the local community and helped the contractor to gain the community's support.

16.8 Summary

Project managers work at the project-functional-customer interface, integrating project elements to achieve time, cost, and performance objectives. They have ultimate responsibility for the success of projects yet often work outside the traditional hierarchy and thus have little formal authority. To influence decisions and behavior, they tend to rely on negotiation, alliances, favors, and reciprocal agreements. Their strongest source of influence is the respect they gain through skillful and competent administration, technical competency, and charisma.

Successful project managers are perceived as both technically and administratively competent. They have both business and domain competency—broad knowledge encompassing the full scope of the project. They also have strong behavioral and communication skills and are able to function effectively in uncertain, fluid conditions.

The role of project manager is best filled by one person who is involved in the project from start to finish. Sharing or rotating the role among several people is usually less effective, although appointing different project managers for different project phases is sometimes necessary to meet technical, administration, or political considerations.

Project managers get work done through a team composed of people from various functional and support groups scattered throughout the parent company and from outside contractors. Providing administrative assistance to the project manager is the project office. Functional managers contribute to the technical content of the project and share responsibility for developing plans, schedules, and budgets for tasks performed by their areas. They maintain the technical base from which projects draw.

Top management, the manager of projects or PMO director, the program manager, and the project champion and project sponsors all play key roles in the project. Top management establishes the policies, responsibilities, and authority relationships through which project management is conducted. The manager of projects or PMO director ensures that projects are consistent with organizational goals and receive the necessary resources. The champion rallies support for the project and convinces others of its benefits and value. The sponsor supports the project and through organizational clout helps the project get the needed priority and resources.

Numerous other stakeholders support or resist the project and can have a big impact on its success or failure. The project manager needs to know who they are and their interests in and influence on the project and develop strategies for the most important stakeholders to gain their project support or mitigate or accommodate their opposition.

People find project work challenging, rewarding, and exhilarating, but, without question, they often also find it taxing and stressful. Maximizing the chances of project success—and minimizing human casualties along the way—requires special skills for dealing with groups and individuals. These are covered in the next chapter.

Review Questions

1. What is the project manager's primary role?
2. What is meant by "the project manager is an evangelist and entrepreneur"?
3. Describe the responsibilities of a project manager. In what ways are budgeting, scheduling, and controlling considered integration and coordination responsibilities?
4. Discuss the relative need for both technical and managerial competence in project management.
5. Why is a broad background essential for the project manager? What is a broad background?
6. What is legal authority? How does it differ from charismatic authority?
7. Describe how and in what ways people in organizations, regardless of hierarchical position, influence others.
8. How does the authority of the typical project manager differ from authority of other managers?
9. What is meant by the "authority gap"?
10. What is the most common source of influence used by project managers? How does the project manager use this influence to induce functional managers to assign personnel to the project?
11. List the ideal qualifications—personal, behavioral, technical—for project managers. How do they differ from the qualifications for functional managers? How do these vary depending on the project?
12. Discuss the considerations in selecting a project manager from among each of the following groups: experienced project managers, functional managers, and functional specialists.
13. Discuss the pros and cons in the various ways of filling the role of project manager (e.g. part-time, multiple project managers for one project, one manager for multiple projects, etc.).
14. How are project managers trained on the job? What are the advantages and drawbacks of relying upon on-the-job training as a source for project managers?
15. Describe the responsibilities of key members of the project office for a large-scale project.
16. Describe the responsibilities of the manager of projects or PMO director.
17. Describe the project-related responsibilities of top management.

18. Describe the responsibilities of the functional manager, the project leader, and the work-package supervisor in project management and their interfaces with one another.
19. Who is the project champion, and who is the project sponsor?
20. Who are the stakeholders? What influence do they have on a project, and why is it important to consider them? What should the project manager do to "manage" stakeholders and their expectations?

Questions About the Study Project

1. In your project, what is the formal title given to the role of project manager?
2. Where in the organization structure is the project manager? Show this on an organizational chart.
3. Describe in one sentence the overall role for the project manager of your project. Now, list his or her *specific* responsibilities.
4. In your opinion, is the so-called project manager the *real* project manager, or is someone else controlling the project? If the latter, what effect does this have on the project manager's ability to influence the project?
5. Would you describe the project manager's orientation as being more technical or more managerial? Explain.
6. Describe the project manager's professional background. Has it helped or hindered her ability to be a project manager? (You might pose this question to the project manager.)
7. Describe the project manager's authority. How much legal authority does the project manager have? Is the project manager's authority specified in the organization charter?
8. How big would you say is the project manager's authority gap? Explain. Does the project manager have any complaints about it?
9. From where does this organization get its project managers? Does it have a procedure or seminars for training and selecting project managers? Where did the manager of your project come from?
10. How does this project manager fill the role: part- or full-time, shared or rotated with other managers, manager of several projects at once? Explain. Does the project manager have enough time to do an effective job? Would another way of filling the position be more effective?
11. Is there a project office? If not, how are the responsibilities (e.g. for contract administration) handled? If so, who is in the project office (project engineer, contract administrator, field representative, etc.)? Are they on loan, full-time, or part-time? Describe their responsibilities.
12. What functional managers are involved in this project? Describe their responsibilities in the project and decisions they make unilaterally or share with the project manager.
13. Is there a manager of projects or PMO director? Project champion? Sponsor? Describe their responsibilities and influence on the project.
14. What has been the role of top management in your project? What, in general, is the involvement of top management in projects in this organization?
15. Who are the other key stakeholders? How has the project manager communicated or worked with, engaged, or otherwise accommodated them in planning and executing the project?

CASE 16.1 THE LOGON PROJECT

Top management of the Iron Butterfly Company (IBC) has decided to adopt a project-management form of organization for the LOGON project. As a consultant to top management, you have been given two tasks to help implement this. First, you must develop a project management policy statement and a project manager job description. The policy statement should define the project manager's role with respect to functional managers and clarify the role of functional managers in the project. The job description must define the specific responsibilities and legal authority of the project manager. You should consider the functional managers' reactions to the policy statement and job description and how best to get their "buy in." How can the project manager have sufficient authority to manage the LOGON project without usurping the authority of the other managers whose support is necessary? You should also suggest to top management what forms of incentives can be used to get team members to work together toward project goals. Remember, the functional departments are also currently involved in their own work and work in other project activities.

Your second task is to specify and document the qualifications for the position of LOGON project manager. After considering the nature of the project (technical scope, risks, complexity, etc.) as described in Case 15.1, prepare a list of qualifications—general background and experience; personality characteristics; managerial, technical, and interpersonal skills—for screening candidates and making the final selection. IBC has some employees who have worked as project coordinators and expediters, but none are experienced as a pure project or matrix manager. Consider the assumptions and pros and cons of selecting a functional manager or technical specialist from inside IBC or an experienced project manager from outside the company. A contract has been signed, and LOGON is to begin in 4 months.

See Chapter 15

CASE 16.2 SELECTING A PROJECT MANAGER AT NUWAVE PRODUCTS COMPANY

Nuwave Products Company, a medium-sized manufacturer of small motors and motor parts, recently contracted with a software consulting firm, Noware, Inc., to design software for a new integrated manufacturing system to be installed in the near future. The software design is part of a much larger project that also involves procurement and installation of new manufacturing equipment, a new production process, and retraining of workers. The new production process will involve "lean production" concepts that are very different from Nuwave's current process; it will engage workers in improvement efforts and ultimately require no less than a *cultural change* among Nuwave's managers, supervisors, and line workers.

Ordinarily, the manufacturing department assigns a project manager to projects that involve new processes. However, no one in the department has any experience with a project of this scope, the new software and equipment, or with lean production concepts and cultural change. Some Nuwave managers think that besides designing the software, Noware should oversee the entire project—equipment installation, the "lean transition," and worker training. In contrast, the manufacturing department manager thinks that one of his senior engineers, Roberta Withers, should handle the project. She has a thorough knowledge of the current manufacturing process and is the department's expert in mechanical systems. She is a degreed mechanical engineer and has been with Nuwave manufacturing department for 6 years. She knows nothing about lean production or integrated manufacturing systems, but her boss thinks the project would provide a good opportunity for her to learn.

Assume that you must act on the information provided: if it were up to you, who would you select to manage the project: Noware, Roberta, or someone else? Explain.

CASE 16.3 STAKEHOLDERS IN BOSTON'S BIG DIG[31]

(Refer to Example 16.5, previously.) Before the Massachusetts congressional delegation could seek federal funding for the Big Dig project, it first had to poll constituents about sensitive transportation issues. Then-Speaker of the House Thomas "Tip" O'Neill wanted to know where his supporters—voters of East Boston—stood. When first told about the project, he said, "We're not building any tunnel." He changed his mind when supporters predicted that "the trade unions are going to be marching on you (if you veto the tunnel)" and assured him that "no homes would be lost" in East Boston. The delegation then faced opposition from the Reagan administration and FHWA, both of which initially argued that the project was ineligible for federal funding.

An early responsibility of the Joint Venture/DPW management team was to prepare an environmental impact statement, the draft of which consisted of several thick volumes. Part I described impacts in 17 categories, including "transportation," "air quality," "noise and vibration," "economic aspects," "visual characteristics," "historic resources," "water quality," "wetlands and waterways," and "vegetation and wildlife." Under "economic aspects," it described commercial and industrial activity, tourism, and employment patterns in the affected areas. The report claimed the project would not displace any residences but would relocate 134 businesses with 4,100 employees.

At the first public hearing, 175 persons spoke, including some from the EPA and the Sierra Club, and 99 provided written commentary. The project's magnitude and complexity is reflected in a sampling of the public interest groups represented: The 1000 Friends of Massachusetts, American Automobile Association, Archdiocese of Boston/Can-Do Alliance, Beacon Hill Civic Association, Bikes Not Bombs, Boston Building Trades Association, Boston Society of Architects, Charles River Watershed Association, Conservation Law Foundation of New England, and Haymarket Pushcart Association.

The Massachusetts Secretary of the Environment issued a certificate of approval, allowing construction to proceed only after certain measures had been implemented to mitigate environmental impacts. The certificate recommended planning for utilization of 27 acres of downtown Boston that would be newly created by the removal of the elevated Central Artery and urged formulating "creative strategies" for integrating the new highway system with mass transit, limiting downtown parking, and reserving highway lanes for high-occupancy vehicles.

Beyond environmental matters, the project had to respond to issues raised by hundreds of groups, businesses, and agencies; officials put the number of early mitigation commitments at 1,100 for an added project cost of $2.8 billion, including $450 million for temporary lanes, curbs, and sidewalks that would enable businesses to continue during construction and $230 million for the City of Cambridge to build a park along the Charles River.

QUESTIONS

1. From information provided here and in Example 16.5, create a list of the project's stakeholders. Expand Figure 16.6 to include them and show possible links (relations or influences) between them. For each stakeholder, state its likely interests in the project and ways it could influence the conduct of the project and its outcomes.
2. Considering the project's technical aspects (building tunnels, roadways, and bridges; demolishing the elevated structure and replacing it with parks) and its political, economic, environmental, and social impacts (and stakeholders for each), what characteristics (skills, background, competencies) would the "ideal" manager need to oversee a project of such scope and magnitude?

Notes

1. Sayles L. and Chandler M. *Managing Large Systems: Organizations for the Future*. New York: Harper & Row; 1971, p. 204.
2. Ibid., p. 212.
3. Ibid., p. 204.
4. Portions adapted from Smith R. *The Carving of Mount Rushmore*. New York: Abbeville Press; 1985.
5. Ibid., pp. 17–18.
6. Ibid., pp. 164.
7. Archibald R. *Managing High-Technology Programs and Projects*. New York: Wiley-Interscience; 1976, p. 35; Atkins W. Selecting a project manager. *Journal of Systems Management*; October 1980: 34; and Roman D. *Managing Projects: A Systems Approach*. New York: Elsevier; 1986, p. 419.
8. Lawrence P. and Lorsch J. *Organization and Environment: Managing Differentiation and Integration*. Boston: Graduate School of Business, Harvard University; 1967, Chapter 3.
9. These bases of interpersonal power were first described by French J. and Raven B. The bases of social power. Reprinted in Cartwright D. and Zander A. (eds). *Group Dynamics*, 3rd edn. New York: Harper & Row; 1968, pp. 259–269.
10. Hodgetts R. Leadership techniques in the project organization. *Academy of Management Journal* 11; 1968: 211–219.
11. Rich B. and Janos L. *Skunk Works*. Boston: Little, Brown & Co; 1994.
12. Katz R. and Allen T. Project performance and the locus of influence in the R&D matrix. *Academy of Management Journal* 28(1); 1985: 67–87.
13. Archibald. *Managing High-Technology Programs*, p. 55.
14. Adams J., Barndt S. and Martin M. *Managing by Project Management*. Dayton: Universal Technology; 1979. p. 137.
15. Gaddis P. The project manager. *Harvard Business Review*; May–June 1959: 89–97.
16. Ibid., p. 95.
17. Roman. *Managing Projects*, pp. 439–440.
18. Cusumano M. and Selby R. *Microsoft Secrets*. New York: Free Press; 1995, pp. 105–106.
19. Kerzner H. *Project Management: A Systems Approach to Planning, Scheduling, and Controlling*. New York: Van Nostrand Reinhold; 1979, p. 99.
20. An example is the movie Heaven's Gate, where the director was allowed to virtually dominate the movie's producers. Scheduled for completion in 6 months at a cost of $7.5 million, the production was released a year late and $28 million over budget. The movie was a box office flop and helped clinch the demise of the film's underwriter, United Artists. From Bach S. *Final Cut*. New York: William Morrow; 1985.
21. Responsibilities for project engineers are described in Chase W. *Management of Systems Engineering*. New York: Wiley-Interscience; 1974, pp. 25–29.
22. According to Archibald. *Managing High-Technology Programs*, pp. 124–128, 199.
23. Ibid., pp. 128–131.

24. Katz and Allen. Project performance and the locus of influence, pp. 83–84.
25. Cleland D. and King W. *Systems Analysis and Project Management,* 3rd edn. New York: McGraw-Hill; 1983, p. 358.
26. Ibid., pp. 362–363.
27. See Schibi O. *Managing Stakeholder Expectations for Project Success*. Plantation, FL: J Ross Publishing; 2013; Roeder T. *Managing Project Stakeholders*. New York: Wiley; 2013.
28. Hughes T. *Rescuing Prometheus*. New York: Vintage Books; 1998, Chapter 5; Luberoff D., Altshuler A. and Baxter C. *Mega-Project: A Political History of Boston's Multibillion Dollar Artery/Tunnel Project*. Cambridge, MA: Taubman Center, John F. Kennedy School, Harvard University; 1993, www.bigdig.com/:http://lfmsdm.mit.edu/news_articles/sdm_business_trip_fall03/sdm_business_trip_fall03.html
29. Figure 15.6 shows stakeholders prior to 1992. After that, Joint Venture accountability shifted from the Massachusetts DPW to the Massachusetts Highway Department; after 1997, it shifted to the Massachusetts Turnpike Authority (MTA). In 1998, Joint Venture and MTA formed an "integrated project office" to combine Joint Venture's management-consultant expertise with MTA's long-term dedication and specialized experience. Source: Completing the "Big Dig": Managing the Final Stages of Boston's Central Artery/Tunnel Project. National Academies Press; 2003, Chapter 5, http://books.nap.edu/openbook.php?record_id=10629&page=31, accessed May 8, 2007.
30. Klinger A., Belmonte D., Chou E., Phares C., Volman N. and Pina R. *The McCormick Place West Expansion Project*. Loyola University Chicago Report, February 2005.
31. Source: Hughes. *Rescuing Prometheus*.

Chapter 17

Leadership, teamwork, and conflict

Eh! Je suis leur chef, il fallait bien les suivre.
Ah well! I am their leader, I really ought to follow them!

—Alexandre Auguste Ledru-Rollin

Teambuilding. We don't need that!
I'll skip this chapter.

—Anonymous Project Manager

During the manned landings on the moon, researcher Richard Chapman conducted a study of NASA project management.[1] This was during NASA's heyday—a period marked by extraordinary achievements and a time when NASA was upheld as exemplar of a large public agency that actually worked. It is instructive to begin this chapter with some of Chapman's observations about the project managers of that era; paraphrasing his comments:

> Besides technical competency and management capacity, all agree that the project manager must have the ability to build a cohesive project team.
>
> (p. 93)

> Those project managers who developed the most closely knit project teams placed an emphasis on decentralized decision-making and technical problem-solving at the level where both the problem and the most experience reside. They encouraged project members to feel a sense of responsibility for problem-solving at their respective levels, within the assigned guidelines.
>
> (p. 83)

> Most project staff believed they received generous support and attention from the project manager, and most acknowledge that the project manager is vigorous and fair in bestowing recognition on team members and in rewarding them to the best of his capability.
>
> (p. 82)

In another study of NASA, E. H. Kloman compared the performance of two large projects, Lunar Orbiter and Surveyor. Lunar Orbiter was a success and fulfilled objectives within time and resource limits; Surveyor was less successful and experienced cost and schedule overruns. The study characterized customer/contractor organizations in Lunar Orbiter as tightly knit *cohesive* units, with good *teamwork* and mutual *respect* and trust among project counterparts. In contrast, teamwork in Surveyor was characterized as "slow and fitful" to grow and "spurred by a sense of anxiety and concern."[2] Kloman concluded:

> What emerges perhaps most forcefully from a broad retrospective view is the importance of the human aspects of organization and management. Both projects demonstrated the critical nature of human skills, interpersonal relations, compatibility between individual managers, and teamwork.
>
> (p. 359)

The fact that these studies were conducted some years ago shouldn't matter, because numerous studies since then of project leadership and teams have concluded the same things: that behavioral issues such as leadership style, decentralized decision-making, and teamwork are all crucial to project performance.[3] Unfortunately, such matters are often overlooked in project management practice and education, possibly because inexperienced managers and specialists in the "hard" disciplines (technicians, engineers, and business people) see them as "soft" and relatively inconsequential. But in reality, these are not soft; they are hard as nails and can profoundly impact project performance.

This chapter discusses issues broached by these studies: leadership, participative decision-making, teamwork, and the related topics of conflict and emotional stress in work.

17.1 Leadership in project management

Leadership style

Chapter 15 described organizational forms suitable for different purposes and types of projects. Likewise, there are a variety of suitable leadership styles, depending on the situation. Leadership is the ability to influence the behavior of others to accomplish something desired; *leadership style* is the way a leader achieves that influence.

Leadership style can be categorized between the two extremes of *task-* or *goal-oriented* and *relations-oriented*. Task-oriented managers show higher concern for the goal and the work and tend to behave in a more dictatorial, bureaucratic fashion. The style is also referred to as *vertical leadership*, implying top-down influence whereby people simply do whatever they are told to do. Relations-oriented managers show greater concern for people and tend to behave more democratically. Close variants of this style are *shared leadership* and *distributed leadership*, meaning that team members are allowed to participate as needed in decision-making, sharing accountability, helping each other, and performing duties ordinarily expected of the project manager.[4] The project manager shares or distributes the leadership role among team members, seeking their advice and opinions and, sometimes or always, delegating decision-making responsibility.

Numerous studies have attempted to discern the most effective leadership style. Most conclude that no one leadership style is best for all situations. Effectiveness of style depends upon characteristics of the leader, the followers, the leader's interpersonal relationship with followers, the type of project, and the nature and environment of the work. This perspective, called the *contingency* or *situational approach* to leadership, suggests that the leader should apply the style that best fits the situation and *not* use the same style for all employees and situations. The following section briefly describes two such approaches as conceived by researchers Fred Fiedler and Hersey and Blanchard.

Contingency and situational leadership

According to Fiedler,[5] the three variables that most affect a leader's influence are whether (1) the work group accepts or rejects the leader, (2) the task is routine or complex, and (3) the leader has high or low formal authority. A project manager might encounter any of these situations, although commonly:

- The project manager gets along with team members and is respected for his ability and expertise.
- The task is relatively complex and requires a good deal of judgment or creativity.
- The project manager has relatively low formal authority.

Fiedler's research indicates that under these conditions, a *relations-oriented* style is the most effective. The most prominent behavior in this style is the leader's positive emotional ties with and showing concern for his subordinates.

Hersey and Blanchard[6] developed a model called *situational leadership* that weighs the interplay of three variables: (a) the amount of direction and guidance a leader gives (task behavior), (b) the amount of socio-emotional support he gives (relations behavior), and (c) the readiness of followers to perform the task (maturity). The last variable, "maturity," has two aspects: the followers' *skill* or *ability* to do something and their *motivation* or *willingness* to do it. According to the model, the most effective leader behavior depends upon the maturity level of the followers. Project managers seldom manage unskilled laborers; more often, they deal with technical specialists, managers, professionals, tradespeople, and other skilled people. Thus, they usually work with people who are either (1) able but perhaps unwilling to do what the manager wants, or (2) both able and willing to do what he wants. For Group (1), the model recommends a *participative* style; that is, the leader facilitates, supports, and communicates with followers, and the leader shares decision-making with them. For Group (2), the model recommends a *delegating* style; that is, the leader identifies the problem or goal, then delegates to followers responsibility for solving the problem and determining how to implement it.

Occasionally, project managers encounter a Group (3)—people willing to work but relatively unable or unskilled (e.g. recent college graduates). For this group, the model recommends the leader provide instruction and close supervision. This situation is a special case, however, for even when the project manager does provide instructions, he encourages followers to develop the capabilities necessary to enter the ranks of Group (2).

In researching the management of scientific and technical personnel, Hersey and Blanchard found that people with high-level education and experience respond well to participating and delegating leadership and *do not* respond well to detailed directions and close supervision. Of course, this is not to say that project managers never face workers who are unwilling to follow instructions or take initiative. In cases where participation or delegation fails, a project manager with legal authority (e.g. a pure project manager) may need to cajole, give orders, and even terminate workers.

Other studies support these findings and conclude that in most project environments, an engaging, participative style works best; even in engineering and construction, where the leader needs to provide a strong sense of direction to the team, project managers tend to involve members in helping set that direction and in determining how best to achieve project goals.[7]

Project circumstances

Effective leadership style also depends on project circumstances. For example, a more directive style may be appropriate when there is pressure to complete the work quickly; in other words, sometimes the *pace* of work calls for a more directive leadership style, and the intensity of work serves as the motivator. Also, in a high-paced project, there might be little time to build the trust necessary for a more participative style; this is sometimes the case when the project team involves subcontractors or a workforce that the project manager is unfamiliar or unaccustomed to working with. In such situations, the project manager may need to be more directive and assertive. As in other regards, the project manager must be adaptable—able to wear different leadership-style hats and change them quickly.

17.2 Participative management and shared leadership

The models of both Fiedler and Hersey and Blanchard offer similar conclusions about project leadership: the most effective style for project managers is a relations-oriented style—engaging, sharing, supportive, facilitative, and encouraging. Sometimes project managers must give orders or tell people what to do, but in most project situations, participation and delegation work best, even when combined with task- or goal-oriented behavior. This means that, usually, project managers involve others in decision-making, are supportive, and avoid dogmatic or intolerant behavior. Especially in projects with high potential for conflict, they invest considerable emotional energy in developing trust and interpersonal relationships.

This conclusion is further supported by research from large technical projects showing that the most effective leadership style is *participative management*. Managers in those projects seldom give orders to those they must influence, partly because most of these individuals are not subordinate to the project manager, partly because giving orders induces a negative "I won't do it" or "Do it yourself" reaction, and partly because the "subordinates" are, after all, the experts in their fields. Project managers use participative management because, to an extent, they must. Although they have a good view of the total project—its goals and constraints—they are usually farther removed from technical problems and less qualified to resolve those problems than the people who report to them.[8]

But participative project managers do not relinquish responsibility; depending on the situation, they delegate it and share it. Even when they have legal authority, they involve others by acquainting them with problems, consulting them for their opinions, and giving frequent feedback. This participation does not imply that everyone on the team participates equally and in everything (although sometimes, in agile teams, for example, most everyone *does* participate in most everything!). Throughout the project, the project manager must decide who is the most qualified and should be delegated authority; those individuals and their level of participation will sometimes change as needed, depending on the project phase or particular situation. People and situations vary, so the project manager also must determine for each worker how much responsibility she can handle and how much she needs to be monitored and directed.

Regardless of their level of participation in planning and delegated responsibility, project individuals and teams must still be directed to ensure their decisions and efforts keep moving the project toward its goals and within budget and schedule constraints. Lacking direction, groups and individuals might do things or make decisions that are detrimental to the project as a whole. As mentioned, the project manager is the "big picture" person and must *steer* teams and individuals to meet projects goals—even in participative, shared leadership situations.

Despite the evidence about effective leadership styles in projects, simply *telling* a project manager she needs to develop a participative, relations- and task-oriented style is not enough. Old behavioral patterns remain, and new ones are hard to develop. Unless a project manager receives support in altering styles, she might not be able to do it. Often, companies provide training in interpersonal skills and team building to help managers make the transition. Even with training, however, not everyone is able to change leadership style. The hope in training is that each leader, if so motivated, will at least know which way to try to steer his behavior.

In the words of Bennis and Nanus, the most effective leaders are able to "align" the energies of people and groups behind the goal. They lead by "pulling rather than by pushing; by inspiring rather than by ordering" and by creating achievable, challenging expectations and rewarding progress rather than by manipulating.[9] The ample evidence, anecdotal and empirical, is that effective project managers are strong leaders who utilize participative management.

Motivation

One function of leadership is to motivate behavior. The work in projects can itself be motivating—it can be stimulating, satisfying, and provide a great sense of achievement. So do elements of project management—contracts, project goals, schedules, budgets, and so on; they provide clear targets plus constant pressure that motivate people to meet them, especially when combined with financial and career rewards.

But project work includes de-motivators as well. Too much pressure leads to stress, tension, and conflict. On large jobs, people can lose sight of project goals. One advantage of participative management and shared leadership is that through engagement in planning and decision-making, workers gain appreciation for plans and decisions and feel more closely associated with the project and dedicated to its success.

17.3 Teams in project management

Project organizations are composed of groups. As Figure 17.1 illustrates, in a large project, some of these groups are composed of people from within one organization (on the figure, the project office, midlevel management team, and functional and cross-functional work package teams), while others come from multiple organizations (the project management team and cross-organization functional team). Membership in many of these groups overlaps, and people serve multiple roles that link the groups together.

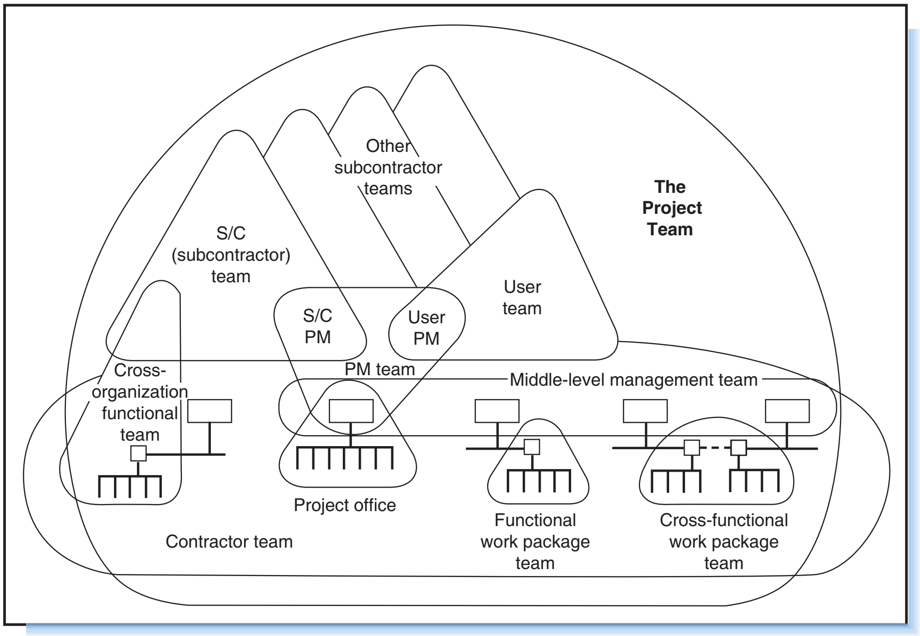


Figure 17.1
Groups making up the project team.

The term *project team* as used here refers to any group that works on the project or to all the groups in combination. The difference between a group and a team is that the former is simply a collection of people, whereas the latter is a collection working toward a *common goal*. Virtually all work done in a project, mental and physical, is the product of teams. To be successful, a project needs *teamwork*.

The trouble with teams

Failures in projects often can be traced to the inability of a team to make the right decisions, perform the right tasks, or perform the tasks right. These failures often stem from the maladies of teams: internal conflict, time wasted on irrelevant issues, and haphazardly made decisions. Teams often are more concerned with getting the task *done* than with doing it *right*. Many teams never know what their *purpose* or goal is, so they never know when or if they have achieved it.

In projects with multiple teams, each might be oriented to different goals. They might be in separate offices and physically isolated, which creates and reinforces perceived boundaries and an attitude among the teams of "us versus them." These make for a portentous project environment that bodes ill for project success.

High-performing teams

In contrast, successful projects result from the efforts of *effective* teams—teams that succeed in achieving whatever they set out to do. What makes a team effective? Peter Vaill studied a large number of highly effective teams, teams that "perform at levels of excellence far beyond those of comparable systems."[10] The prominent feature he found among all effective teams is that they know and are committed to team goals. Members are never confused about why the team exists or what their individual roles are. Leaders inculcate belief in the team's purpose, eliminate doubts, and embody a team spirit. He also found:

- High motivation and commitment to the team purpose.
- Teamwork focused on the *task*. Distinctions between functions dissolve and members work together to do whatever they must.
- Leadership is strong, clear, and never ambivalent. Leaders are reliable and predictable, regardless of style.
- The team views itself as distinct from others; members feel "we are different."

Vaill found three characteristics *always* present in high-performing teams, which he calls *time, feeling*, and *focus*. First, leaders and members are fully committed to the project and devote extraordinary amounts of time to it. They work at home, in the office, in taxicabs—anywhere. Second, they feel very strongly about attaining the goal. They care deeply about the team's purpose, history, future, and members. And third, they focus on key issues; they have a clear list of priorities in mind. Time, feeling, and focus are always found together. Vaill encourages would-be leaders to: "Seek constantly to do what is right and what is needed (focus); do it in terms of your energy (time); put your whole psyche into it (feeling)."[11]

For project managers, these findings underscore the importance of clear definition of and strong commitment to achieving project objectives, clarification of team members' roles and tasks, and a "project spirit" that bonds everyone together.

Example 17.1: Time, Feeling, and Focus in Project Management: Renovating the Statue of Liberty

The renovation of the Statue of Liberty is a good example of the kind of commitment and effort required to successfully manage a large-scale project.[12] Over 25 firms submitted proposals for the task of leading the team of 500 engineers, architects, artisans, and craftsmen who would do the renovation. Selected for the job was the small construction management firm of Lehrer/McGovern, Inc.

Hofer describes the firm's partners: Lehrer is soft-spoken and generally conservative in appearance; McGovern clean-shaves his head, has a handlebar mustache, and wears cowboy boots. Despite differences in appearance, the two share similar goals and broad experience as civil engineers and construction managers.

Did they devote a lot of time to the project? To coordinate the more than 50 businesses doing the job, Lehrer and McGovern often worked 16-hour days. They handled everything from helping architects and craftsmen implement plans to making arrangements with subcontractors and ensuring that materials were ordered and delivered on time.

Did they instill feeling for the project? Said Lehrer, "This project is a labor of love. The spirit and pride of hundreds of men and women involved bring out the best of us as Americans."[13] They expected and inspired feelings like that from everyone else, too. They only hired people who had "the same commitment and dedication as we do, who are aggressive and ambitious and understand that virtually nothing is impossible."[14] Before beginning the job, they lectured each subcontractor that nothing be allowed to damage the "crown jewel of the United States."

Did they maintain focus? Their major emphasis was on top-quality work. The two partners believed that management's close and personal involvement was crucial to quality, so they made frequent visits to the site and personally supervised or handled thousands of details.

This was an exceptional project, highly publicized and faced with considerable political pressure, but many projects bomb, despite high pressure and publicity. In this case, management's time, feeling, and focus helped the project succeed.

Effective project teams

Project work requires close collaboration. People in project teams must rely on and accept one another's judgments and support each other. Managers must share information and consult with each other to make decisions. Every person and group must be committed to project objectives, not just their own. Most studies show a correlation between teamwork and project success. In general, greater team collaboration, cohesion, and communication correspond to better project outcomes.[15]

One way to increase collaboration and commitment is by locating everyone in the project team in the same office quarters. Frequent daily contact makes it more likely individuals will identify with the team and project goals. We've repeated this theme a number of times.

But even if co-locating team members were possible, close proximity alone will not guarantee an effective team. Vaill's findings show that effective teams are clear about their purpose, committed to it, know their individual roles, and understand how to work together as a team. In many projects however, especially where people have not previously worked together, team members don't know the team's goals or their own responsibilities, and they never learn to work together. A purpose of team building is to ensure that doesn't happen.

17.4 The team-building approach

In a study of two NASA research centers, 36 project managers were asked to rank the most important functions of their job. Ranked as either first or second by all managers were the functions of organizing, directing, and motivating the *project team* and supporting groups.[16] In another study involving 32 research and product development projects, *group cohesiveness* was identified as the single most important factor to achieving project goals.[17]

Group cohesiveness and effectiveness do not just happen. Like any other purposeful system, a team or organization must be developed. This is the purpose of *team building*, a procedure whereby a team formally addresses how it should work or has been working, with the goal of improving its effectiveness. Team building considers group process issues, which are the processes or methods by which it gets things done. The issues relate to decision-making, problem solving, team objectives, internal conflict, and communication. Effective groups recognize and monitor these issues. During team building, a group explores such issues and then *plans* how it will address the issues and perform its work.

When it is needed

The need for team building depends on the team and the nature of the task. Generally, the more varied the backgrounds and responsibilities of team members, the greater the need. For example, members of multidisciplinary teams have different work backgrounds and outlooks on planning and doing work; some take a wider perspective, others are detail oriented. Team building can help both types accept their differences and work toward common goals.

Projects involving innovation, new technology, high risks, and tight schedules place teams under heavy stress. Some stress will motivate a team, but too much is detrimental. Team building can help the team to deal with the stress and to disclose and resolve problems as they occur, before they escalate and interfere with team performance.

Aspects of team-building efforts

The purpose of team building is to improve a group's ability to work together. To this end, the approach strives to build norms such as:

1. Effective communication among members.
2. Effective resolution of group process issues.
3. Constructive resolution of conflict.
4. High-level collaboration among team members.
5. A trusting, supportive atmosphere within the group.
6. Clarification of the team's purpose and the role of each member.

Three features common to any team-building effort are:

- It is carefully planned and facilitated, often by an outside party—a consultant or staff person from human relations or the PMO.
- The outside party collects data about the team's process functioning in advance, then helps the team "work through" the data during a diagnostic/problem-solving workshop.
- The team plans for later self-evaluation and follow-up.

Following are examples of team building as applied to three situations: an experienced work team, a new team, and multiple teams that must work together.

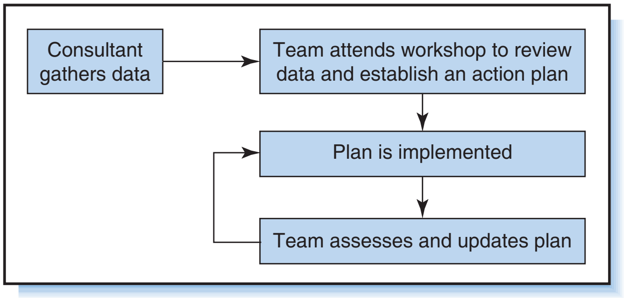


Figure 17.2
The team building process.

17.5 Improving ongoing work teams

Consider how team building is applied to an existing team such as a cross-functional management team; design-build team; Scrum team; or team of clients, contractors, and subcontractors. Problems typical to such teams include inability to reach agreement, lack of innovative ideas, too much conflict, or complacency of team members. A formal team building process such as summarized in Figure 17.2 can help avoid or overcome these problems.

Initially, a human relations consultant or other person with facilitation skills is called in by the project manager or PMO director to facilitate the effort. Her function is to help the group *solve its own problems* by drawing attention to the *way* the group's behavior is affecting its decisions and performance.

The consultant collects data from members about the team's functioning using personal interviews or questionnaires. She then summarizes the data, keeping the sources of individual comments anonymous. This summary will later be presented to the entire team at an upcoming workshop.

The consultant first shares the results with the team leader (project or department manager, work package supervisor, etc.) and coaches him on how to prepare for the workshop. The consultant remains impartial: the *entire team* is her client.

At the workshop, members review the summary and analyze the group's problems. This workshop differs from ordinary staff meetings in many ways. It convenes at an off-site location away from interruptions, can last up to several days, and includes all team members. The atmosphere is open and candid, without the usual superior–subordinate restrictions. The consultant facilitates the workshop.

The workshop specifics vary. One common format is this:[18]

1. The workshop begins with a discussion of the agenda. Team members describe what they would like and do not want to happen.
2. The consultant posts a summary of the information collected on the wall for easy reference. Discussion may be necessary to make sure everyone understands the issues. The consultant may also post anonymous quotes from the interviews, for example:

   "Our meetings are always dominated by the same two or three people."
   "Our way of getting things done is slow and unorganized."
   "I have no voice in decisions that affect my functional group."
   "Even though the team leader asks for our opinions, I know she ignores them."
   "Our team has no scheme for how to fit new tasks into the existing workload."
   "There is nothing to distinguish the roles of engineers and researchers in this project."

3. The team prioritizes the problems it wants to resolve within the time constraint of the workshop.

4. The team works to resolve the priority issues. In the meantime:
    a. The consultant monitors the session and points out dysfunctional behaviors of the group, encourages members to express their feelings, confronts behaviors that leads to defensiveness or distrust, and reinforces effective behavior.
    b. The group periodically critiques itself. After working through a problem, it pauses to evaluate what helped or hindered the process.
    c. The group prepares a formal action plan with solutions, target dates, and people responsible. The plan may include "operating guidelines" specifying how the group will function. (Typical guidelines are described in the next section.)

One of the authors has worked with project teams in workshops to effectively resolve problems ranging from technical issues to interpersonal conflict.

To ensure that action steps are implemented, follow-up work is scheduled formally in sessions held 2 to 3 months later or, less formally, during regular meetings. The team takes stock of its functioning, any improvements it has made, and what is still needed. The group itself takes over the consultant's role; should new problems emerge, it repeats the process.

Two conditions are necessary for team building success. First, the team leader and upper managers must accept the issues uncovered and assist in (or provide resources for) working toward solutions. Second, team members must *want* to resolve the group's problems. They must be open and honest in providing information, willing to share in the responsibility for having caused problems, and willing to work toward solutions.

17.6 Building new teams

Commonly, people in *new* teams quickly develop interpersonal bonds based on attributes such as similar age, gender, or nationality. Unfortunately, such bonds can be superficial and harmful to team unity and performance; what is better in terms of team cohesion and performance is that they develop bonds around shared skills, competencies, and tasks. Thus early team-building efforts should provide team members an opportunity to work together on tasks related to project goals and to develop competency- or task-oriented relationships.[19]

The purpose of team building for a newly formed team is for the team to reach agreement on its purpose, how it will achieve its purpose, and the roles of its members. The team also addresses how its members will work together in a manner so as to effectively accomplish its purpose and leave everyone feeling good about it and one another.

A team-building workshop is convened by a facilitator. During the workshop, members will become acquainted, reach agreement on objectives, and decide how they will function as a team. In *Team Building: Issues and Alternatives*, William Dyer describes the agenda of such a workshop, as follows:[20]

Step 1: develop a priority level

Members of a team sometimes differ in the priority they place on the project goal or work tasks. Especially in ad hoc teams or task forces with part-time members, some members give the project high priority, others low. One way to acknowledge these differences is for each member to indicate on a scale of 0 to 10 the priority of the project compared to her other work. Another way is to ask each one to indicate the amount of time she can devote to the project each day or week. The information is tallied and posted on a chart similar to Figure 17.3. The team members discuss the differences in their commitments to the project, and individuals are invited to explain their positions on the chart. The discussion helps reduce the potential resentment of some members committing to more work or less work than others.

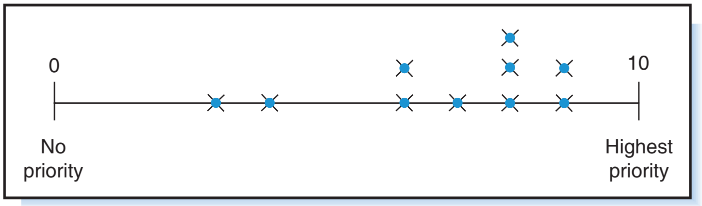


Figure 17.3
Priority ranking of project for ten team members.

Step 2: share expectations

Each person is asked to think about the following: (1) What would this team be like if everything worked ideally? (2) What would it be like if everything went wrong? (3) In general, what kinds of problems occur in work groups? and (4) What actions should be taken to make this an effective team? The responses are shared verbally and then posted. Concerns are discussed. These will be worked through later in step 4.

Step 3: clarify purpose and objectives

The team discusses and records its purpose and objectives. Sometimes, this is straightforward, such as when the objectives have already been set; other times, the group will have to define its objectives from scratch. Either way, the purpose and objectives should be clearly defined and accepted by everyone. The group then develops subobjectives so that members may be given specific assignments. The objectives should complement any user and system objectives and requirements as defined in the SOW or charter (described in Chapters 3–5). In fact, a session like this can be used to create the SOW or charter.

Step 4: formulate operating guidelines

Group dysfunction often arises over mixed expectations about work roles, job assignments, and how the group ought to work. This can be avoided by the team establishing operating guidelines that address, for example:

1. *How will the team make decisions?* By dictate of the leader, by vote, by consensus, or by other means? Who should be involved in making decisions? For example, in some cases, maybe only two or three members should be involved; in others, only the best-informed people; in still others, the entire team.
2. *How will the team resolve differences among members and subgroups?* Disagreements waste a lot of time, so guidelines should address the kinds of conflicts likely to arise and options for resolving them—consensus, vote, or calling in a mediator.
3. *How will work be assigned?* Which tasks should be handled by the whole group, which by subgroups or individuals? Should tasks be assigned according to expertise, position of authority, or personal preference? If several people want to do a task, how should they be chosen—by skill, experience, or availability?
4. *How will the team ensure that work is completed?* One person falling behind can delay the work of others. How will the team ensure that assignments and completion dates are clear and that corrective

action is taken when efforts lag or are out of control? Who will assist if someone falls behind? How will the team handle slackers?

5. *How will the team ensure open discussion?* The team must ensure that members are able to openly discuss issues so that ideas are not ignored or suppressed and everyone is heard. How will people less inclined to speak up because of personality, language, or culture be kept engaged? How will loquacious people be quieted?
6. *How frequently and where will the team meet?* Who will be expected to attend? How will absent people be informed about what happened at meetings?
7. *How will the team evaluate its process and any needed changes?* The team specifies a procedure for periodically reviewing whether the previous guidelines are working or need to be changed. Some teams appoint one member each meeting the role of making sure the team conforms to the guidelines.

The teams might also discuss current roles and responsibilities of its members and identify any ambiguity, overlap, or conflict.

A new team does not have to wait for problems to arise before it takes action. Through team building, it can develop expectations and guidelines to prevent common group problems.

Disbanding teams

Opposite team building is team disbanding. Successful teams generate close ties and strong relationships; when the project ends, people are usually reluctant to abandon relationships and may actually suffer feelings of loss. These feelings should be acknowledged and shared. The closeout of the project may be followed by a ceremony—a banquet, party, or informal get-together—to recognize the team for its accomplishments and say goodbye.

17.7 Intergroup problem solving

When several teams must work together, issues among them arise such as communicating or withholding information, competition among them, or coordinating their efforts. Intergroup problem solving (IGPS) is a technique for improving working relationships among multiple teams; following is an example.[21]

The two groups meet together for a day. At that time:

1. Each group compiles four lists: (1) what they believe the *other* group is responsible for, (2) what they feel are the other group's strengths and weaknesses, (3) what the group thinks are its *own* responsibilities, and (4) what the group anticipates the other group thinks about them (strengths, weaknesses, responsibilities).
2. The groups meet to share their lists. The only discussion allowed is to clarify points of disagreement.
3. The groups separate, this time to discuss what they learned from each other's lists and to list and prioritize the issues that need to be resolved.
4. Finally, the groups meet together again to discuss differences and develop a mutual plan to resolve them.

The groups meet again a few weeks later at a follow-up session to assess how well their plan is working. The result is usually a much-improved understanding of each group's expectations about the other and a better working relationship.

IGPS is applied whenever groups interface or must work together. Examples are project teams composed of groups from different contractors. Without IGPS, each group often tries to optimize its *own goals*, and overall goals of the project or program suffer. IGPS is useful whenever there are interdependencies, deadlines, or situations that induce intergroup conflict and stress.

Participants in an intergroup session are likely to have a "gee whiz" experience. Each group may discover that its expectations differ significantly from (and conflict with) those of other groups. This realization is a first and necessary step to aligning expectations and planning to resolve differences.

One caveat is that groups should not participate in IGPS until they first resolve any serious *internal* problems. In other words, a group must first have its own house in order (team-build itself) before it attempts to resolve its issues with other groups.

17.8 Virtual teams

Sometimes everyone on the project team—the manager and all its members—is located in a different place. Such teams, called *virtual* or *distributed* teams, are common in design and development projects where specialists are located around the globe. On occasion, the project manager or team members might meet with other members face to face, but often that never happens and their interaction is solely via communication technology.

Although many of the leadership and team-building principles described earlier apply, managing virtual teams requires special consideration. People cannot walk across the hall to ask questions or call a meeting on a whim; they must rely upon technology to communicate. This makes it more difficult to make decisions, follow up on commitments, monitor results, and build relationships and team cohesiveness. And everything gets worse when the team is spread across different time zones, languages, and cultures.

Communication technology[22]

Virtual teams exist by virtue of technology. When travel budgets are meager, or when people are precluded from meeting face-to-face (the Covid-19 pandemic) most communication happens electronically. There are many available technology options, and a project will usually employ several. All fall under the heading of "groupware," which is software to facilitate people working together on a common task.

Groupware that emulates face-to-face meetings and enables people to talk continuously and simultaneously is called *synchronous*; it includes:

- Desktop, real-time data conferencing
- Electronic meeting systems
- Videoconferencing
- Audio-conferencing
- Instant messaging (IM).

Groupware that permits only intermittent, back-and-forth communication is called *asynchronous*; this includes:

- Email
- Personal computing devices
- Group calendars and schedules
- Bulletin boards
- Team websites.

The appropriate technology largely depends on the task. Ambiguous or challenging tasks and decisions require technologies that are "media-rich" and mimic normal conversation—that is, synchronous technologies. Asynchronous technologies such as email are not media rich; their use should be confined to sharing information and documentation. Virtual teams, however, share lots of documentation, because, in general, in the absence of face-to-face meetings, writing replaces conversation. Even audio conferences and old-fashioned phone calls need to be followed up in writing to ensure clarity.

The technology to be used must be compatible with the hardware/software at different team members' sites. Also, members must be comfortable with using the technology and have access to training.

Team cohesion[23]

In general, in a cohesive team, the members share a vision and trust each other. Among ways the project manager builds a shared vision are to:

- Explain to the team the importance of the project and each member's contribution. In an international team, the project manager might have to travel to every site to do this.
- Negotiate and clarify everyone's roles, responsibilities, and accountabilities.
- Identify results-oriented performance measures for each member; the measures must be specific enough so the project manager is able to gauge each member's performance.
- Related to the previous point, develop methods to review progress. This might require weekly audio-conference reviews.
- Establish communication protocols regarding:
  - preferred communication modes—email, voice, IM, texting, and so on
  - acceptable elapsed time in responding to messages
  - best time of day to call or schedule meetings
  - times when people are in the office
  - non-office times acceptable to call or meet.
- Create team operating guidelines for decision-making, conflict resolution, and so on and include them in the team charter. If the team can meet face to face or teleconference at least once, this can be done using the procedure in Section 17.6. The leader must expect and reinforce compliance to the guidelines.

Trust[24]

Team cohesion also depends on the level of trust among the project manager and team members. The best all-around way to build trust is through face-to-face contact. A virtual team cannot do that on a regular basis, although it can occasionally by allowing/encouraging members to *visit each other's sites*. An alternative is for representatives from subteams at different sites to "float" among the other project sites. Another is for the entire team to meet for a project kickoff meeting. Regardless of the alternative, the visits/meetings must be long enough (several days or weeks) for people to get to "know" each other and develop personal bonds; this is more the purpose of the visits than doing work. Ideally, face-to face visits/meetings happen at the start of the project; if that isn't feasible, they should happen whenever it is. At minimum, the project manager should try to meet with everyone at least once in person, though ideally more often, if possible. Cohn calls this "management by flying around"—the virtual-team equivalent of management by walking around. He says to expect the travel budget to increase with virtual teams, not decrease![25]

In general, trust develops when people see others performing competently, acting with integrity, and showing concern for others' well-being; it erodes when they doubt each other or the leader. It is important that everyone receive critical information at the same time, else individuals might perceive they are being excluded or forgotten by the leader or others.

Definitive clues about performance in virtual teams are lacking, so even a little negative information can destroy an individual's or team's reputation. The project manager and team members must support the team and the project in good times and bad; this is true for face-to-face teams but more so for virtual teams. Information indicating poor performance should never be accepted without investigating it first.

Virtual meetings[26]

Managing meetings of a virtual team raises special problems. Duarte and Snyder recommend the following.

- **Participation**. Not everyone needs or has time to attend all meetings. The project manager must decide for each meeting which team member's attendance is mandatory and which is optional. Explain to people not invited the reason and when or if they will get the results of the meeting. Store important documents in a web folder so people not at meetings can stay up to date.
- **Preparation**. Distribute the meeting agenda beforehand so people can prepare. Explain which people will be expected to contribute, how much (a little or much), and in what ways. Try to get peoples' reactions on issues and answers to questions in advance of the meeting.
- **During the meeting**. Allow time at the start for small talk and chit-chat. At voice conferences, always preface talk by announcing *who* is talking. Cohn suggests at audio-conferences appointing one person at each location with a good ear for voices to hold up a picture of whoever is speaking on the other end. People get accustomed to this and actually look at the photo as if it were the photo doing the talking![27]
- **Be inclusive**. Greet each member or ask him to introduce himself. Make sure everyone is heard; ask everyone to participate and call on people who have not spoken. Be culturally sensitive so as not to put anyone on the spot. Seek a diverse point of view, such as asking one member to play devil's advocate. Practice communicating in ways that lead to trust: show respect, use names people prefer to be called, create dialogue—not monologue—and listen attentively. Be forgiving when someone makes a mistake.
- **Pace the meeting**. Guide discussion toward a resolution or postponement; remind people of remaining time. Set time allotment for each item; ask if the team wants to extend the meeting.
- **Enforce participation**. Check frequently that everyone is staying with the agenda. Notice if members have not spoken and ask for their input. In meetings not conducted in the team's native language, members might have trouble keeping up with the discussion. Provide breaks for them to organize and collect their thoughts.
- **Summarize**. At the end, summarize the discussion and make sure decisions or actions are recorded. Get commitments about who will do what. Try to make the meeting minutes available to everyone within a few days of the meeting. Be careful to make sure the minutes (and interpretations of what was said) are correct.

17.9 Conflict

In all organizations, differences in objectives, expectations, and values lead to conflict. Projects are no exception and, if anything, are predisposed to conflict. Conflicts arise between customers and contractors, project and functional groups, and subcontractors and departments. It occurs between people on the same team, different teams in the same organization, and teams in different organizations. And it is common in virtual teams where electronic communication media can amplify misunderstandings and make it more difficult to build trust. Some conflict is natural and beneficial; too much is destructive.

Between user and contractor

Seeds of customer–contractor conflict are sown early during contract negotiations. People representing the two parties are usually less concerned with developing trust than with driving a hard bargain for their own best interests. The customer wants to minimize cost, the contractor to maximize profit. One's gain is the other's loss. In the extreme, each side strives for an agreement that provides an "out" in case it cannot keep its part of the bargain; each tries to make the other responsible in case of failure. Says one manager,

> You start with science and engineering, but the project, once it's decided on, has to be costed. You have to select contractors and get budgets approved. Then you turn to the contractors working with you and write contracts that say you don't trust them. What starts as a fine scientific dream ends up being a mass of slippery eels.[28]

The contract itself becomes a source of conflict. A cost-plus agreement might provide little incentive for the contractor to control expenses, and the customer must closely supervise everything. Such scrutiny is a constant irritant to the contractor. In a fixed-price contract, the contractor might request periodic upward revisions, also a source of conflict. Any contract with poorly specified terms for cost, schedule, or performance is likely to have multiple interpretations and lead to disagreements.

Within the project organization

High-level interdependency in projects between functional areas increases the amount of contact between them and, at the same time, the chances of conflict. The different areas have different ideas, goals, and solutions for similar problems—differences that sometimes must be resolved without the benefit of a common superior.

In addition, the functional areas' needs are often incompatible with the project's needs, and functional areas often request changes to the project plan that the project manager must refuse. The project manager might have to compromise the high technical standards of the functional departments with project time and cost considerations. Even when project managers agree with the technical judgment of specialists, they sometimes disagree over the means of implementation.

In matrix organizations, functional managers sometimes see project managers as impinging on their territory, and they resent having to share planning and control with them. They might refuse to release certain personnel to projects or try to retain authority over personnel they do release. Workers with dual reporting relationships often feel conflicted over priorities and loyalties.

Moreover, people are ordinarily reluctant to accept change, yet with projects, change is the norm. Administrative procedures, group interfaces, project scope, and resource allocations are in constant flux. Changes in the labor force make it difficult to establish lasting reporting relationships.

Finally, projects inherit feuds that have nothing to do with them. Regardless of the setting, clashes arise from differences in attitudes, personal goals, and individual traits, and from people trying to advance their careers. These create a history of antagonisms that set the stage for conflict well before a project begins.

The project life cycle

Thamhain and Wilemon[29] investigated sources of conflict in a study that involved 100 project managers. They determined that the three greatest sources of conflict are schedules, project priorities, and the workforce—all areas over which project managers generally have only limited control. Other sources of conflict identified are technical opinions and performance tradeoffs, administrative and organizational issues, interpersonal differences, and costs. Costs are a relatively minor cause of conflict, the authors surmise, not because costs are unimportant but because they are difficult to control and usually dealt with incrementally over a project's life.

They also found that the sources of conflict change from one phase to the next, as summarized in Figure 17.4.

Start ——— Project life cycle ——→ Finish

Project conception	*Project definition*	*Project execution*	*Project closeout*
Priorities	Priorities	Schedules	Schedules
Procedures	Schedules	Technical	Personality
Schedules	Procedures	Manpower	Manpower
Manpower	Technical	Priorities	Priorities

Figure 17.4
Major sources of conflict during the project life cycle.

Source: Adapted from H. Thamhain and D. Wilemon, "Conflict Management in Project Life Cycles," Sloan Management Review (Spring 1975): 31–50.

During project conception, the most significant sources of conflict are priorities, administrative procedures, schedules, and labor. Disputes between project and functional areas arise over the relative importance of the project compared to other activities, the amount of control the project manager should have, the personnel to be assigned, and scheduling the project into existing workloads.

During project definition, the chief source of conflict remains priorities, followed by schedules, procedures, and technical issues. Priority conflicts carry over from the previous phase, but new disputes arise over the enforcement of schedules and functional departments' efforts to meet technical requirements.

During execution, friction arises over schedule slippages, technical problems, and labor issues. Deadlines may become difficult to meet because of accumulating schedule slippages. Efforts aimed at system integration, technical performance of subsystems, quality control, and reliability also encounter problems. Manpower requirements grow to a maximum and strain the available pool of workers.

During closeout, schedules remain the biggest source of conflict as accumulated slippages make it difficult to meet target completion date. Pressures to meet objectives and anxiety over future projects increase tensions and personality-related conflicts. The phasing in of new projects and the absorption of personnel back into functional areas create further conflicts.

Conflict consequences

Conflict is inevitable in human endeavors and is not always detrimental. Properly managed, a certain amount of conflict is good because it:[30]

1. Compels people to search for new approaches.
2. Causes persistent problems to surface and be dealt with.
3. Forces people to clarify their views.
4. Stimulates interest and creativity.
5. Gives people the opportunity to test their capacities.

In fact, total absence of conflict is unhealthy. Called *groupthink*, it is a sign of over-conformity. It causes dullness and sameness and results in poor or mediocre judgment. In contrast, some amount of conflict over differences in opinion stimulates discussion and can enhance problem solving. In project groups charged with exploring new ideas or solving complex problems, some conflict is essential.

Conflict between groups that are in competition is beneficial because it increases group cohesion, spirit, loyalty, and the intensity of competition. However, conflict between teams that should be *cooperating* can be devastating. Each group develops an "us versus them" attitude and selfishly strives to achieve its own objectives. Left uncontrolled and unresolved, conflict spirals upward and creates hostility. Within a project, conflict fosters lack of respect and trust and destroys communication between groups and individuals. Ideas, opinions, or suggestions of others are rejected or discredited. Project spirit breaks down, and the project organization splinters apart.

Example 17.2: Conflict in Product Development Teams[31]

Microsoft forms small teams around products and then allows them to organize and work as they wish. It hires bright, aggressive people right out of school, then pushes them hard to get the most and best out of them.

As author Fred Moody describes, each product team consists of designers whose assignment is to try to add features to the product, developers whose partial role is to resist the features for the sake of meeting deadlines, and a program manager whose role is to mediate and render verdicts. Besides having different assignments and goals, there is a big chasm between developers and designers in terms of temperament, interests, and styles. Developers often feel it is impossible to make the designers understand even the simplest elements of a programming problem. Designers might spend weeks on some aspect of a product, only to be rudely told by a developer that it will be impossible to implement. Designers are from the arts; developers from math and science. Designers tend to be female, vegetarians, talkative, and live in lofts; developers tend to be male, eat fast food, and talk little except to say "Not true." The way they deal with conflict also differs. Developers are given to bursts of mischievous play and will pepper a designer's door with shots from a Nerf-ball gun. Designers merely complain to their supervisor.

This adversarial relationship levies a toll on the team, the product, the customers, and the company. Moody quotes the lead developer on one project, who said, "I've never been through anything like this. We made the same mistakes before, and now we're making them again. Every project is like this. We keep saying that we learn from our mistakes, but we keep going through the same [expletive] over and over again."

17.10 Managing group conflict

How do people deal with conflicts? In general, there are five ways:

1. Withdraw or retreat from the disagreement.
2. Smooth over or de-emphasize the importance of the disagreement (pretend it does not exist).
3. Force the issue by exerting power.
4. Compromise or bargain to bring at least some degree of satisfaction to all parties.
5. Confront the conflict directly; work through the disagreement with problem solving.

All of these are at times appropriate. In a heated argument, it may be best to withdraw until emotions have calmed down or to de-emphasize the disagreement before it gets distorted out of proportion. But neither of these resolves the problem, which will likely arise again. A manager might force the issue by using authority; this gets the action done but risks creating hostility. As discussed earlier, if authority must be used, it is better that it be based upon knowledge or expertise. To bargain or compromise, both sides must be willing to give up something to get something and, ultimately, they may feel they lost more than they gained. Of the five approaches, the only one that works at resolving the underlying issues is *confrontation*.

Confrontation

Confrontation involves identifying potential or existing problems, then facing up to them. At the organizational level, this happens by all areas involved in the project agreeing on project objectives, plans, labor requirements, and priorities. It requires careful monitoring of schedules, close contact between project groups, and prompt resolution of technical problems.[32]

At the individual level, a project manager confronts conflicts by raising questions and challenges such as:[33]

> How do you know this redesign will solve the problem? Prove it to me.
> What have you done to correct the malfunctions that showed up on the test we agreed to?
> How do you expect to catch up on lost time when you haven't scheduled overtime?

Questions like these demonstrate that the project manager is vitally interested and alert and that everything is subject to question. It is a crucial part of effective project management.

However, there is a catch: the very *process* of being confrontational is itself a source of conflict, but at the *interpersonal* level. Frequently, what begins as a conflict of schedules, priorities, or technical matters degenerates into a conflict over "personalities."

Successful confrontation assumes a lot about the individuals and groups involved. It assumes that they are willing to reveal why they favor a given course of action and that they are open to and not hostile toward differing opinions. It assumes that they are all working toward a common goal and are willing to abandon one position in favor of another.

The simple fact is, many groups and managers are highly critical of others' opinions. Faced with differences, they tend to operate emotionally, not analytically. For individuals to use confrontation as a way to resolve conflict, they must first be able to manage their emotions.

Role clarification technique[34]

Conflict in projects often arises because people have mixed expectations about work plans, roles, and responsibilities. In particular, disagreements arise because:

- The project is new and people are not clear about what they are supposed to do and what others expect of them.
- Changes in projects and work reassignments have made it unclear how individuals in the team should interact.
- People get requests they do not understand or hear about things on the grapevine that they think they should already know.
- Everyone thinks someone else is handling a situation that, really, no one is.
- People do not understand what their group or other groups are doing.

The *role clarification technique* (RCT) is a systematic procedure to help resolve these sources of conflict. As the title "role clarification" suggests, the goal is that everyone understand their own and other's major responsibilities and duties and that everyone knows what others expect of them.

RCT is similar to team building. It includes data collection, a day-long meeting, and a consultant who serves as facilitator. When incorporated as part of team building for a new team, it allows the project manager and team to negotiate team member roles. It is especially useful in cases where responsibilities are somewhat ambiguous.

The technique as applied to an existing team begins with each person answering a questionnaire prior to a meeting:[35]

1. What does the organization expect of you in your job?
2. What do you actually do in your job?
3. What should others know about your job that would help them?
4. What do you need to know about others' jobs that would help you?
5. What difficulties do you experience with others?
6. What changes in the organization or activities would improve the group's work?

At the start of the group meeting, ground rules are announced: people must be candid, give honest responses, and express their concerns, and everyone must agree to decisions. The meeting begins with each person reading the answers to the first three questions. As each person reads, others are given the chance to respond. It is important that each person hear how others see their job and what they expect of them.

Each person then reads the answer to Question 4 and hears responses from the people she identified. Issues in Question 5 that have not already been resolved are addressed next. Throughout the process, the emphasis is on solving problems, not placing blame. The group then discusses Question 6 and tries to reach consensus about needed changes.

17.11 Managing emotional stress[36]

Working in projects can be stressful. Long hours, tight schedules, high risks, and high stakes take a toll on social relationships and individual mental and physical health. Projects achieve great things, but they also instigate ulcers, divorce, mental breakdowns, and heart attacks. Emotional stress affects the performance and physical health of project workers and is a problem that at one time or another most project managers face.

Factors influencing stress

How much emotional stress a person experiences and how well he deals with it depends on the fit between two factors: the demands of the environment and the adaptive capabilities of the individual. In other words, work-related stress depends upon a person's perception of the demands or opportunities of the job and his self-perceived abilities, confidence, and motivation to perform. A manager faced with impending failure to meet a deadline might feel stressed if he believes the deadline must be met at all costs but feel no stress if he simply accepts that meeting the deadline is impossible. Stress is a reaction to prolonged internal and environmental conditions that overtax a person's adaptive capabilities. To feel distressed (negative stress), an individual's capabilities must be overtaxed. Even when a person is able to handle a situation, he will still feel distressed if he lacks self-confidence or cannot make a decision.

Stress in projects

Among numerous causes of stress in projects are rapid pace; transient workforce; anxiety over discrepancies between performance and goals; and impending failure to meet cost, schedule, or contract requirements. In construction, for example, say Bryman et al.:

> [The project manager] is in the front line controlling the labor force; he's answerable to the client, to his organization at a high level; he's responsible for millions of pounds [or $] worth of work . . . In a very fragile environment he is at the mercy of the weather, material deliveries, problems with labor, and problems with getting information.[37]

We will restrict discussion to three main causes of stress in projects: work overload, role conflict, and interpersonal relations.

Work overload is experienced in two ways. One is having too much work or doing too many things at once, with time pressures, long hours, and no letup. The other is taking on work that exceeds one's ability and knowledge. Overload can be self-induced by an individual's need to achieve, or it can be imposed by the responsibilities of the job. It is prevalent during crash efforts to recover lost ground and to rush projects toward completion. When overload is balanced with abilities, it can be positive and motivating; when it exceeds abilities, it is distressful. A related problem, *work underload*, occurs with too *little* workload or work beneath a person's ability. Underload can occur during a long hiatus between projects.

Role conflict happens, for instance, when a person reports to a functional manager and a project manager and the two managers impose contradictory or incompatible demands. It also happens when one person takes on multiple incompatible roles. For example, a project manager might discover that to be a good administrator requires doing things that conflict with her values as a professional engineer.

Role ambiguity results from inadequate or confusing information about what a person needs to do to fulfill his job or the consequences of not meeting job requirements. The person knows neither where he stands nor what to do. Role conflict and role ambiguity are common in projects where workers try to satisfy the expectations of many people. Project managers in particular might feel frustrated because they have limited authority to satisfy the requirements of numerous stakeholders.

Stress also develops from the demands and pressures of *social relations*. Managers who are self-centered and dictatorial create stress for their workers. Irritable, abrasive, or condescending personalities make others feel unimportant and provoke anxiety.

In short, the typical project is a haven of environmental stressors—stress is inevitable.

Stress management

Most people accept stress as the price of success; however, although stress is inevitable, *distress* (negative stress) is not. Project managers should be able to anticipate which work demands are most stressful and try to ameliorate the negative effects.

In general, ways to reduce negative stress at work are aimed either at changing the organizational conditions that cause stress or at helping people better cope with stress. Because stress results from the interaction of people with their environment, both are necessary. Organizational means are aimed at task, role, physical, and interpersonal stressors; individual means are aimed at peoples' ability to manage and respond to stressful demands. We will focus on organizational means—methods applied by managers to reduce the stress in projects.[38]

Set reasonable plans and schedules

One way to reduce stress is planning and scheduling projects so as to allow for reasonable work hours and time off. Well-conceived plans and schedules prepared in advance help balance the workload; workers know what is expected and when, which helps avoid ambiguity, work overload, and the "crunch" that precedes milestones and project closeout.

Modify work demands through participation

Dictatorial, self-centered leaders (the too-bossy boss) cause stress; so does the opposite, the do-nothing, under-demanding leader. In contrast, there is supporting research that the least stressful style of leadership is participative. Allowing workers decision latitude and autonomy commensurate with their ability can help reduce stress in projects. Participative leaders set goals and define task limits but allow workers flexibility as to how to achieve those goals and limits.

Social support

One way to reduce stress arising from work roles and relationships is to increase *social support* within project teams. Social support is the assistance one gets through interpersonal relationships. Generally, people are better able to cope when they feel others care about and are willing to help them.

Vital sources of social support are family; close friends; and a supportive boss, coworkers, and subordinates. Social support from managers and coworkers does not necessarily alter the stressor, but it does help people to cope better. A supportive project manager helps buffer against destructive stress; her subordinates are less likely to suffer harmful consequences than those with unsupportive managers. Coworker social support is equally important; caught between the conflicting expectations of a functional manager and project manager, a person with supportive coworkers will be better able to deal with the conflict.

How do people become supportive? Simply telling someone to be supportive does not work. Even when managers try to be supportive by giving advice, they often leave the distressed person feeling worse off. Giving physical assistance is easy, but giving true emotional support is difficult and subtler. Empathic listening, understanding, and real concern are essential parts of support often missing in naive efforts to help. Thus, usually, it is necessary to provide some training in social support skills and reinforce and reward the usage of these skills. Unfortunately, as with many other behavioral aspects of management, training in empathy and sensitivity are considered "soft" issues and are devalued as "not productive."

17.12 Summary

Contingency theories of leadership suggest that the most effective leadership style in most project situations is relations oriented and participative; this is because project managers must rely upon the opinions of knowledgeable members of the project team and others.

A significant factor affecting project performance is team cohesiveness and teamwork. Teamwork must be developed and nurtured. But groups need help in developing effective teamwork, especially when the team comprises members from different backgrounds or exposes members to high stress. Methods for team building apply to a variety of situations, such as for resolving problems in an experienced team, building teamwork in a new group, or resolving issues between two or more groups. With slight variation, these methods can be adapted to bring customers, subcontractors, and suppliers together at the start of a project. Many project teams rarely or never meet face to face. Virtual teams, a feature of the modern project landscape, rely on technology to communicate but require special skills to manage and lead.

Conflict is inevitable in projects and, properly managed, beneficial. The primary conflict sources in projects include schedules, costs, priorities, manpower levels, technical opinions, administrative issues, and interpersonal conflicts; these vary in relative importance depending on stages of the project life cycle. Conflict is generally best dealt with through confrontation, that is, examining the issues and attempting to resolve the conflict at its source.

Stress in projects is also inevitable. Stress induces energy and increases vitality but in excess can be debilitating. The main sources of stress in projects are demanding goals and schedules, work tasks, roles, and social relations. Advance planning of workloads and deadlines can reduce many of the technical sources of stress. Participative management and social support help workers cope with stress; the former gives workers latitude in meeting requirements, the latter shows workers that others care about them and are willing to assist or provide support.

Review Questions

1. Explain the difference between task-oriented and relations-oriented leadership styles.
2. Describe the contingency approach to leadership. According to this approach, what is the best way to lead?
3. Discuss the differences between the leadership models of Fiedler and Hersey-Blanchard. What do these models say about leadership in the situations faced by project managers?
4. How are participative management and shared leadership useful for motivating and gaining commitment?
5. Why is teamwork important in projects? Isn't it enough that individual workers be highly skilled and motivated?
6. What characteristics are common to Vaill's high-performing systems?
7. What is meant by group process issues? What kinds of issues do they include?
8. What is the purpose of team building? Where is team building needed?
9. Outline the steps in a team-building session for a group that has been working together. Outline the steps for building a new project team.
10. Outline the steps in the IGPS process.
11. What conditions of management and the team members are necessary for team building interventions to succeed?
12. Describe some situations that you know about where team building could be used.
13. What do you think are the reasons team building is not used more often? What barriers are there to applying team building?
14. List the technologies available for virtual teams. For what tasks/decisions do each apply?
15. How are trust and cohesion developed in virtual teams?
16. List some special considerations in managing virtual meetings.
17. What are the sources of conflict between the user and the contractor? How do contracts lead to conflict?
18. What are the sources of conflict between parties in the project organization?
19. Describe how the sources of conflict vary with the phases of the project life cycle.
20. Why is some conflict natural and beneficial?
21. Describe four ways of dealing with conflict.
22. Explain how the project manager uses confrontation to resolve conflict.
23. What conditions must exist for confrontation to be successful?
24. Describe the role clarification technique. What sources of conflict does it resolve?
25. Describe these sources of stress in projects: project goals and schedules, work overload, role conflict and ambiguity, and social/interpersonal relations. Describe your work experiences with these sources of stress.
26. Describe the means by which participative management helps reduce work stress.
27. What is "social support"? What are the sources of social support? How does social support reduce job stress?

Questions About the Study Project

1. How would you characterize the leadership style of the project manager in your project? Is it authoritarian, laissez-faire (do nothing), or participative? Is the project manager task oriented, relations oriented, or both?
2. What kind of people must the project manager influence? Given the theories of this chapter, is the project manager's leadership style appropriate? Despite the theories, does the style used by the project manager seem to be effective?

3. What do you think are the primary work motivators for people in this project? Discuss the relative importance of salary, career potential, incentives, and participation in decision-making.
4. Describe the different groups (management teams, project office, functional groups) that make up the project team in this project.
5. What mechanisms are used to link these groups—for example, coordinators, frequent meetings, or close proximity of workers?
6. What kinds of formal and informal activities are used to increase the cohesiveness of the project team? Can any of these be termed team building?
7. Is the project team a virtual team? If so, what special provisions does the manager take to lead and manage the team?
8. Are steps taken to resolve problems involving multiple groups?
9. How would you characterize the level of teamwork in this project?
10. Ask if the project manager knows about formal team building and intergroup problem-solving procedures like those described in this book.
11. At the end of this (or other projects), how does the organization disband a team? Are there procedures for recognizing members or dealing with their feelings about disbanding?
12. How prevalent is conflict, and what effect does it have on individual and project performance?
13. How does the project manager resolve conflict? Is confrontation used?
14. Are formal procedures used, such as RCT or IGPS, to resolve conflicts?
15. Emotional stress is a personal issue, and most people are hesitant to speak about it other than on a general level. Still, you might ask the project manager or other team members about stresses they personally feel or perceive in the project.
16. Is this a high-stress or low-stress project? Explain. If high stress, is it taken for granted, or do people take steps to reduce the stress?
17. Does the project manager try to help team members deal with job stress? Explain.

CASE 17.1 WILMA KEITH

Wilma Keith had worked for over 20 years as a successful project manager. But even with that background, she found the Wiseteam Project frustrating and overwhelming. Soon after being assigned to the project, she met with Cappun Queeg, the VP of communications. "Wilma," he said, "the long and short of it is that the Wiseteam Project *must* be completed and operational inside six months." She had already estimated the project would take about a year and protested. Queeg became annoyed and said, "Just do it!" Wilma scoured the company for the best people she could find, settling on four young technical analysts from different departments. None of them were people oriented or very good at communicating; technically, however, they were the best. Upon reviewing the project requirements, they all agreed: it would take a year—at least. When Wilma reported back to Queeg, he said, simply, "If you don't finish in six months, you're fired. That's a promise!"

So Wilma set the team to work. Everyone knew Queeg's deadline. At one point, he dropped by to say that if they didn't succeed, they would *all* be fired. This unnerved the analysts, but Wilma promised that if anyone were to be fired, it would be her, not them. She also promised that she would handle all dealings with Queeg, buffer them from his abuse, and take responsibility for any delays or problems. The team warmed to Wilma and set out to work—on average 6 days a week, 15–20 hours a day. Wilma never left them; if they were working, so was she. She started bringing brownies—lots of brownies, acting like a "den mother," and treating the team like they were family. Indeed, given the long hours, the team seldom saw their real families, and Wilma's maternal care seemed to fill a void.

Several months into the project, Queeg stormed in and asked Wilma why she had requested help from two outside consultants. She said despite the long work hours, the team was still behind and needed additional resources to meet the deadline. Queeg fumed that he was not about to hire any consultants. Wilma looked him straight in the eyes. "You don't, and I quit!" Queeg knew she was serious. "All right," he said, "but that's all you'll get." The team was amazed: Wilma had stood up to the vice president. This bonded them even closer and united them against the common "enemy."

The intense pressure, long hours, strong competency of the team, and Wilma's nurturing worked: the team finished the project 2 weeks early and under budget—even with the expense of the two consultants. But ultimately, the project failed because the Wiseteam system that Queeg had demanded did not provide anything new to its users. Queeg had never talked to the users; Wiseteam was his own "pet" project. A year later, he was gone from the company.

QUESTIONS

1. What do you think about Wilma's leadership style? What aspects of her style motivated the team? Would you say Wilma's style is more task oriented or relations oriented?
2. What aspects of Wilma's style do you think are typical of good project managers?
3. This was a stressful project. What did Wilma do that helped the team manage stress?
4. Is this case realistic? Are unrealistic demands like this actually put on project managers?

CASE 17.2 MARS CLIMATE ORBITER SPACECRAFT[39]

NASA designed the Mars Climate Orbiter spacecraft to collect data about Mars' atmospheric conditions and serve as a data relay station. Instruments aboard the Orbiter would provide detailed information about the temperature, dust, water vapor, and carbon dioxide in Mars' atmosphere for approximately 2 Earth years. The Orbiter would also provide a relay point for data transmissions to and from spacecraft on the surface of Mars for up to 5 years.

Nine months after launch, the Orbiter arrived in the vicinity of Mars and fired its main engine to go into orbit around the planet. Everything looked normal as it passed behind Mars as seen from the Earth. After that, the Orbiter was never heard from again; presumably it had crashed into the planet. Paraphrasing project manager Richard Cook, "We had planned to approach the planet at an altitude of about 150 kilometers, but upon review of data leading up to the arrival, we saw indications that the approach altitude was much lower, about 60 kilometers. We believe the minimum survivable altitude for the spacecraft would have been 85 kilometers."

Later, an internal peer review attributed the $280 million mission loss to an error in the information passed between the two teams responsible for the Orbiter's operations, the spacecraft team in Colorado and the mission navigation team in California. In communicating back and forth, one team had used imperial units (feet, pounds), the other had used metric units (meters, grams). Without knowing it, the two teams were using different measurement systems for information critical for maneuvering the spacecraft into proper Mars orbit.

QUESTIONS

1. How could such a mistake have occurred between the two teams?
2. What does the mistake suggest about the degree of interaction and coordination between the teams?
3. How might this problem have been prevented?

Notes

1. Chapman R. *Project Management in NASA: The System and the Men*. Washington, DC: NASA SP-324, NTIS No. N75–15692; 1973. The project team referred to is the project office staff, which numbered from a few members on small matrix projects to 70 in large pure projects.
2. Kloman E. *Unmanned Space Project Management*. Washington, DC: NASA SP-4102; 1972, p. 23.
3. Laufer A. and Hoffman E. *Project Management Success Stories: Lessons of Project Leadership*. New York, NY: Wiley; 2000. (This book provides ample anecdotal evidence provided by managers from many more recent NASA projects); Edward J. Kinlaw C. & Kinlaw D. Developing superior project teams: a study of the characteristics of high performance in project teams. Paper presented at PMI Research Conference 2000, Paris, France. Newtown Square, PA: Project Management Institute, 2000; Geoghegan L. and Dulewicz V. Do Project Managers' Leadership Competencies Contribute to Project Success? *Project Management Journal* 39(4); 2008: 58–67.
4. Pretorius S., Steyn H. and Bond-Barnard T. Exploring project-related factors that influence leadership styles and their effect on project performance. *South African Journal of Industrial Engineering* 28(4); December 2017: 95–108; Lindgren M. and Packendorff J. Project leadership revisited: Towards distributed leadership perspectives in project research. *International Journal of Project Organisation and Management* 1(3); 2009: 285–308.
5. Fiedler F. *A Theory of Leadership Effectiveness*. New York: McGraw-Hill; 1967.
6. Hersey P. and Blanchard K. *Management of Organization Behavior: Utilizing Human Resources*, 4th edn. Upper Saddle River, NJ: Prentice Hall; 1982, pp. 150–173.
7. Müller R. and Turner R. Leadership competency profiles of successful project managers. *International Journal of Project Management* 28(5); July 2010: 437–448.
8. Sayles L. and Chandler M. *Managing Large Systems: Organizations for the Future*. New York: Harper & Row; 1971, p. 219.
9. Bennis W. and Nanus B. *Leadership: Strategies for Taking Charge*. New York: Harper & Row; 1985, pp. 224–225.
10. Vaill P. The purposing of high-performing systems. *Organizational Dynamics*, Autumn; 1982: 23–39.
11. Ibid., p. 38.
12. This discussion is largely based on Hofer W. Lady Liberty's business army. *Nation's Business*; July 1983: 18–28; see also Hall A. Liberty lifts her lamp once more. *National Geographic*; July 1986: 2–19.
13. Ibid., p. 28.
14. Ibid., p. 21.
15. An exception is projects that require high innovation and creativity and wherein, in general, strong teamwork tends to *reduce* team effectiveness. This suggests in high-innovation projects that teams be allowed for periods of collaborative work as well as *less-collaborative* and *individual* work to facilitate individual creative-thinking skills. Hoegl M. and Parboteeah K. Creativity in innovative projects: How teamwork matters. *Journal of Engineering and Technology Management* 24(1–2); March–June 2007: 148–166.
16. See Chapman. *Project Management in NASA*, pp. 59–62. The other functions of project management were defined to be project planning, information and control, and consultation.
17. Keller R. Predictors of the performance of project groups in R&D organizations. *Academy of Management Journal* 29(4); December 1986: 715–726.
18. This format is based upon Dyer W. *Team Building: Current Issues and New Alternatives*, 3rd edn. Reading MA: Addison-Wesley; 1995. For other approaches, see: Katzenbach J. and Smith D. *The Wisdom of Teams: Creating the High-Performance Organization*. New York, NY: HarperBusiness; 2006; Harvard Business Review. *Harvard Business Review on Building Better Teams*. Brighton, MA: Harvard Business Review Press; 2011.
19. Based on research in Gratton L., Voight A. and Erickson T. Bridging faultiness in diverse teams. *MIT Sloan Management Review* 48(4); 2007: 3

20. This discussion largely based on Dyer. *Team Building*.
21. Blake R., Shepard H. and Mouton J. *Managing Intergroup Conflicts in Industry*. Houston: Gulf Publishing; 1965.
22. This section is largely based upon Duarte D. and Snyder N. *Mastering Virtual Teams*. San Francisco, CA: Jossey-Bass; 2006, pp. 31–80.
23. Portions of this section are from Duarte and Snyder. *Mastering Virtual Teams*, p. 77.
24. Based upon Duarte and Snyder. *Mastering Virtual Teams*, pp. 145–147; and Cohn M. *Succeeding with Agile,* pp. 367–370.
25. Cohn. *Succeeding with Agile*, p. 370.
26. Much of this section adapted from Duarte and Snyder. *Mastering Virtual Teams*, pp. 170–183.
27. Cohn. *Succeeding with Agile*, pp. 376–377.
28. Sayles and Chandler. *Managing Large Systems*, p. 278.
29. Thamhain H. and Wilemon D. Conflict management in project life cycles. *Sloan Management Review*; Spring 1975: 31–50; and Thamhain H. and Wilemon D. Diagnosing conflict determinants in project management. *IEEE Transactions of Engineering Management*; February 22, 1975.
30. Schmidt W. Conflict: A powerful process for (good or bad) change. *Management Review* 63; December 1974: 5.
31. Moody F. *I Sing the Body Electronic*. New York: Viking; 1995, pp. 110–115.
32. Thamhain and Wilemon. Conflict management, pp. 46–47.
33. Sayles and Chandler. *Managing Large Systems*, p. 216.
34. Method based upon Dyer. *Team Building*, pp. 109–116.
35. Ibid., p. 112.
36. Portions of this section adapted from Huse E. and Cummings T. *Organization Development and Change*, 3rd edn. St. Paul: West; 1985, Chapter 12; Quick J. and Quick J. *Organizational Stress and Preventive Management*. New York: McGraw-Hill; 1984; and Williams J. *Human Behavior in Organizations*, 2nd edn. Cincinnati: South-Western; 1982, Chapter 9.
37. Bryman A. et al., The concept of the temporary system: The case of the construction project. *Research in the Sociology and Psychology of Organizations* 5; 1987: 253–283.
38. Portions of this section adapted from Huse and Cummings. *Organization Development and Change*; Quick and Quick. *Organizational Stress and Preventive Management*; Williams. *Human Behavior in Organizations*; House J. *Work Stress and Social Support*. Reading, MA: Addison-Wesley; 1981; and Warshaw L. *Managing Stress*. Reading, MA: Addison-Wesley; 1982.
39. NASA website, December 1999.

Part V

Project management in the corporate context

Beyond project organization, leadership skills, and tools and methods for management, what else is needed to improve project success? One answer is that the organization must provide support to its managers and encourage and enable them to apply project management best practices. Another is that the organization must choose projects that are viable and beneficial to the organization, that is, projects that meet sound criteria based upon the organization's objectives and available resources. And still another is that, if the project is but one element of many in a larger endeavor—a program or portfolio—then that larger endeavor must itself be well managed. These are the topics of Chapters 18 and 19.

In the growing globalization of today's business and technology, projects of international scope are accelerating in number and becoming increasingly influential on commerce, technology, and the environment. The question of how to manage such projects, which span international borders and cultures, is the subject of Chapter 20. The topics of this chapter span most everything covered in this book and serve as a fitting summary and review of all that is project management.


Taylor & Francis
Taylor & Francis Group
http://taylorandfrancis.com

Chapter 18

Meta-management of projects and program management

Meta-management of projects refers to important aspects of project management over which project managers typically have little or no influence. For example, the general approach to be taken and preparedness of an organization to perform projects usually depends on others—senior managers and directors—and, given that, the likelihood of project success depends partly on measures taken by the organization. Such measures, the first topic of the chapter, include project management maturity, project management methodology, knowledge management, and the project management office. Frequently, projects are undertaken as part of a larger agenda—programs—and these require their own kind of management, program management, which is the second topic of the chapter.

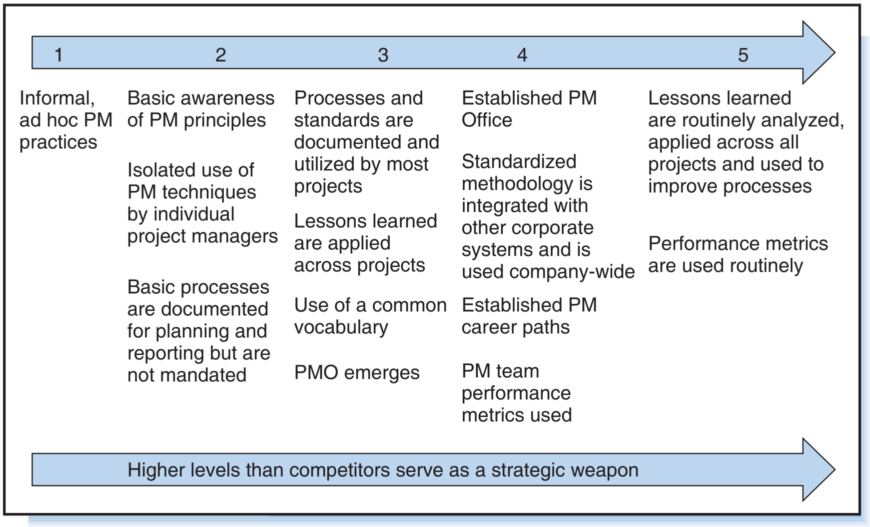
18.1 Project management maturity and maturity models

How good are we really? How well do we measure up to our competitors? In which areas should we improve? These are questions that companies continually ask themselves about their capabilities and competencies. An organization's capability or competency regarding project management is referred to as its "maturity."

Maturity continuum

Just as people mature physically and mentally, organizations mature in project management. Typical levels or phases of increasing maturity are shown in Figure 18.1.

The first level of project management maturity is when a few people in the organization learn the principles of good project management and practice them on their own. Of course, for the organization to further develop its capability, *many* people must practice the principles; for that to happen, it requires executive-level awareness about the importance of project management and willingness to support aspects of those principles throughout the company. These aspects include documenting lessons learned in every project for the benefit of future projects and developing a common language of project management terms to be used throughout the company. A company with projects around the world might create a glossary of terms in multiple languages. Naturally, moving to higher-level maturity also requires that the organization develop a project management methodology. Ultimately, the



1	2	3	4	5
Informal, ad hoc PM practices	Basic awareness of PM principles Isolated use of PM techniques by individual project managers Basic processes are documented for planning and reporting but are not mandated	Processes and standards are documented and utilized by most projects Lessons learned are applied across projects Use of a common vocabulary PMO emerges	Established PM Office Standardized methodology is integrated with other corporate systems and is used company-wide Established PM career paths PM team performance metrics used	Lessons learned are routinely analyzed, applied across all projects and used to improve processes Performance metrics are used routinely

Higher levels than competitors serve as a strategic weapon

Figure 18.1
Levels of project management maturity/competency.

organization will be in the position to benchmark its project management capabilities against organizations that are industry leaders.[1]

Maturity models

Project management maturity is gauged according to so-called "maturity models." There are many recognized models, although none has achieved uniform acceptance worldwide.[2] Maturity models fall into three categories:[3]

- Technical delivery process models
- Project management process models
- Total organization models.

Technical delivery process models originated in the total quality management movement of the 1980s when companies started to measure their quality management capabilities. An example is the capability maturity model (CMM) developed by the Software Engineering Institute of Carnegie-Mellon University during the 1980s and 1990s to help identify competent software contractors. The model, which emphasizes process documentation, similar to ISO quality standards, has five levels of maturity similar to Figure 18.1 but with a software engineering focus.

Project management process models focus on knowledge areas.[4] Many of these models are based on the ten knowledge areas of the Project Management Institute's Guide to the Project Management Body of Knowledge,[5] where the level of maturity achieved in each knowledge area is determined by comparison to standardized criteria during an audit. Figure 18.2 shows the audit results for the assessed maturity levels for eight knowledge areas.

Process models commonly specify five levels of maturity, comparable to those in Figure 18.1:[6]

- Ad hoc: no formal procedures or plans
- Individual project planning

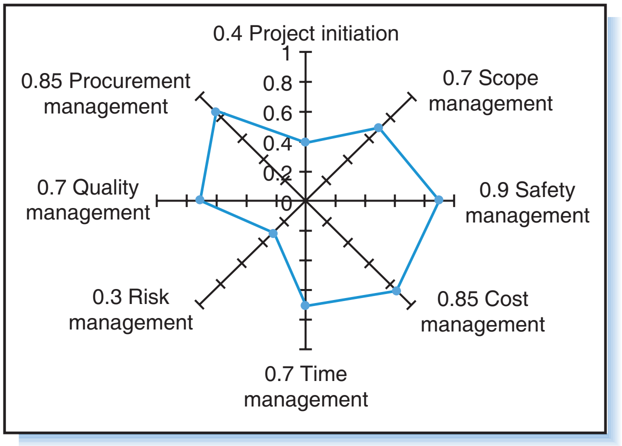


Figure 18.2 Results of maturity assessment regarding project management knowledge areas.

- Systematic project planning and control
- Integrated multiproject and formal planning and control
- Continuous PM improvement.

Following development of the CMM, the PMI sponsored research at the University of California Berkeley and George Washington University that produced the organizational project management maturity model (OPM3).[7] This is an example of a total organizational model, so called because it addresses the entire organization and how it manages projects, programs (discussed later in this chapter), and portfolios (discussed in Chapter 19).

See Chapter 19

How good should we be?

It would be incorrect to presume that an organization should strive for the highest-level maturity in all aspects as prescribed by these models. Different companies have different needs that require different levels of maturity. For example, whereas a company doing research with limited internal funding needs strong capability in project selection, a construction contractor with capacity to accept whatever work comes along does not. Likewise, a company that develops nuclear reactors needs high maturity in environmental and safety practices, but a company that develops computer games likely does not. One study of project management maturity in product development found that standardized tools and project management processes increase project success up to a point, but beyond that, they reduce success; in other words, conformity to industry standards can take you only so far.[8] No single maturity model enables project success across all types of industries and projects. Each organization must identify which areas of competency are important and avoid wasting resources to achieve high maturity in areas not important or irrelevant.

Benefits and shortcomings of maturity models[9]

Having achieved a high maturity level according to a standard maturity model gives a company bragging rights. For example, the company can point out in its proposals the high ratings it achieved for a recognized maturity model.

By their very nature, however, maturity models emphasize formal processes and procedures and focus only on explicit knowledge, which is knowledge that can be documented. A weakness of the models is they ignore tacit knowledge, which is knowledge that cannot be easily written or described. Leadership, communication, teamwork, and the knowledge and skills held by project managers and team members play a big role in project success, yet, being tacit, they represent knowledge not accounted for by the maturity models.[10]

Project maturity and project success

Studies indicate that about two-thirds of organizations rate at levels 1 or 2 on the five-level maturity scale. Not very high. Companies in petrochemical and defense industries tend to be more mature; those in insurance, financial and health services, pharmaceutical R&D, and telecommunications tend to be less mature.[11]

Does higher maturity according to the models correlate to greater project success? The empirical evidence is paltry, but the answer is, "not necessarily." Project success depends on many things, including the project environment, team, and project manager, none of which the maturity models address. Most senior managers see little association between maturity level and project performance.[12] A few studies claimed a positive correlation between maturity and project success, but they lack a theoretical basis and, not surprisingly, were conducted by consultants, not researchers.[13] And it is not obvious that maturity alone offers a competitive advantage. The models measure only explicit knowledge—that which can be standardized and documented and hence copied or adopted by every other company. So, an organization that mimics standard practices and ignores developing its own unique strengths can never become better than its competitors.[14]

To reach maturity levels 3 and higher in Figure 18.1, processes and standards for managing projects—a *project management methodology*—must be created and utilized. Also important are to document and utilize lessons learned, which relates to *knowledge management*, and to create a PMO. These topics are described next.

18.2 Project management methodology[15]

A project management methodology is a framework or procedure specifying who should do what at each stage of the project life cycle. Standards such as the PMBOK Guide provide processes and tools that often are incorporated into the methodology. The methodology used by an organization typically addresses many of the topics of this book, although organized in a way to best suit the organization. It provides a structure so that all projects are managed and performed in a standardized, disciplined, and systematic manner, using common practices to increase the likelihood of project success. An organization creates or adopts a methodology that uniquely fits its business requirements, procedures, and culture and the size, scope, and technology of its projects. Some methodologies prescribe the technical tasks of a project; our focus is on those that prescribe the *management* tasks of projects.

Why methodology?

By encouraging conformance to a prescribed project management methodology, an organization helps ensure that all projects are conducted and managed in a similar manner. Lacking a methodology, individual project managers use their own management practices and tools—some good, some not so good.

The aim of the methodology is to ensure that recognized "good" and "best" practices are applied across all projects and to elevate the practices of all project managers to those of its best managers. The methodology provides a common way to do things and a common terminology. Everyone doing things in similar ways enhances communication and learning about those ways. Every manager in the organization should follow the methodology. Those managers who are accustomed to a structured, documented approach to project management will be more likely to adopt a standardized methodology; those not accustomed will possibly resist it.

What does the methodology mandate?

The methodology specifies the stages of the life cycle for projects in an organization and the roles and management tasks of project managers and stakeholders at each stage. For instance, it specifies who is responsible for initiating, proposing, reviewing, and selecting projects and roles and responsibilities within the project review board (discussed in the next chapter) and the PMO (discussed later in this chapter). It also specifies the individuals who must review the project at gates and sign off on budgets and schedules.

Phases and gates

Most projects are conducted in phases and stages. The project management methodology defines the phases or stages into which projects are divided—for example, initiation, feasibility, definition, development, and launch—and what should happen in each. At the start of each phase, there might be a "gate," so called because at that point, the status of the project and plans for the remainder of the project are assessed and a decision is made whether to continue, hold, or cancel the project. The number of phases and gates depends on the methodology, with the minimum usually four or five. For example, the Motorola methodology in Case 18.2 had 16 sub-phases within five phases for its cellular systems projects. The gates can also represent approval of, say, project initiation, systems requirements, system validation, and system launch. Decisions at each gate are based on specific criteria.

The gating process is common in organizations that conduct concurrent internal projects in product development, IT, infrastructure, product development, or process improvement and where the projects "compete" for product or market goals and resources. It is one way of culling out weaker, less promising projects so that scarce resources are devoted to stronger, more promising projects; it also reduces risk in large, stand-alone projects.

Relationship with project life cycle

Figure 18.3 illustrates a project management methodology for a seven-stage project life cycle (initiation/feasibility through maintenance). In general, a methodology should conform to the technical and business practices of the organization; for example, stages 4 and 5 in the methodology in Figure 18.3 must be compatible with whatever development methodology the organization employs—waterfall, spiral, iterative, or Scrum.

Elements of the methodology

A typical methodology defines the phases or stages of the project life cycle and for each phase the tasks and deliverables and the stakeholders and their responsibilities.

The content of a project management methodology has been the subject of most of this book. In fact, one way to create a methodology is to look at the topics and methods in project management books,

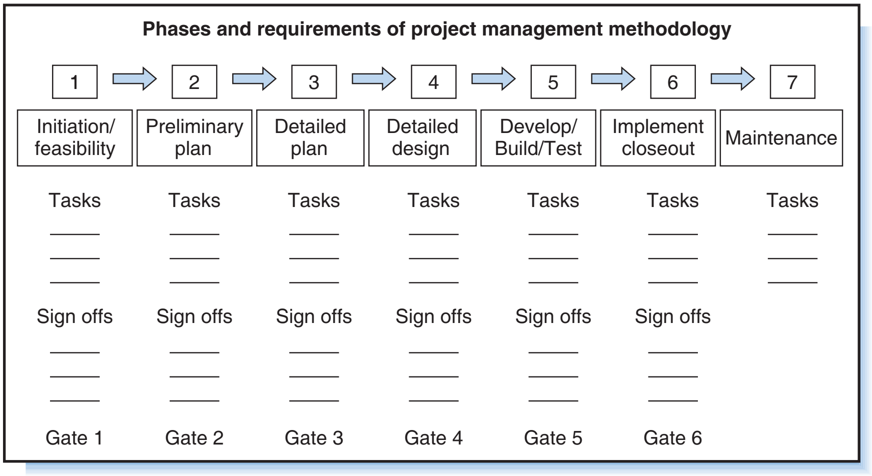


Figure 18.3
Project management methodology: phases and associated tasks and requirements.

determine which are applicable to the organization's projects, and then arrange them into a framework according to the project life cycle.

The actual content and details of the methodology—its tasks and requirements—depend on the scope and scale of the organization's projects. For large, complex, risky projects, the methodology would specify detailed tasks and methods for analysis, definition, planning, monitoring, control, and closeout. For small, low-risk projects, a somewhat simplistic methodology is adequate. Choices about which aspects of the methodology must be followed and which can be bypassed in a given project should be stated in the methodology and not left to the project manager's discretion.

This book has used the phases of conception, definition, and execution, each with a series of stages; in general, however, a particular project can be defined using any number of phases or stages. The methodology defines the nominal phases or stages in terms of whatever best represent the "natural" progression of the organization's projects, from initiation to execution and closeout.

The project phases can be based upon standards. For example, organizations involved in large engineering/construction projects commonly employ a life cycle with phases as defined by the Construction Industries Institute (CII), namely *feasibility*, *concept*, *detailed scope*, *design and construction*, *startup and commissioning*, and *operations*. Companies that build facilities for the chemical, mineral and oil and gas industries often use the phases recommended by independent project analysis (IPA), which are: *generate/shape idea*, *define opportunity* (FEL-1), *develop scope* (FEL-2), *define the project* (FEL-3), *execute*, and *produce*. The early phases of this methodology were discussed as "front-end loading" in Chapter 4.

See Chapter 4

The methodology can also include stages preceding and following the actual project, such as the post-project maintenance stage in the methodology in Figure 18.3.

Required tasks and deliverables

For each phase or stage, the methodology specifies project management tasks and deliverables, for example, Phase 1: initiation/feasibility in the methodology in Figure 18.3 might specify:

- Assemble team and identify stakeholders.
- Prepare project charter.

- Prepare a preliminary task list.
- Perform risk analysis and prepare key-risk list.
- Develop a requirements list.
- Prepare funding request.
- Prepare resource plan, timeline, spending plan.
- Prepare project proposal.

The methodology will specify tasks and deliverables to cover virtually all of the topics covered in this book, such as those in Table 18.1.

Who is responsible—sign-offs and approvals

When the methodology includes gates at which the project must be approved, it also specifies the persons having sign-off authority and the roles of particular stakeholders such as the client, sponsor, champion, and project manager.

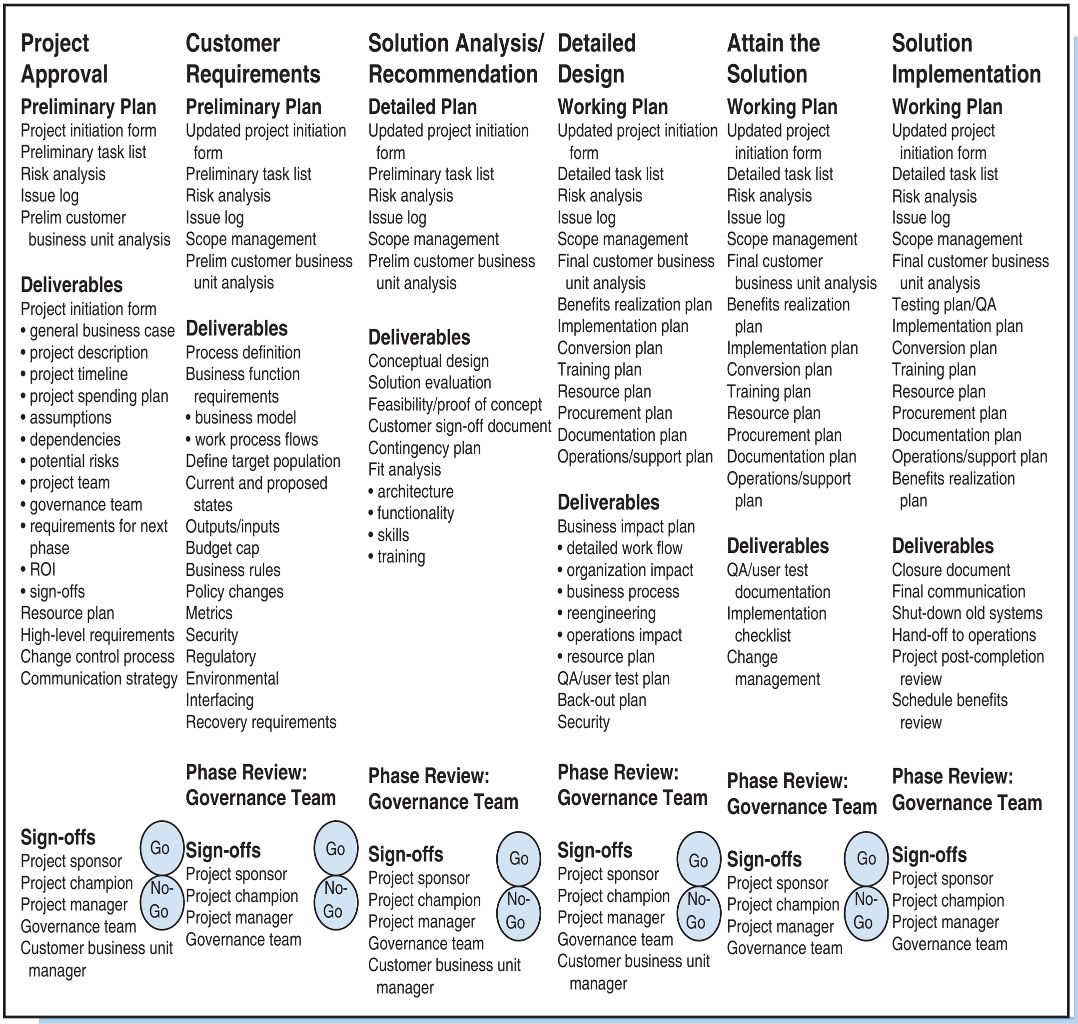
The methodology for a large company is shown in Figure 18.4. Interesting in its details, it exemplifies the scope of the tasks, deliverables, and responsibilities covered in a comprehensive project management methodology. Note the required sign-offs at each phase.

The PRINCE2 methodology

An example of a standard methodology is PRINCE2, which the UK government developed to assist organizations in developing their own unique methodologies. PRINCE2 defines the roles of high-level managers (corporate or program), project board, project manager, and team managers. It prescribes the project stages of *pre-project*, *initiation*, *subsequent-delivery stage(s)*, and *final delivery*. The methodology includes prescribed documentation: the pre-project stage is initiated by a *mandate* document, the initiation stage by a *project brief*, and the subsequent-delivery stages by project initiation documents (PIDs). PRINCE2 also prescribes a stage-management process to be followed upon completion of the initiation and subsequent-delivery stages. The process defines the project manager's responsibilities to enable the project board to assess the stage, approve the plan for the next stage, update the overall project plan, and manage product delivery in the final delivery stage.

Table 18.1 Project management tasks and deliverables.

Project initiation/proposal
Stakeholder identification
Project selection
Proposal development
Project planning
Requirements/specifications
Work definition
Resource needs
Time and cost estimating
Scheduling
Budgeting/accounting
Risk analysis
Procurement/contract management
Recruiting, training, layoffs
Project tracking/review
Data entry
Reporting to management
Project auditing
Quality control/assurance
Process control
Change control
Project closeout
Post-project review
Post-implementation review
Knowledge management



Project Approval

Preliminary Plan
Project initiation form
Preliminary task list
Risk analysis
Issue log
Prelim customer business unit analysis

Deliverables
Project initiation form
- general business case
- project description
- project timeline
- project spending plan
- assumptions
- dependencies
- potential risks
- project team
- governance team
- requirements for next phase
- ROI
- sign-offs

Resource plan
High-level requirements
Change control process
Communication strategy

Sign-offs
Project sponsor
Project champion
Project manager
Governance team
Customer business unit manager

Go / No-Go

Customer Requirements

Preliminary Plan
Updated project initiation form
Preliminary task list
Risk analysis
Issue log
Scope management
Prelim customer business unit analysis

Deliverables
Process definition
Business function requirements
- business model
- work process flows

Define target population
Current and proposed states
Outputs/inputs
Budget cap
Business rules
Policy changes
Metrics
Security
Regulatory
Environmental
Interfacing
Recovery requirements

Phase Review: Governance Team

Sign-offs
Project sponsor
Project champion
Project manager
Governance team

Go / No-Go

Solution Analysis/ Recommendation

Detailed Plan
Updated project initiation form
Preliminary task list
Risk analysis
Issue log
Scope management
Prelim customer business unit analysis

Deliverables
Conceptual design
Solution evaluation
Feasibility/proof of concept
Customer sign-off document
Contingency plan
Fit analysis
- architecture
- functionality
- skills
- training

Phase Review: Governance Team

Sign-offs
Project sponsor
Project champion
Project manager
Governance team
Customer business unit manager

Go / No-Go

Detailed Design

Working Plan
Updated project initiation form
Detailed task list
Risk analysis
Issue log
Scope management
Final customer business unit analysis
Benefits realization plan
Implementation plan
Conversion plan
Training plan
Resource plan
Procurement plan
Documentation plan
Operations/support plan

Deliverables
Business impact plan
- detailed work flow
- organization impact
- business process
- reengineering
- operations impact
- resource plan

QA/user test plan
Back-out plan
Security

Phase Review: Governance Team

Sign-offs
Project sponsor
Project champion
Project manager
Governance team
Customer business unit manager

Go / No-Go

Attain the Solution

Working Plan
Updated project initiation form
Detailed task list
Risk analysis
Issue log
Scope management
Final customer business unit analysis
Benefits realization plan
Implementation plan
Conversion plan
Training plan
Resource plan
Procurement plan
Documentation plan
Operations/support plan

Deliverables
QA/user test documentation
Implementation checklist
Change management

Phase Review: Governance Team

Sign-offs
Project sponsor
Project champion
Project manager
Governance team

Go / No-Go

Solution Implementation

Working Plan
Updated project initiation form
Detailed task list
Risk analysis
Issue log
Scope management
Final customer business unit analysis
Testing plan/QA
Implementation plan
Conversion plan
Training plan
Resource plan
Procurement plan
Documentation plan
Operations/support plan
Benefits realization plan

Deliverables
Closure document
Final communication
Shut-down old systems
Hand-off to operations
Project post-completion review
Schedule benefits review

Phase Review: Governance Team

Sign-offs
Project sponsor
Project champion
Project manager
Governance team

Figure 18.4
Comprehensive six-stage project management methodology.

One size fits all?

Most methodologies are flexible. They specify project management requirements for a generic kind of project but allow for exclusion of some requirements and inclusion of others, depending on the unique features of each project. When all projects in an organization are similar in terms of scope, size, and technology, then one methodology might fit all of them.

To accommodate projects of different size and complexity, the methodology can be "scalable" or come in, say, three or four versions, the particular one to be applied depending on the capital resources, duration, number of work packages and contractors, and risk of the project. A problem with multiple methodologies, however, is deciding which is appropriate for a given project. The decision is usually based upon factors of the project, as discussed in Section I.3 of the Introduction: novelty, complexity, technology, and pace.[16]

Most organizations have one basic—perhaps scalable—methodology because their projects all tend to be similar. But organizations such as oil and gas companies, which undertake projects in different categories (product development, exploration, construction, applied research, marketing) have multiple, very different methodologies. One methodology would be applied to, say, projects in search of new oil sources, another for projects to construct new refineries or ocean-drilling platforms, another for researching petroleum substitutes. The technical stages, tasks, and life cycles of these projects vary and thus require different project management methodologies.

Creating the methodology

Two ways an organization can develop its methodology are to create it from scratch or adopt it from elsewhere. In the first way, a small group of the organization's best project managers meet to create a methodology that incorporates methods they use or recognize as good and believe should be adopted for use in every project. In the second way, managers look at methodologies used by other organizations and that represent industry standards and adopt portions of the ones they find most suitable. Many companies have developed their own somewhat unique methodologies, some of which can be found online. Many of these methodologies are similar in terms of scope and details and are a good source for ideas.

When an organization looks at an industry standard or another organization's methodology, it should use those as baselines from which to create its own methodology and then precisely tailor it to its projects and business practices. Ideally, the tailoring is done by a group of the organization's best project managers (not senior managers or paid consultants); this helps ensure the methodology is appropriate for the organization's projects and will be accepted by its project managers.

Evolving, continually improving methodology

A project management methodology is not static; it is subject to change and improvement based upon experience and a changing environment. A methodology should be periodically reviewed to account for changes in projects, technology, and business practices. As new steps and requirements are added, others are pruned to prevent the methodology from becoming unwieldy. Of course, ability to improve the methodology depends on how much the organization is able to learn from its past projects—its knowledge management, covered next.

Perhaps the desideratum for any methodology is that the payoff from using it exceeds the effort in creating and upholding it. The methodology must not become yet more red tape, forcing managers to attend more to the rules than to managing projects. It should not become "Let's just fill out these forms and 'tick the boxes' so we can get on with the work."

18.3 Managing project knowledge

One potential pitfall in managing projects is treating each project as if it were completely distinctive and ignoring lessons from other projects. Solutions to problems are invented . . . and reinvented. Mistakes are repeated . . . and repeated again. Why does that happen? As the saying goes, "Fool me once, shame on you. Fool me twice, shame on me!"

As an example, consider a project that is thought to be truly unique. The project manager must ponder what to expect and how to proceed. He starts with a clean slate and presumes there is no one in the organization to help him, because—after all—the project is unique. But rarely can it be said that there is no one in the organization who can help. Usually there is someone, somewhere, with experience and knowledge that is relevant to the project. If only the project manager knew who that someone was!

Authors O'Dell and Grayson describe the problem of wasted knowledge in their book *If Only We Knew What We Know*.[17] The knowledge exists, but people don't know it exists or how to access it. Often the waste occurs because the organization has no formal process for capturing and disseminating knowledge—it has no *knowledge management*. In a project organization, knowledge management helps ensure that people in every project learn something and that whatever they learn will be available to others who could use it. Knowledge management can provide project managers with the knowledge they need, even in cases where they themselves don't know they need it!

Organizational forgetting

According to the classic learning curve, knowledge accumulates with experience: the more of something you do, the more you learn and the better you get, at least up to a point. The same holds for organizational learning but sometimes with a twist: initially, the organization gains knowledge through experience—learning more as it does more—but then it reaches a plateau or starts regressing, knowing less even as it does more. This "organizational forgetting" happens when workers, especially those with tacit knowledge (discussed later), leave the organization, new processes and technologies render old ones obsolete, procedures are not documented, or records are discarded or lost.[18] When teams disband after each project, it is easy for them (and the organization) to forget what they learned or miss opportunities to learn from their experience and share it for future projects.

Capturing knowledge

Knowledge is information put to use. Everything experienced in projects is a source of information, but to learn from each experience, managers and teams must reflect on what happened, what they did, and the outcomes, and they need to draw conclusions; otherwise, they won't learn or will forget.

One opportunity to learn from a project is the *post-completion project review* or postmortem, discussed in Chapter 5. During the review, the project team carefully looks at what it did and what it learned from doing that. It reflects on significant events, successes, and failures and the actions that led to them.

See Chapter 5

Sometimes the post-completion review is not enough; it happens once, at the end of the project, by which time memories of events have faded, recollections of details have dimmed, and information has been lost. Therefore, especially in long projects, additional *mid-stream* reviews should be held at key milestones and after notable events. Unlike status reviews that measure progress and identify problems, the purpose of these reviews is to reflect on actions taken and to learn from experience.

Common knowledge and knowledge transfer[19]

Nancy Dixon defines *organizational common knowledge* as knowledge available and easily accessible to everyone in the organization. It is "how-to" knowledge gained through the experiences of the company, largely unique to the company, and generally not available to the public. Because it is gained from experiences inside the company and not known to outsiders, it potentially sets the organization apart. It cannot be measured by maturity models, yet is perhaps the most important kind of knowledge for moving an organization ahead of the competition.

But for organizational knowledge to become "common," it must be captured, retained, and shared through a mechanism called *knowledge transfer*. Knowledge transfer can happen broadly throughout the organization or directly between individuals.

Documentation and databases

One way to transfer project-related knowledge is to document learnings from post-completion and mid-stream reviews and to incorporate those into the project management methodology and checklists for "lessons learned," "risks and pitfalls," and "best practices." Documented knowledge can also be transferred via project report libraries, training seminars, and online knowledge databases. These sources provide information useful for, among other things, "analogy" estimating in project proposals.

Example 18.1: Preparing a Proposal Using Databases and Peer Advice

Jacque has received an RFP from a client to provide engineering consultation for a new process. The client wants an answer soon. Jacque accesses the company knowledge database to see what his company has done and is doing now concerning the process. He also reviews online abstracts and articles to learn about leading industry practices for the process, and then checks the company's competency tracking system for names of people inside the company who know the process. The name Leslee pops out, someone he met earlier at a companywide networking meeting, which Jacque's company frequently holds for the express purpose of enabling people to meet each other and share project experiences. Jacque calls Leslee and arranges a phone conference, but before the conference, Leslee checks the company database for background about Jacque's client. During the conference, Leslee and Jacque work out the details of the proposal, which Jacque completes and sends to the client—barely a week after receiving the RFP.

Databases play a useful role in knowledge management, but their creation and upkeep is a subject of its own and is beyond the scope of this book. Suffice it to say, a knowledge database requires substantial effort and is ideally managed by a team of knowledge experts who know how to make it useful and user friendly. Ernst & Young, for instance, retains a database of the best-written and most informative proposals, presentations, and plans arranged into topical areas called "Powerpacks,"[20] each managed by a team of experts, documented in a standardized form, and targeted to specific user groups.

One problem with information retained in a database is that it is *latent*: it exists but is useful only when the database is accessed. A person needing information has to *initiate* the transfer process by accessing the database—and know where to look in the database and what questions to ask.

Some companies actually *impose* potentially useful information on people who need or could use it. A project support group (PSG) or PMO tracks information that might be of use and forwards it to those who might need it. If, for example, a project has done an outstanding job at reducing material costs, the PSG will write a brief report about the project and send it to managers in other projects who might be interested. This documenting and distributing of "best practices" reports helps the organization to expand its common knowledge.

Tacit knowledge and personal interaction

But some kinds of knowledge cannot be abridged into written reports and hence cannot be transferred via a document or database. Such was the case in Example 18.1, where Jacque relied not only on databases but also on Leslee. Personal interaction like this is necessary for transferring *tacit knowledge*, that is, knowledge that is difficult to put into written words or even pictures—and that exists only in people's heads and is sometimes hard to articulate. (For example, although you can easily recognize a person's face, you might be hard pressed to describe the person's facial features that enable you to do that.)

Much of the knowledge required to manage and conduct a project is tacit, which means it cannot be retained or transferred via databases, documents, reports, or checklists. Jacque's firm encourages exchange of tacit knowledge through networking meetings where people make acquaintances they might one day have to rely on.

After-action reviews

Teams that remain intact from project to project can learn and develop a growing knowledge storehouse through after-actions reviews (AARs). The concept is derived from troop teams in the US Army, which use AARs to debrief and learn from the consequences of their actions immediately following an event.[21] An AAR is a quick meeting immediately after an incident wherein a team looks at what it did, what happened, what was supposed to happen, and what accounted for the difference. Not really a "meeting" but rather a part of the way the team functions, an AAR is quick, to the point, and takes as little as 20 minutes. Everyone involved in the action participates, and one member facilitates. The imperative is that everyone is candid and speaks truthfully without fear of recrimination. AARs are most effective for projects that have clear, specific goals and where the team has established clear measures to assess the impact of its actions toward reaching the goals.[22]

Information from an AAR is usually kept confidential, which encourages candor and reduces fears of the team or individuals getting a bad reputation. Teams wanting to learn must feel free to try out different actions—some that might not work—and to openly admit mistakes. Whatever the team learns in an AAR remains with the team, unless it decides to share it with outsiders.

Peer consultation and project resource groups

AARs apply to intact teams doing repetitive projects. What about newly formed teams just starting out and where much about the project is new to them—its technology, geographic location, culture, and so on? Likely the knowledge they need resides somewhere in the organization, but the trick is to connect those who need it (knowledge receivers) with those who have it (knowledge providers) so the two parties can *interact* personally, one on one.

Why interact personally? Because when knowledge providers and receivers get together, amazing things happen, like questions and solutions occurring between them that neither the provider nor receiver would have thought of beforehand. Perhaps you have experienced this: you ask for someone's advice, which leads them to ask you a question, which leads you to ask a question back, and so on. Often this back-and-forth questioning results in going down paths that neither of you anticipated. The knowledge provider sees the situation in a new way, draws parallels, and comes up with insight and new ideas. The question is: What can an organization do to bring knowledge providers and receivers together so this can happen?

Example 18.2: Peer Consultation

A team of spacecraft engineers is preparing a proposal to bid on a satellite for a telecommunications corporation. The team has reviewed the requirements of the customer and prepared a preliminary design but is not able to decide on features of the satellite's configuration because of the project's large risk and investment. For advice, the team leader contacts 11 people at different company divisions whom he knows personally or from the grapevine. Six respond that they are willing to help out—four from company divisions in California and Texas, and two working at NASA, and the leader arranges for the six ("peer consultants") to meet in person with her team for one day in California. At the meeting, the satellite team presents data it has collected and posts diagrams and charts on the walls. The peer consultants question the team about the implications of the data, and then everyone works together to develop criteria for deciding the final configuration. The satellite team then leaves the room briefly while the peer consultants review everything and prepare recommendations. When the satellite team returns, the consultants summarize their conclusions. No decision is made about the final configuration at the meeting; however, the satellite team has learned much about the issues it still needs to resolve.

For any project manager from the company in Example 18.2 that requests peer consultation, the company will help arrange it and cover the consultants' expenses for travel and time off. The consultation process emphasizes questioning, analysis, and feedback. The peer consultants offer guidance, but the project team makes its own decisions.[23]

Some companies use a "locator system," which provides names, addresses, phone numbers, and other pertinent information of people worldwide working in specific knowledge areas; some companies supplement that with their own internal full-time consultants.

Example 18.3: Project Support Group[24]

The project support group of a large pharmaceutical corporation includes ten consultants available on request to provide expert support to any project manager who requests it. Also available are the part-time services of over 50 managers throughout the corporation with experience in project planning and execution. As a profit center, the PSG charges fees to the company units of the project managers it assists. The PSG also sponsors semi-annual forums where project managers meet to share experiences.

The benefits of the PSG are illustrated in the story of Trevor, a typical project manager. Around the time his project was nearing completion, Trevor attended a company forum. Confident that his project had been a big success, he was surprised to learn of two other similar recently completed projects. One had developed a process that, had he known, could have shaved 3 months off his project; the other had made mistakes similar to ones made in Trevor's project, and had he known, would have saved the project $50,000. In other words, the cost of Trevor *not* knowing what others in his company already knew was 3 months and $50,000!

For his next project, Trevor contacted the PSG, which assigned Jiang to work with him. Although Trevor's department had to pay for Jiang's services, Trevor felt the advice he would receive could substantially benefit his $250 million project. The PSG also provided a database of current projects with state-of-the-art practices, which Jiang and Trevor used to develop the project plan. Throughout the 2-year project, Jiang contributed ideas, management tools, benchmarking goals, peer review, and on-call availability for mentoring and coaching.

Although many project managers in the company use knowledge databases, the most important way they gain project-specific knowledge is from the consultants who devote the time to understand a project well enough to draw upon their tacit knowledge for insight and suggestions. They are "living databases" who travel from project to project, tailoring their knowledge to the needs of each.

Knowledge transfer from personal interaction works best when the organization supports and facilitates the process. Requests for assistance are viewed as a legitimate business process, not as asking for favors. People freely ask for help without feeling intrusive. Everyone is encouraged or required to take advantage of the process. Knowledge is power, and that is another reason to formalize the process: sad but true, in some organizations, knowledgeable but power-hungry people resist requests for assistance and avoid sharing what they know.

Discussion

Companies with the best knowledge management practices utilize a variety of methods that account for both tacit and explicit knowledge. For instance, spacecraft designers at Hughes Space & Communication Company are able to reduce development costs by "reusing" designs wherever possible. So as to avoid reinventing anything, they rely on the "Knowledge Highway," a process that includes an intranet database of lessons learned and best practices compiled by an editorial team and pointers to experts.[25] At Microsoft, information sharing is encouraged through monthly informal, cross-group lunch meetings. Managers from Word, Excel, and MS Project product teams meet for 2 hours to talk about their work, problems, and thoughts; they are also encouraged to informally meet with or give presentations to other managers companywide and worldwide.[26]

Who is responsible for project knowledge management? The project manager is responsible for capturing knowledge in each project and sharing it with his peers, but responsibility for organizational "common knowledge" must fall to the managers or organizational units that oversee all projects. In many cases, that responsibility resides in a PSG or knowledge management team. Often the team is a part of the PMO.

18.4 Project management office[27]

Think for a moment about everything the project manager does as described in this book, and you soon realize that being a project manager is a lot of work! Much of that work involves collecting and processing data and preparing documents, reports, plans, budgets, and presentations. The workload can be overwhelming, and sometimes there is not enough time in a day to do it all.

Example 18.4: Bay Area Medical Center

Gaurav and other project managers from the Bay Area Medical Center attended a series of seminars on project management. At the end of the series, everyone agreed on the value of the tools learned, and they returned to work with every intention of putting them into practice. Months later, the reality was that Gaurav and his colleagues had used little of what they had learned, and almost nothing had changed about the way they managed projects. Gaurav had started to create a WBS and Gantt chart for his bigger projects but gave up; already working long hours, he had scant time remaining to devote to them. Besides, BAMC offered neither support nor recognition to use these or any common project management tools.

BAMC is no different from many organizations: they send project managers to seminars to learn new and better ways but then do nothing to encourage or support usage of those ways. The tools fall by the wayside and nothing changes.

Countering this in other organizations is the *project management office* (also called the *project support office*), a department or unit whose purpose is to assist and support project managers, allocate project resources, and, in general, facilitate good project management practice. The PMO establishes and maintains the project management methodology, instigates initiatives that will increase the organization's project management maturity, and oversees knowledge management. A PMO formalizes the practice of project management but assists project managers so they are not overwhelmed and can adapt to the formalization.

Project management office leadership

Senior managers often do not understand project management; they see it as a role or job, not a profession. To them, projects are discrete occurrences that have little in common. They allow project managers to work independently but grant them little formal authority. An early challenge of the PMO is to impress on senior managers the importance of the project manager role and that of everyone adhering to a prescribed project management methodology. To gain the attention of senior managers, the PMO must be staffed with some of the organization's most experienced and respected project managers.

The PMO can take many forms. Typically, it is a permanent staff that helps guide projects in all or certain departments of the organization; sometimes it is created to serve a single large project or program and disbands upon project closeout. Some PMOs are client centered or department centered; that is, they provide services for projects oriented toward particular clients or for departments where the work is largely project based, such as IT, research, or product development.

What exactly does a PMO do? The foci and activities of a PMO, shown in Figure 18.5, are described in the following sections, in each case starting with the basic activities of most PMOs and ending with those of only mature project organizations.

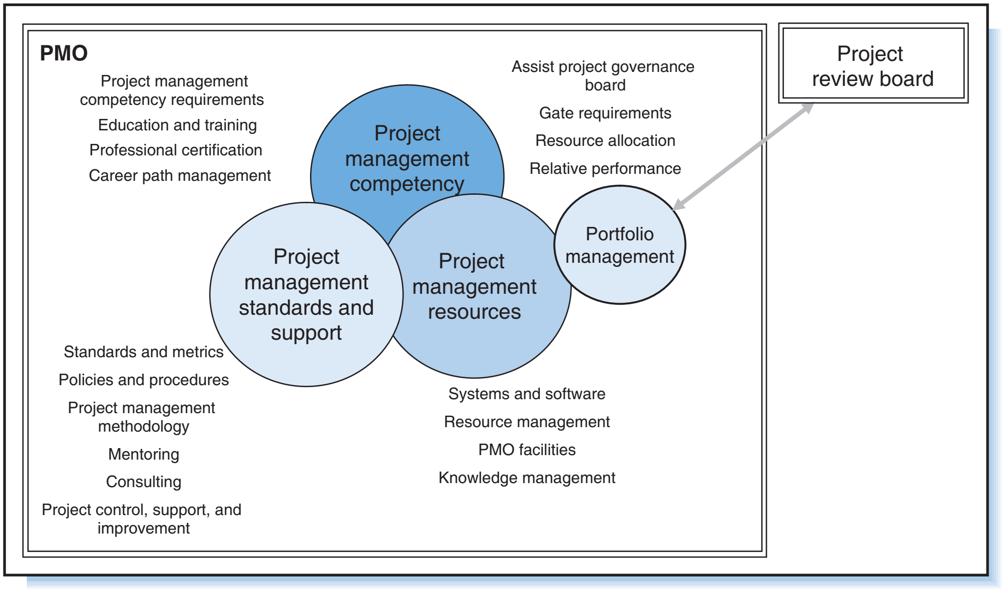


Figure 18.5
Major functions and responsibilities of the PMO.

1. Project management standards and project management support

Project management methodology

Methodology is the organization's prescribed way to manage a project; if it is the "law," then the PMO is the "law-maker," "law promoter," and "law enforcer." Often the PMO originates the methodology, maintains it, and is responsible for its implementation and improvement.

Project management policies, procedures, standards, and metrics

Application of the methodology requires policies, procedures, standards, and metrics. One example is a policy that requires managers of all projects of a certain size to conform to the methodology. If the methodology includes "Create the Project Plan," it will also specify details about what constitutes the "plan" and the procedures to create it (e.g. define scope, create WBS, estimate resources, time, and cost, etc.). The PMO sets the policies and defines the procedures.

Ideally, the PMO also provides project managers with support and assistance regarding the policies, procedures, or requirements it suggests or mandates. So that the policies and procedures are readily doable and not overly burdensome, the PMO offers various forms of assistance, such as providing clerical, data collection, and data entry support and easy-to-use standard forms, templates, and checklists.

Mentoring, consulting, and knowledge management

As discussed, the PMO staff can include technical experts and experienced project managers on call for advice and consultation. Also, the PMO schedules and facilitates team-building sessions, status meetings, and post-completion reviews and provides facilitators to guide the sessions.

The PMO is the project knowledge management center, not only by virtue of its consulting and mentoring services but by promoting organizational common knowledge by organizing forums, professional gatherings, and discussion groups where project managers meet and share experiences and lessons learned.

The PMO promotes knowledge management in two ways.[28] First, it facilitates knowledge transfer directly between projects by, for example, organizing meetings and forums so managers of different projects can directly share their experiences and learnings with each other. Second, it accumulates, organizes, and retains knowledge gained from multiple past projects (via lessons learned and project post-summary reviews) and transfers that knowledge to new projects via guidelines, project methodology, workshops, and project consultants and support groups (Example 18.3).

2. Project resources

Resource management

A common problem in project-based organizations is that projects simply do not receive adequate resources, which happens when projects are approved and initiated without considering the resources they will require. Short on resources, the organization shifts resources from one project to another; some projects are delayed or deferred so others can be started or finished.

In this capacity, the PMO maintains a record of project resources, such as the number of full-time employees in each job title or skill category. For each resource, the record includes the number allocated to current projects and the number available for new project assignments. This enables the organization to determine for a new project whether sufficient resources are available, additional resources must be acquired, or the project should be postponed or not approved.

In many organizations, the selection and relative priority of projects are set by a project review board (PRB). The PMO provides the information about resources so the PRB can determine the feasibility of undertaking each new project and allocate resources to projects with the highest priority. Chapter 19 covers this.

See Chapter 19

Project management software and communication technology

In most project-based companies, all project managers use the same project management software or set of software, depending on project size. Often this software is integrated with other software for procurement, human resources, and finance and has Internet/intranet and telecommunication applications. The software constitutes an "enterprise project management system" that is part of the company's ERP system. Frequently, responsibility for procurement, installation, and upgrade of the software, plus training in its usage and applications, lies with the PMO. For software that requires time-consuming data entry for scheduling, budgeting, planning, and tracking, the PMO provides clerical and data-entry support.

Project facilities

Projects situated at stand-alone sites (e.g. construction projects), away from the home organization (e.g. overseas projects), or involving multiple functions or organizations need a central place—a physical office—for the project staff to meet and work. The PMO arranges for the project office and facilities, such as meeting rooms for conferences and forums. For overseas projects, it might also arrange for travel, lodging, and other needs of the project staff.

3. Project manager competency

The PMO oversees most matters pertaining to the skills and abilities of the organization's project managers; specifically, it:

- Determines skill and competency requirements for project managers
- Assists in hiring new project managers
- Arranges for project managers to attend training courses and seminars
- Prepares career paths for project managers and offers career-path coaching
- Helps managers in preparing for certification (PMP, CPM, APM, CAPM, RegPM)
- Assists in the assessment and promotion of project managers
- Offers training in project management methodology, tools, and leadership and communication skills.

4. Liaison with project review board

For now, suffice it to say that the PRB is charged with broad oversight of all significant projects, including deciding which to approve, which to defer, and which to kill (discussed further in Chapter 19). The PMO provides the PRB with the information necessary to make these decisions and serves as its advisor. As each project moves through the gating process, the PRB assesses its performance, partly based on information from website-posted project "dashboards" that compare each project's performance to that of other projects in terms of a few key metrics. The PMO makes sure that projects arriving at a gate have met the documentation and other gating requirements, and updates posted information on the dashboard for the PRB to review. It could be said that the ability of the PRB to make effective decisions

See Chapter 19

rests largely on the PMO's ability to provide it with accurate and timely project information. The PMO director sits on the PRB and assists with project selection and priority decisions.

Evolution of the project management office

Creating a PMO is a project in its own right. Sometimes PMOs are established all at once and with the aid of outside consultants, although commonly they are created more slowly and internally. They begin with a small staff and limited purpose, instigated by one or a few veteran project managers who recognize the need for a standardized approach to project management. Most often, this happens in IT or product development departments where the work is project based.

The managers who instigated the PMO, with support from a higher-level manager as sponsor, create a project management methodology, plus the procedures, standards, forms, and templates needed to make the methodology workable, and begin to offer training to project managers. Initially, the PMO might consist of one person—the PMO "director," who (not coincidentally) is often the same person who conceived the PMO and helped create the methodology.

Eventually, the director's role and the PMO staff expand as their responsibilities grow to include counseling, consulting, refining the methodology, and providing clerical and technical support. At first the PMO oversees projects only in the area of the organization wherein it emerged, such as PD or IT. If all goes well, projects in that area will improve and, noticing this, senior management will direct other departments to use the same methodology on their projects. At this point, the role of the PMO enlarges to assisting project managers throughout the company in applying the methodology, developing alternative methodologies to better account for the diversity of projects throughout the company, organizing forums and seminars, accumulating lessons learned, and creating competency lists and knowledge databases (knowledge management). The PMO might also be requested to establish a gating process and assist the PRB in project selection and prioritization. Eventually the PMO might become a full-fledged department wherein all project managers are "based" and from which they are assigned to projects throughout the company.

In response to this section, some readers might react, "That's not like the PMO in my organization!" Fact is, project managers sometimes view the PMO as being little more than top management's "project police," whose main purpose is to keep an eye on projects, post red, yellow, or green tickets on the project dashboard, and enforce top management–mandated practices and requirements. Such PMOs are PMOs in name only and are contrary to the intended spirit of the PMO, which is to facilitate project management best practices and enable project managers to do their jobs better.

18.5 Program management

A program (or programme) is *a set of projects* and other activities organized and coordinated to achieve an *overarching purpose* or *goal*. Often the projects are interrelated (interdependent or linked in predecessor–successor relationships); share common customers, technology, or resources; and provide a collective capability. An example is an automobile manufacturer's program to develop "green vehicles." The program consists of multiple projects, some devoted to developing electric motors, hybrid motors, and alternative-fueled motors, others to developing battery technology and lightweight materials for auto-body components. Like the elements of a system, each serves a function necessary for the success of larger system—the program.

Program management prioritizes and coordinates the set of projects and other activities to meet program goals and attain benefits that not could not be achieved by any one project alone. Program management is sometimes viewed as an extension of strategic management, since it implements strategic initiatives and manages change in the organization or community. The green vehicle program, for instance, can be viewed as the manufacturer's strategic initiative to move its technology and production toward non–carbon fueled cars.

Project management and program management share common features, but program management is a discipline unto itself. This is necessary because, simply, programs are different than projects.

Programs vis-à-vis Projects

The main differences between a project and a program are:[29]

- A project provides specific deliverables—products, services, or other results—for a specific cost at a specific date. A program provides benefits—for example, greater revenue, profits, customer satisfaction, or knowledge; better community service; decreased costs or environmental damage; improved business processes and outcomes. The benefits accrue from the deliverables of the projects or other activities and, usually, align with business strategies.
- The program might have no set end date and run indefinitely.
- A project provides outcomes to particular customers and clients. A program provides benefits to multiple stakeholders with differing needs throughout the organization, community, or society.
- A program can evolve over time in response to competitive, technological, or political changes.
- Multiple projects, activities, and resources enable the program to attain benefits that exceed those from any single project.

Elaborating on the last point, it says: the benefits of a program go *beyond* those of any of its component projects. For example, when a construction company forms programs based upon the kinds of projects it does, for, say, roadway construction, roadway resurfacing, and water retention systems, each program provides benefits—for example, consolidation of proposals and work approvals and streamlining of processes—that could not be attained from any of the individual projects.

Kinds of programs[30]

Three common types of programs are goal-oriented, improvement, and portfolio.

A *goal-oriented program* is a group of projects and other activities that, combined, implement an organizational strategy or change or develop and implement a new application or technology. The program coordinates the projects and other activities to achieve overarching benefits tied to business strategies and broad organizational goals. The green vehicle program is one example; the Mercury Exploration program in Case 18.4 is another.

An *improvement program* provides regular enhancements to existing systems, processes, or infrastructure through advances provided by individual projects. The program serves as the framework for dealing with requests from throughout the organization for added functionality, capacity, performance or maintenance and does so for the life of the system or process it aims to improve. One example is a hospital adopting methods of "lean production." The program involves numerous projects and activities—improvement events, training sessions, changes to processes and procedures—that must be coordinated and aligned with hospital goals and ongoing operations. Another example is a government-sponsored jobs training program that serves as a clearinghouse for institutions offering training/education for high school equivalency, adult basic education, career-skill training, college degrees, certifications, apprenticeships, and internships.

A *portfolio program* is a group of projects that are otherwise independent but share common resources or technology. The purpose of the program is to coordinate the projects vis-à-vis each other, allocate shared resources, or consolidate procedures so as to improve performance of the overall set of projects.

The construction company mentioned previously that forms programs based on same types of projects is an example.

Programs can also be classified by how they are initiated.[31] Some programs derive from a clear strategy: the program concept is created around a strategic vision, and then projects and other initiatives are created to achieve the vision. Goal-oriented programs are formed in this way; for example, the NASA Apollo Program goal of manned lunar landings led to many hundreds of projects that, collectively, fulfilled that goal.

Alternatively, a program "emerges" because someone recognizes that pre-existing projects could be better managed if they were organized and coordinated. If the projects are largely independent, they can be grouped into a project portfolio; if they are related and contribute to a greater purpose, they can be grouped into an improvement program.

18.6 Program life cycle[32]

Programs, per se, have no specific end dates, so they do not follow the project life cycle. Rather, those programs that are goal oriented or improvement oriented follow a different life cycle—the *program life cycle*. Whereas the *project* life cycle typically ends upon delivery of the end-item, the *program* life cycle can be extended to include the organization's transition to and initial operation of the end-item. The typical program life cycle is divided into the phases of *program initiation, definition, project execution,* and *closeout*. At the end of the project execution phase, the program might repeat the phases of definition and project execution in cycles (called *renewal*) until program goals are met, at which point the program moves to closeout.

Program initiation (or formulation) phase

A program is initiated in response to a pressure or need placed on the organization, for example, new or changing customers, goals, challenges, strategies, or competitors. An executive (program sponsor) creates a high-level business case that defines the program's objectives, justifies its feasibility, and aligns it with organizational strategies. Based on the business case, the program governance board either approves or denies the program. If approved, a program manager and the program team are selected.

Definition phase

The definition phase follows the program initiation phase or a renewal decision, described subsequently. If the phase follows initiation, it includes creating a more detailed business case and program objectives, a program plan, and a budget, and defining and sequencing the initial as-known projects and other work that will make up the program. It also involves creating an organizational structure for program governance and management, allocating program responsibilities, and setting up operational procedures and systems.

If the phase follows a renewal decision, the definition phase is repeated, this time to revise strategies and goals, establish new or revised projects and other initiatives, and update the program plan and responsibilities. The gate following the definition phase determines if the program and its component projects are ready to move to the project execution phase.

Project execution phase

As the name implies, during this phase, the projects and other work activities constituting the program are executed. The program team monitors the projects' collective performance and interdependencies, and senior management assesses program benefits and any changes needed to keep the projects or the program aligned with program objectives. The phase includes overseeing delivery of project end-items, preparing the organization for changes, and ensuring support for the installation and operation of end-items. The gate after this phase assesses benefits accrued thus far, program risks, and the projects' alignment with organizational goals and determines whether the program will be sustained ("renewal") or closed out. With renewal, the program continues as is or with changes to its direction or composition and begins a new cycle of definition and project execution.

Closeout phase

The program is terminated because the objectives were achieved, the program is no longer justifiable, or greater benefits are available in other endeavors. Unfinished projects and other work are terminated or allocated to other programs. A post-program review is conducted for lessons learned, and the program team disbands and is reassigned.

18.7 Program management themes

Four themes pervade program management: decision management, benefits management, program governance, and managing stakeholder expectations.

Decision management[33]

How will decisions be made and implemented in the program? The answer must account for the complexity of program decisions due to the large number of stakeholders, uncertainty about the future, ambiguity over alternatives, and linkages between outcomes and strategic objectives.

Most decision-making in programs happens iteratively. Stakeholders discuss matters, agree on a shared vision, and make a series of small decisions aligned with the vision. Decisions and actions are always based on the *benefits* of project deliverables and other activities. Organizations without program management tend to assess projects in terms of ability to meet requirements but not their longer-term benefits to the organization or its mission and strategies.

Benefits management

Benefits are tangible business improvements that support strategic objectives.[34] They can be measured only after the end-items or capabilities of projects or other activities have been implemented and are operational.

Benefits management refers to assessing the organizational impact of the program and managing the interdependent benefits delivered by projects. The benefits as expected during program initiation are first defined in the business case. Later, in the definition phase, a *benefits plan* is created, which specifies how the benefits align with organizational strategies and will derive from program outcomes. This plan also includes a schedule for the realization of benefits, metrics for measuring them, roles and responsibilities for managing them, and means for transferring benefits from the program to the organization. In project execution, the benefits are monitored, and in renewal and the closeout phase, responsibility for sustaining the benefits is transferred to customers and other parties.

Program governance

Program governance refers to the way elements of the program are organized and coordinated to meet program objectives. Governance starts with creating program vision and objectives based on business strategies and stakeholders' needs, devising ways to monitor the program, and keeping the program aligned with objectives and strategies. It includes the phase-gate reviews mentioned earlier to decide whether the program should be renewed or closed out.

Governance responsibility is shared among the program governance board (or steering committee), program director, program manager, and program team. The board—a committee of senior managers—serves many roles: initiate the program, align it with the organization's strategies, approve plans and high-level change requests, review progress and benefits, assist the program manager on difficult issues, ensure resource availability, and keep the program in compliance with organizational policies and procedures. The board meets only periodically and thus relies on the program team for program oversight and guidance. In organizations with many programs, governance responsibility is shared with a program management office; this and other program governance roles are discussed later.

Managing stakeholder expectations

See Chapter 16

Managing stakeholder expectations, discussed in Chapter 16, includes the steps of identifying the stakeholders, their interests, expectations, and influence; communicating with them; and working to increase their acceptance or support of the program and decrease resistance. It is sometimes called "stakeholder engagement," because stakeholders should be engaged in defining and executing the program (plus, generally, they don't like being "managed"). Often, stakeholders have considerable authority and formal power, which requires a facilitative, shared-leadership style on the part of the program manager. Stakeholders frequently have differing or conflicting expectations, so reaching agreement can involve much negotiation.

Key stakeholders are considered program "partners," and their engagement is a two-way street: the program aims to meet stakeholders' expectations, but at the same time, stakeholders must aim to meet program expectations—for example, cooperate in defining program requirements and expected benefits and, later, supply information and give approvals as requested. Throughout a program, both the stakeholders and their expectations might change, sometimes often.

18.8 Program organization[35]

The roles and relationships in a typical program organization are illustrated in Figure 18.6.

Topping the organization are the program director, governance board, sponsor, business change manager, and key stakeholders. The governance board, as mentioned, is responsible for defining the program's relation to organizational strategy and goals, overseeing and guiding the program, and creating an environment that is supportive of the program. The board is led by a *program director*, an executive who "owns" the program and has overall responsibility to ensure it meets objectives and delivers benefits. Often, however, the key decision-maker on the board is the *program sponsor*, who champions the program and gives it top-management's ratification. She is responsible for the smooth "transitioning" of project end-items into ongoing business operations and informing the board about resulting benefits. (Sometimes the transitioning responsibility is handled by a special role, the business *change manager*.)

Figure 18.6 also shows a program management office and program office. The two terms are sometimes used interchangeably, but as defined here, they are different. The *program office* is the team that assists the program manager in administering the projects or other initiatives within a *single program*. The office

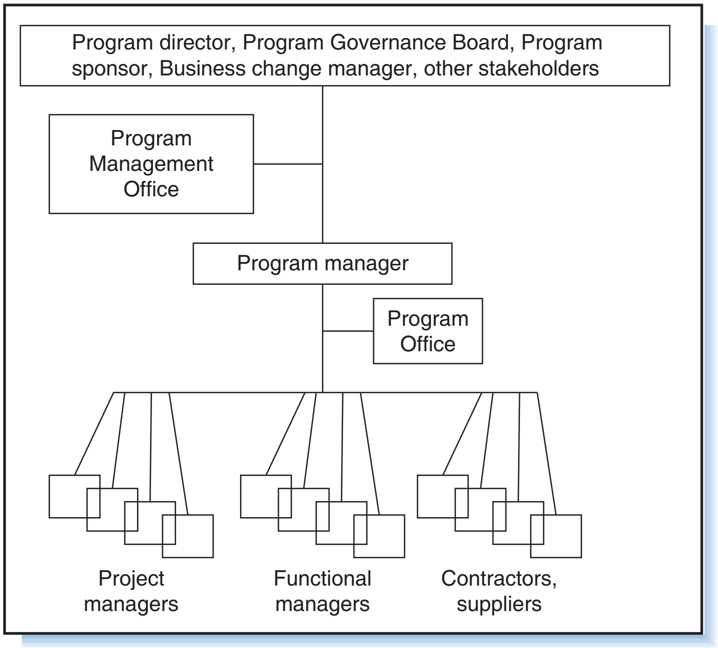


Figure 18.6
Program organization, roles, and relationships.

handles myriad functions for these projects: contracting, budgeting, training, risk management; eliminating redundancies, tracking outcomes, reporting status, and monitoring and assessing program-level benefits of project outcomes. In large programs, it allocates resources and coordinates efforts among constituent projects. At program closeout, the program office disbands.

In contrast, the program management office (PmMO) is a permanent office that provides administrative support to *all programs*. It serves a role similar to the PMO, discussed earlier, except aimed at programs, not projects.

In the middle of the program organization is the *program manager*, whose overall responsibility is to achieve the program outcomes as defined in the benefits plan. Specific duties include:[37]

- Develop program-level plans and schedules.
- Review and approve project plans for conformity to program strategies, plans, and schedules.
- Be accountable to the governance board for the schedule, budget, and quality of all program activities; provide the board with updates on program progress.

The program manager works with the "program team," which in Figure 18.6 includes the program office, managers of the constituent projects and other program initiatives, and anyone else involved in administering the program.

18.9 Special considerations

Most program managers have been project managers and are familiar with project management tools and methods. Upon becoming a program manager, however, they discover managing programs differs from managing projects in many ways, such as the following.

Transition management

Transitioning is a central issue in program management; it is the transfer of project outcomes—products, capabilities, knowledge—to program stakeholders (users, operators, customers). It refers to everything associated with the handover of project outcomes to the customer or user, such as taking physical possession, operational testing and training, and monitoring and support. In terms of the system development cycle, it is Phase D, operation, or at least enough of it to determine whether the expected benefits have been realized. Whereas in a project, handover of end-items usually happens just once, at the end of the project, in a program, it happens repeatedly, at the end of each of a succession of projects or other activities. Consequently, program success hinges on repeated successful implementations and calls for ongoing transition planning and oversight as provided by program management.

Risk and interface management

Program risk management involves identifying, assessing, and managing *program-level* risks. One such risk is "interface risk," that is, risk caused by interdependencies among the component projects. Each project might be the successor or predecessor of at least one other project and thus can delay or be delayed by those projects for lack of end products, information, services, or resources. Addressing such risks is called "interface management," and it involves identifying interfaces (inputs/outputs) among projects and ensuring that the inputs necessary for each project will be produced (as outputs) by at least one other project, activity, or external source. It also involves coordinating project schedules so that outputs from one project become available as needed by other projects.

Program managers tend not to meddle with individual project activities. They view each project as an entity with inputs and outputs, and they schedule the projects to account for their interdependencies or when their deliverables are needed or to allow time for the organization to absorb changes. Appropriate timing of deliverables is often achieved by treating each interface as a contract—a formal agreement between managers of the interfacing projects about what each can expect from the others.[36]

Work definition

How is the work in a program defined? In a project, work is defined with a WBS. Can a similar approach be used to define program work? The answer depends on the kind of program.

For a typical improvement program, the starting point is a long-range (5+ years) plan that specifies the program goals, direction, and priorities. Periodically, projects are added to the program based upon their ability to fit the plan and the emerging needs of the organization. Thus, the program work is based on whatever projects are felt necessary to advance program goals; in many cases, this is simply the defined work of the projects selected for the program.

For a goal-oriented program, work definition is more challenging, since the requirements of the program goal must be defined and then allocated among a set of to-be-determined projects. Often the goal involves innovation, new technology, and uncertain requirements, so program planning happens "incrementally." Knowledge gained from earlier projects determines next steps and the work of future projects.[37] This is similar to the phased-planning process described in Chapter 4. The main work elements in a goal-oriented program can be displayed on a *program breakdown* structure (PBS) that decomposes the program into "program packages." These packages—the work elements of the program—become the basis for creating the projects that will constitute the program; often, the packages define the top one or two levels of WBSs for the projects.

See Chapter 4

In a portfolio program, the program work is largely "predefined": it is simply the work of the individual projects that make up the program. The projects are largely independent, so the program work is merely the sum of the work of the projects and other activities in the portfolio.

Planning and control

Planning for goal-oriented and improvement programs includes identifying the program's constituent projects. The managers of these projects each develop a plan that shows his project's estimated time and resource requirements and interfaces with other projects. From these, the program manager creates a digest that summarizes all the projects' work, schedules, resource needs, and interfaces. This enables her to create a program-level schedule with milestone dates for program outcomes and to sequence projects to account for project interdependencies and resource constraints.

Once the program is underway, the program manager tracks expenditures, buffer consumption, and other performance measures for each project; looks for potential problems; and assesses the impact of each project on the others and the overall program. Methods for doing this are covered by sources in the end notes.[38] Often, the plans and outputs of individual projects must be reworked to accommodate changes in program-level resources and milestones.

Change control

Changes within a particular project that do not affect other projects or the program as a whole are handled by individual project managers; however, those that do affect other projects or the program must be handled by the program manager. Similar to project change control, program change control is a process for assessing, then approving or denying, change requests and communicating follow-up actions. The program manager must also address required or requested changes emanating from the outside for their impacts on the program and notify managers of the affected projects to take appropriate action.

Procurement management

Most programs are somewhat long term, and, correspondingly, so are relationships with contractors and suppliers. Contractors often participate in multiple projects within a program, in which case the contracting emphasis switches from meeting immediate requirements to developing long-term relationships and partnerships based upon the program's and contractors' mutual needs.

Program management misconceptions

Program management should not be confused with multiproject management, mega-project management, or managing several projects as if each were a work package.

Multiproject management refers to managing a set of projects that draw from common resource pools. The projects might have nothing in common yet must be coordinated and scheduled so as to meet their individual goals yet not exceed resource constraints. A principal purpose of multiproject management is to enable individual projects to meet their own deadlines and goals, which is unlike program management, where the overriding emphasis is on meeting program goals.

Sometimes a large project—a "mega" or "super" project—is more easily managed by breaking it down into multiple subprojects. But unless managing the subprojects in this way provides benefits (other than ease of management) in excess of the sum of the benefits of all the subprojects, managing such a thing is still project management, not program management.

Finally, program managers cannot manage the projects in a program in the same way a project manager manages work packages in a project. There are many reasons; here are two: (1) program managers usually do not have authority to "control" project budgets and schedules in the same way project managers control work packages, and (2) they cannot use a technique like earned value to assess program progress, since such progress derives from project *interdependencies*; program progress is more than just the mathematical sum of the progress of its component projects.

18.10 Summary

The first four topics of this chapter—maturity, project management methodology, knowledge management, and the PMO—lie largely or wholly beyond the project manager's responsibility and capability, yet are critical or at least relevant to project success.

The project management methodology provides a framework and set of structured tasks, tools, and techniques to conceive, define, plan, schedule, budget, track, control, and close out projects. The methodology defines the phases or stages of the project and what should happen during each, including the roles and tasks of the project manager and of other project stakeholders. It is the means by which projects in an organization are managed and performed in a standardized, disciplined, and systematic manner using recognized best practices.

Project management maturity refers to an organization's capability or competency in managing projects, including the extent to which it employs a methodology and formalized methods for planning and control, multiproject integration, and continuous improvement. A high rating on a maturity model indicates the organization has achieved a high level of standardization in its project management practices and processes, but it alone is no guarantee of project success.

Projects are unique and temporary; hence, it is easy for individuals and organizations to miss opportunities to learn from project experience, forget what they learned, or not apply learning to new projects. A formal knowledge management process is necessary to learn from project experience and to retain and share that learning with others. Ways of learning from projects include reviews—mid-stream, post-completion, and after-action. Ways to retain and share explicit knowledge from projects include checklists, databases, and other forms of documentation of tacit knowledge include peer consultation, project resources support groups, and expert knowledge consultants.

The PMO is a unit devoted to supporting project managers and improving project management practice. The PMO establishes and maintains the methodology, instigates initiatives to improve the organization's project management maturity, and manages project knowledge. It develops standards and procedures and manages resources for projects. The PMO provides training, consulting, and mentoring and assists in integrated multiproject planning and control and portfolio management.

Program management is aimed at managing programs, which are collections of projects and other activities grouped to meet goals and provide a collective capability or benefits that are beyond that of the individual projects. Program management and project management differ in many ways: the life cycle phases; roles and organization structure; themes of management emphasis; and methods for initiation, planning, definition, and control. Consequently, managing programs requires tools and practices beyond project management and uniquely suited for that purpose.

Review Questions

1. What are the benefits of project management methodology? What are the disadvantages of an organization not having one?
2. What does the project management methodology specify? What aspects of project management does the methodology address? Discuss the kinds of tasks and deliverables covered in the methodology.
3. Where does the methodology originate? Who creates and promotes it?
4. What is the purpose of project gates? Describe where the gating process fits into the project management methodology.
5. Why might an organization have more than one methodology? What are the problems with having more than one?
6. Discuss the meaning of the term "project management maturity."
7. What do project management maturity process models measure or assess?
8. List five levels of project management maturity.
9. Name the benefits of an organization being highly rated on a project management maturity model.
10. What aspects critical to effective project management does the maturity model ignore?
11. In a sentence, what is the purpose of knowledge management in project management?
12. Describe some ways of capturing project knowledge.
13. What is the difference between tacit knowledge and explicit knowledge?
14. Name some difficulties associated with retaining and sharing (transferring) tacit knowledge.
15. What kind of knowledge cannot be retained in a database? Where is that knowledge to be found?
16. What is an after-action review? How does it differ from a post-completion review?
17. How is peer consultation used in knowledge sharing?
18. What responsibility does the project manager have for project knowledge management?
19. What is the overall purpose of the project management office (PMO)?
20. Describe the role of the PMO with respect to each of the following:
    a. project management methodology
    b. project management policy, procedures, and standards
    c. project resource management
    d. project software and communications technology
    e. mentoring, consulting, and knowledge management
    f. project manager competency
    g. project review board (or governance board or project steering committee).
21. How does a typical PMO get started and grow? Describe the role of project managers in initiating and managing the PMO.
22. How do programs and projects differ?
23. Explain the program phases of program initiation, definition, project execution, renewal decision, and closeout.
24. Explain the four themes of program management.
25. Explain the following roles within the program structure: sponsor, governance board, director, business change manager, program management office, program manager, and program office.

Questions About the Study Project

1. Did the project follow an established, formal methodology? If so, describe it. What is the opinion of the project manager and project staff as to the effectiveness of the methodology? Where did the methodology originate?
2. If no formal methodology existed, did the project manager use her own, informal methodology? If so, what was it? Was it effective?
3. What is your opinion about the project management maturity of this organization? Is the organization mature or somewhat immature?
4. Was anything done to capture knowledge in this project? Were measures taken to retain this knowledge for application and transfer to other projects?
5. Among the knowledge management methods described in this chapter, which were practiced in this project? How is knowledge shared in the organization?
6. Does the organization have a PMO? If so, what are its functions? How was the role of the PMO visible in this project? In your opinion, did the PMO help or hinder the project manager? Explain.
7. Was the project part of a larger program? If so, try to answer the previous questions 24 and 25 regarding the program.

CASE 18.1 MAXIM CORPORATION AMERICA (MCA)

Maxim Corporation is a leading provider of risk management services, insurance brokerage, and specialty insurance underwriting. With an employee base of over 50,000 people at 600 offices in more than 100 countries, the corporation has a broad view of the insurance industry and leverages its expertise across hundreds of disciplines worldwide.

IT Operations and PMO

The IT Operations department for the US division is located at Maxim Corporation America corporate headquarters. Previously, the department had over 1,200 employees and was responsible for 80 percent of all MCA IT projects (the other 20 percent going to consultants); it handled three kinds of projects: strategic, infrastructure, and client applications.

In 2009, the ITO department established a PMO to oversee infrastructure projects. The office consisted of a director, support staff, and ten project managers. The director reported to the chief technology officer (CTO), who reported to the global chief information officer (CIO). The PMO's primary role was assigning managers to infrastructure projects and tracking the projects. At any given time about 30 infrastructure projects were underway and many more under consideration.

PM Methodology

One of the PMO director's first initiatives was to develop a project management methodology with the assistance of his most experienced project managers. The methodology, called project management framework (PMF), specifies prescribed project phases, documentation, and gates covering all aspects of the project life cycle from project initiation to completion sign-off and postmortem review. It is thought to be quite good: rigorous but not bureaucratically cumbersome.

PMO Services

The PMO enforced the methodology and assisted project managers in its usage through training and coaching. Besides this, it conducted courses on topics such as project communication and leadership skills, convened meetings for the project managers to discuss their projects, and sponsored seminars. It created templates and forms to reflect the lessons learned from completed projects and arranged for project managers to be coached and mentored by experienced project managers.

Portfolio Management

Also, the PMO assisted the project review board in selection of proposed projects and assessment of underway projects. The PRB is a committee of 10–12 managers that includes the global CIO, CTO, director of the PMO, VP of Finance, and senior managers with budget responsibility for proposed and current projects. The PMO ensured that documentation specified in the PMF for each project was completed and signatures obtained prior to each gate. It also assessed the relative performance of projects to enable the PRB to decide which to approve, hold, or kill at gates.

Reassessment of IT operations

In late 2010, consultants concluded that MCA could save $30–$50 million annually if it outsourced all IT infrastructure operations. MCA responded rapidly and by June 2011 had outsourced all of its IT infrastructure operations to CorCom, a large IT contractor. CorCom had a reputation for operational discipline, solid project management, and good reporting. It had an internal PMO to oversee projects, including those it had acquired from MCA. Of the 600 people in IT Operations at MCA originally working on infrastructure projects, CorCom hired 480.

IT PMO Today

The director of MCA's PMO was retained but his unit reduced to four project managers and one support specialist—mostly to oversee tasks associated with the outsourcing of IT projects and the initiation and feasibility of IT projects. The education role of the PMO has been diminished and its course offerings greatly reduced. The PMO conducts courses to familiarize CorCom staff with MCA's PMF but has ceased providing mentoring and coaching services.

One problem observed since outsourcing IT infrastructure is that CorCom does not become involved in a project until after it has been defined. Whereas in the past, MCA project managers were involved during project conception and requirements definition, CorCom project managers are not involved until after project approval and definition. The stance of CorCom managers is, "Tell us exactly what you want and we'll deliver it." This contrasts to the old way of IT telling its customers "Let us help you define your needs and requirements and determine the best alternatives." CorCom project managers have no say in defining the requirements they must meet. The concern of some units at MCA is that this lack of early user-developer interaction precludes thorough identification of customer needs. But it is too early to tell if this concern is more than just a perception.

The director is convinced of the continued importance of the IT PMO. He has scheduled a meeting with the Global CIO to discuss the PMO's future.

QUESTIONS

1. Does the IT PMO at MCA have a future? What, if any, role can it retain? Can it assist in user–developer interaction?
2. How does the PMO director's role compare to the VP of projects illustrated in Figure 15.8 and the PMO director discussed in Chapter 16?

CASE 18.2 MOTOROLA'S M-GATE METHODOLOGY AND THE RAZR PROJECT[39]

Motorola employs the following 16-stage project methodology called M-Gate:

M15 Idea Concept
M14 Concept Accept
M13 Solution Select
M12 Portfolio Accept
M11 Solution Lock
M10 Project Initiation
M9 System Requirements Baseline
M8 System Requirements Allocated
M7 Contract Book
M6 Design Readiness
M5 System Test Readiness
M4 Ready for Field Test
M3 Ready for Controlled Intro
M2 Volume Deployment
M1 Retirement Plan Approved
M0 End of Life

The methodology corresponds roughly to a five-phase product life cycle:

M15 M14 M13	M12 M11	M10 M9 M8 M7 M6	M5 M4 M3	M2 M1 M0
Business Case	Portfolio Planning	Project Definition	Implementation	Launch and Closeout

Each stage specifies entrance and exit criteria, management and task requirements, and key participants and stakeholders. The full process includes five "go/no-go" gates at which a product's viability must be proved in order for the project to survive.

The M-Gate methodology emphasizes product quality and customer needs, but it was created before the era of ubiquitous cell phones. It produced some well-known successes—but at the snail's pace of one every 3 to 4 years. The stages and gates reduce risk and increase quality, but they also discourage new ideas and hold up product launch—big drawbacks in the fiercely competitive handheld phone market.

In fact, the lengthy process had initially killed the RAZR concept that was to become Motorola's hottest phone in a decade. It imposed cumbersome iterations of market research and mandated requirements that conflicted with RAZR's design goals. Motorola's marketing research showed phone sizes increasing, but RAZR aimed for the opposite—to be the thinnest possible (razor thin). As a rule, product designers were required to incorporate whatever features its wireless company customers desired, though for RAZR, they thought it better to exclude customers in the interest of secrecy. Only through the persistence of a dedicated cadre of engineers was the project approved. Thanks to high-placed supporters, management allowed RAZR the freedom to operate skunkworks-like—a small tight-knit team, working in top secrecy and largely by its own rules.

For the RAZR project, stages M15 and M14 were supplanted with a process better suited for break-the-mold products. In terms of the funnel selection method described in Chapter 19 (Figure 19.3b), the process starts with selected and prioritized product concepts streaming out of the narrow end of the funnel. The concepts then go through five stages:

See Chapter 19

- Stage 1: Prepare a short technical proposal for each product concept.
- Stage 2: Categorize the proposals.
- Stage 3: Develop a resource plan to convert each concept into a prototype.
- Stage 4: Build a prototype to demonstrate the concept to managers and product groups; kill the poorly received concepts.

- Stage 5: Transfer surviving concepts to the portfolio planning team for entry into a multi-year product portfolio (enter M-Gate process at stage M12).

As soon as the RAZR phone was launched, it became an immediate hit, selling more than 110 million units in 4 years and boosting Motorola to second in the cell phone market after Nokia. In 2008, *PC World* ranked the RAZR #12 in *The 50 Greatest Gadgets of the Past 50 Years*.

QUESTIONS

1. Why was it necessary for the RAZR team to work outside of the M-Gate methodology? In what situations might it be necessary to work around or modify an existing methodology?
2. What are the potential drawbacks of allowing projects to deviate from the methodology?

CASE 18.3 TECKNOKRAT COMPANY

Tecknokrat Company, a software consulting firm, has 18 project managers, many of whom started as systems analysts and developers when the company was founded in 1997.

Tecknokrat has a good reputation in terms of quality products and services but has recently seen its business and profits fall because many of its projects are completed late and over budget. To reverse the trend, the firm hired Drago Kovacic, a project manager who had been PMO director of IT at a bank. Drago's mandate is to assist project managers so as to improve project schedule and budget performance.

In his first 2 weeks at Tecknokrat, Drago interviewed the project managers and observed them in practice. He noted the following:

- They all have their own way of doing things. There are no prescriptions about how to manage projects.
- They all work in the same office but seldom interact. No one knows much about what the others are doing.
- Some of the managers seem antagonistic toward each other.
- Some seem to be competing with each other.
- There is no mentoring. Old-timers feel: whatever I know I had to learn through experience; new-timers have to do the same.

Digging further, he discovered some curious company policies:

- At year-end, the "best" project managers in terms of meeting schedules and budgets get awards: best gets $10,000, second best gets $7,000, third best gets $5,000. Every year, for as long as anybody can remember, the same four or five people have won the awards; all of them have been with the company over 20 years.
- The company uses education as an incentive. For each project that exceeds goals or receives praise from the customer, the manager can attend a local business seminar of his choice. The incentive tends to go to a small group of managers that, not coincidentally, includes the same group who gets the year-end dollar awards.

The ostensible purpose of the awards and incentives is to spur managers to do a better job in terms of meeting project goals.

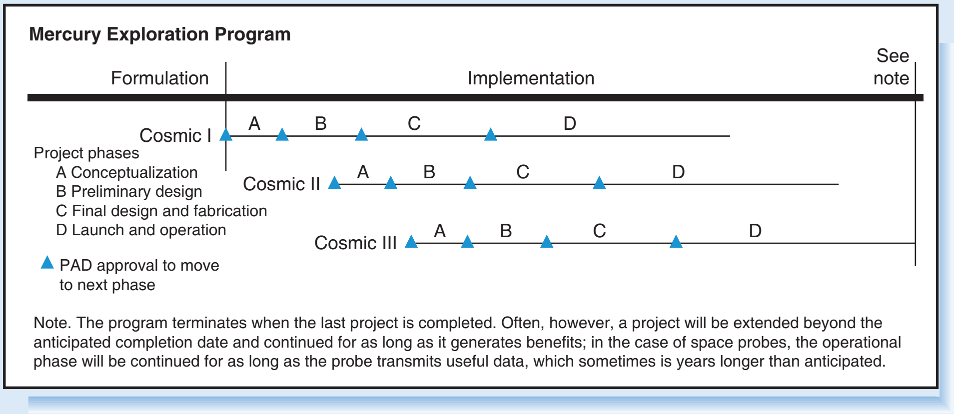
QUESTIONS

1. Based on Drago's observations, what do you think are the main issues in Tecknokrat's project management?
2. What do you think about the awards and incentives? Why haven't they had the desired effect?
3. What should Drago do? What difficulties is he likely to encounter?

CASE 18.4 MERCURY EXPLORATION PROGRAM[40]

An example of program and project management at NASA is the hypothetical Mercury Exploration Program (MEP) for sending a series of three flyby space probes to the planet Mercury. All large space programs at NASA are divided into two phases, formulation and implementation, though details of the phases vary depending on the kind of program.[41] Projects are also divided into phases, which also differ depending on the kind of project. The MEP consisted of several projects, including one for each of the three "Cosmic" space probes. These projects were divided into four phases: A, conceptualization; B, preliminary design; C, final design and fabrication; and D, launch and operation (Figure 18.7).

One of NASA's long-range goals is to collect and analyze data about planets in the solar system. The MEP was initiated when NASA scientists urged the director of Goddard Space Flight Center and director of Planetary Programs at NASA headquarters to approve a feasibility study for sending probes to Mercury to conduct geophysical measurements. The study, which initiated the formulation phase of MEP, would be directed at determining whether the program should be undertaken and, if so, determining the technical course of action and preparing a program plan. A study team of NASA scientists and engineers was appointed by the Goddard director. Besides investigating potential technical approaches for the mission and selecting one, the team identified



Note. The program terminates when the last project is completed. Often, however, a project will be extended beyond the anticipated completion date and continued for as long as it generates benefits; in the case of space probes, the operational phase will be continued for as long as the probe transmits useful data, which sometimes is years longer than anticipated.

Figure 18.7
Mercury Exploration Program and Cosmic projects I–III; not shown are various other support projects and activities in the program. Program timescale is 10–15 years.

technological developments and support activities necessary for the program to succeed, created a program management structure, developed high-level program requirements, and prepared preliminary cost and schedule estimates.

NASA management had selected a team leader to oversee the feasibility study and a liaison officer to coordinate the study with NASA headquarters. Among the requirements for the liaison officer were appropriate technical background and a personality to ensure smooth working relationships with the Goddard director and the study team leader. If the program was approved, this person would become the *program manager*, and the study team leader would become the *project manager* for the space-probe project portion of the program.

Based upon the feasibility study, the study team leader and the liaison officer drafted a project proposal and approval document (PAD) for Phase A, conceptualization, of the space probe—to be called "Cosmic." The document outlined project resources and constraints, estimated the number of space probes and type of launch vehicle needed, and allocated funds and labor. The liaison officer coordinated obtaining all necessary approvals from several NASA divisions and headquarters.[42]

Upon approval of the PAD, MEP was authorized to move into the implementation phase and Phase A of the Cosmic I project, the first space probe. The liaison officer was formally named program manager and the study team leader was named project manager of Cosmic I. The program manager's principal responsibility would be to facilitate all MEP and Cosmic reviews and decisions at NASA headquarters, coordinate work with other governmental agencies, and promote program interests inside and outside of NASA. The program manager position freed the project manager of most liaison work with headquarters and other agencies and provided a "friend" at headquarters to clear away obstacles and provide needed resources and leverage when dealing with other NASA units.

The project manager assembled a team to develop specifications for contractors. (At NASA most actual project "work"—e.g. design, building, and launch of spacecraft—is done by contractors. For example, at its peak, the Apollo lunar program required the support of some 20,000 contractors.) The team prepared schedules and estimated resource requirements and established relationships with NASA and its contractor teams responsible for major areas of the project such as launch vehicle, reliability, data acquisition, and launch operations. It chose the experiments to be conducted on the missions and determined that a total of three spacecraft missions would be required; besides Cosmic (now called Cosmic I), there would be Cosmic II and Cosmic III; each would constitute a project. Phase A of Cosmic I concluded with a preliminary project plan that specified project technical requirements, launch and tracking requirements, needed manpower and funding, and schedules and milestones to meet project objectives.

The plan was approved by management at Goddard and NASA headquarters; in effect, it became the contract between the program office and Goddard. Thereafter, the Cosmic I project manager sent weekly reports to the program manager, and the program manager worked quickly to resolve any snags that required headquarters or other NASA units. For example, whenever a problem arose that required research, the program manager would initiate funds approval to support the research.

The PAD document for Phase A was continuously updated and became the PAD documents for Phases B, C, and D. Upon moving into Phase B, the Cosmic I project appeared on NASA's information system for reporting and control of financial, schedule, and technical progress.

In Phase B, preliminary design, the project team completed technology development and engineering prototyping, and finalized the preliminary design for the Cosmic I space probe and supporting systems. It selected the launch vehicle to be used for all three missions, the Atlas IX rocket, and a common platform for all three probes. Each probe would be unique, but all of them would be built on this platform and use common navigation, communication, and control equipment; this would help save program costs.

The team also revised the baseline project plan and validated that: all project budgets and schedules were complete and adequate for the anticipated risk, the preliminary design complied with requirements, and the project was mature enough to move into Phase C. Upon headquarters' approval of the plan, the project entered Phase C.

See Chapter 3

During Phase C, final design and fabrication, contractors created detailed engineering designs, mockups, and specifications for all major subsystems on the Cosmic I probe. The project team selected contractors (through an RFP-proposal process similar to the one described in Example 3.8 in Chapter 3) to design, fabricate, and test the space probe, Atlas rocket, and operational systems. The team worked with scientists whose experiments would be on the probes, engineers preparing rockets for the three missions, engineers at Kennedy Space Center where the launches would occur, and scientists at Jet Propulsion Laboratory where data from the space probes would be acquired after launch.

Throughout Phase C, the project and program managers participated in numerous formal project reviews. They visited the contractors' plants and participated in meetings for design and test reviews, quality assurance, and system integration. The program manager monitored the project's progress, wrote reports supporting the program's annual budget, and kept the program "sold" at NASA headquarters and to Congressional committees.

Phase D, launch and operation, nominally began when the Cosmic I spacecraft was launched. The project manager oversaw everyone working in this phase, including the launch team, managers of associated NASA projects and programs, scientists whose instruments were on the space probe, contractors that built the probe and Atlas rocket, and the Air Force team that controls the missile range. During countdown before launch, only the project manager had authority to make the final, irrevocable, "go" decision.

Data were recorded between rocket lift-off and successful placement of the space probe in a trajectory toward Mercury, and problems were analyzed so as to avoid repetition on the next probe, Cosmic II. Once communication and instrumentation on Cosmic I were verifiably working and returning usable data, the program manager turned attention to Cosmic II—now in Phase C stage. He continued to monitor Cosmic I's operation so lessons learned from it would be applied to improve the design of Cosmic III, which by then was in Phase B.

QUESTIONS

1. Why was MEP a "program" and not a "project"?
2. What are the distinguishable projects in MEP? Some are named in this case, but what others might there be?
3. Who are the parties/stakeholders in the "project/program team"?
4. What must be "coordinated" among the projects and stakeholders?
5. The program includes three missions to Mercury. What was common to all of them? What was unique to each? In what ways were the projects interdependent?
6. Describe the project manager's role. Describe the program manager's role. Why couldn't one person serve both roles in this program?
7. The case illustrates the phase-gate process. What are the phases and gates? Why do you think the program is managed in this way?

Notes

1. Common language, processes, methodology, benchmarking, and continuous improvement are the five levels of maturity defined by Kerzner H. *Strategic Planning for Project Management using a Project Management Maturity Model*. New York, NY: Wiley; 2001.
2. Jugdev K. and Thomas J. Project management maturity models: The silver bullets of competitive advantage? *Project Management Journal* 33(4); 2002: 4–14.
3. Cooke-Davies T., Schlichter J. and Bredillet C. Beyond the PMBOK Guide. *Proceedings of the 32nd Annual Project Management Institute, 2001 Seminars & Symposium*. Newton Square, PA: Project Management Institute.
4. Jugdev and Thomas. Project management maturity models.
5. Project Management Institute. *A Guide to the Project Management Body of Knowledge (PMBOK Guide)*, 6th edn. Newton Square, PA: Project Management Institute; 2017.
6. Kwak Y. and Ibbs C. *Project Management Process Maturity (PM)2 Model*. Berkeley PM Model, www.ceberkeley.edu/~ibbs/yhkwak/ pmmatrutiy.html; see also Crawford J. *Project Management Maturity Model—Providing a Proven Path to Project Management Excellence*. New York, NY: Marcel Dekker; 2002.
7. Ibbs C. and Kwak Y. Assessing project management maturity. *Project Management Journal* 31(1); 2000: 32–43; PMI. *Organizational Project Management Model*. Newton Square, PA: Project Management Institute; 2003.
8. Milosevic D. and Patanakul P. Standardized project management may increase development project success. *International Journal of Project Management* 23; 2005: 181–192.
9. Pennypacker J. and Grant K. Project management maturity: an industry benchmark. *Project Management Journal* 34(1); 2003: 4–11.
10. Skulmoski G. Project maturity and cost interface. *Cost Engineering* 43(6); 2001: 11–18.
11. Cooke-Davies T. and Arzymanow A. The maturity of project management in different industries: An investigation into variations between project management models. *International Journal of Project Management* 21; 2003: 471–478; Pennypacker and Grant. Project management maturity: An industry benchmark; Crawford L. Senior management perceptions of project management competence. *International Journal of Project Management* 23; 2005: 7–16.
12. Crawford. Senior management perceptions of project management competence.
13. Jugdev and Thomas. Project management maturity models. An example of an industry study is in Nieto Rodriguez A. and Evrard D. *A First Global Survey on the Current State of Project Management Maturity in Organizations Across the World*. Woluwe Garden Woluwedal, Belgium: Price Waterhouse Cooper; 2004.
14. Jugdev and Thomas. Project management maturity models.
15. This section is based on information from interviews with project managers and PMO directors at 11 organizations: Doug Brandt (Abbott Laboratories); Jacki Koehler (ABN-Amro); Ruta Kulbis (Accenture); Holly Wells (Aon); Carson Neally, Jim Yeck, Robert Wunderlick, and Jeff Roberts (Argonne National Laboratory); Douglas Gilman, Joe Wolke, and Eileen Will (Chicago Board of Trade); Martin Wills (Information Resources, Inc.); Cynthia Reyes (Nicor); Thomas Foley (Sears Roebuck); Gurran Gopal (Tellabs); and Carol Bobbe (TransUnion).
16. Shenhar A. and Dvir D. *Reinventing Project Management: The Diamond Approach to Successful Growth and Innovation*. Boston, MA: Harvard Business School Press; 2007.
17. O'Dell C. and Jackson Grayson C. *If Only We Knew What We Know*. New York, NY: Free Press; 1998.
18. Argote L. *Organizational Learning: Creating, Retaining, and Transferring Knowledge*. Boston, MA: Kluwer Academic Publishers; 1999.
19. Dixon N. *Common Knowledge: How Companies Thrive by Sharing What They Know*. Boston, MA: Harvard Business School Press; 2000.
20. Ernst & Young. *Knowledge Management,* www.ey.com/global/content.nsf/Middle_East/Knowledge_Management_-_Tools, accessed April 13, 2007.
21. A Leader's Guide to After Action Review (TC 25–20), US Department of the Army; 1993.
22. Dixon. *Common Knowledge,* pp. 77–79, 81–82.
23. Ernst & Young. *Knowledge Management*; National Library for Health, Knowledge Management Specialists Library. *Peer Assist*, http:/www.library.nhs.uk/knowledgemanagement/ViewResource.aspx?resID=125167, accessed April 14, 2007,
24. Other examples provided by ibid., pp. 103–104, and Welch N. *Peer Assist Overview,* http://003cce4.netsolhost.com/PeerAssit.htm, accessed April 12, 2007.
25. O'Dell and Grayson. *If Only We Knew What We Know*, pp. 51–52.
26. Cusumano M. and Selby R. *Microsoft Secrets*. New York, NY: Free Press; 1995, p. 243.

27. Sources: see note 15.
28. Tshuma R., Steyn H. and Van Waveren C. The role played by PMOs in the transfer of knowledge between projects: a conceptual framework. *South African Journal of Industrial Engineering* 29(2); 2018: 127–140.
29. Pellegrinelli S. Programme management: Organizing project-based change. *International Journal of Project Management* 15(2); 1997: 141–149; PMI. *The Standard for Program Management*, 3rd edn. Newton Square, PA: Project Management Institute; 2013.
30. Pellegrinelli. Programme management: Organizing project-based change.
31. Thiry M. *Program Management*. Dorchester, UK: Gower; 2010, p. 39.
32. Pellegrinelli. Programme management.
33. PMI. *The Standard for Program Management*.
34. Thiry. *Program Management*, pp. 59–63.
35. Ibid., p. 77.
36. PMI. *The Standard for Program Management*; Thiry. *Program Management*, pp. 83–88.
37. Hanford M. Program management: Different from project management. *DeveloperWorks,* www.ibm.com/developerworks/rational/library/4751.html, accessed December 22, 2014.
38. Kendrick T. *Identifying and Managing Project Risk*. New York: Amacom; 2003, pp. 99–100.
39. Pellegrinelli. Programme management.
40. Milosevic D. and Martinelli R. *Program Management for Improved Business Results*. New York: Wiley; 2007; Thiry. *Program Management*.
41. Case derived from: McQuellon R., Pini L., Benedicata M., Mjavanadze D., Madura S., Grzybowski M. and Velasco M. *RAZR Project*. Graduate School of Business, Loyola University Chicago; February 2007; Lashinsky A. RAZR's edge: How a team of engineers and designers defied Motorola's own rules to create a cell phone that revived the company. *Fortune*; June 1, 2006; *Gizmodo* website, Motorola Insider Blame Game: Engineers Shoved Designers Aside B. *Koerner*, http://gizmodo.com/5038839/motorola-insider-blame-game-engineers-shoved-designers-aside, accessed August 24, 2010.
42. Case loosely based upon Chapman R. *Project Management in NASA: The System and the Men*. NASA, SP—324. Washington, DC; 1973, pp. 13–19.

Chapter 19

Project selection and portfolio management

Lilies that fester smell far worse than weeds.

—Shakespeare, *Sonnets*

Errors, like straws, upon the surface flow;
He who would search for pearls must dive below.

—John Dryden

Most organizations develop strategic plans, although it is well known that developing such plans is much easier than implementing them. Projects are the means by which organizations pursue their strategic objectives; hence, doing the *right* projects is critical to their business success. If an organization's objectives are to "be the low-cost leader," "expand market share in Europe," or "adapt to and mitigate climate change," then you would expect that most of its projects would be directed at those objectives. But often, that is not the case. In many companies, projects have little to do with strategic objectives and, instead, represent short-term interests, easily seized opportunities, or the agendas of a few people. "Hobbyhorse" projects of senior executives get sacred-cow status despite questionable benefits and hog resources from projects of obvious greater business value.

A study of 35 predominantly North American firms revealed relatively little spending on projects that contribute to company goals.[1] In general, project resources were spread thin because companies had too many projects and no systematic way to prioritize them. Most projects were "low-hanging fruit"—relatively easy to do but offering few business benefits; such projects waste resources and deprive a company of business opportunities.

Project portfolio management (PPM) includes processes and techniques to support decisions in the selection and prioritizing of projects and provides an effective way to implement strategy and maximize the business value of investments in projects. By providing objective, transparent, and consistent decision-making processes, it facilitates and depoliticizes project decisions that often are politically charged. Limited funds and other scarce resources are allocated in rational ways to maximize business value.

19.1 Project portfolio management

A project portfolio is a group of projects and programs aimed at strategic objectives that share resources and compete for funding. Each portfolio supports a theme—for example, a strategic objective, product

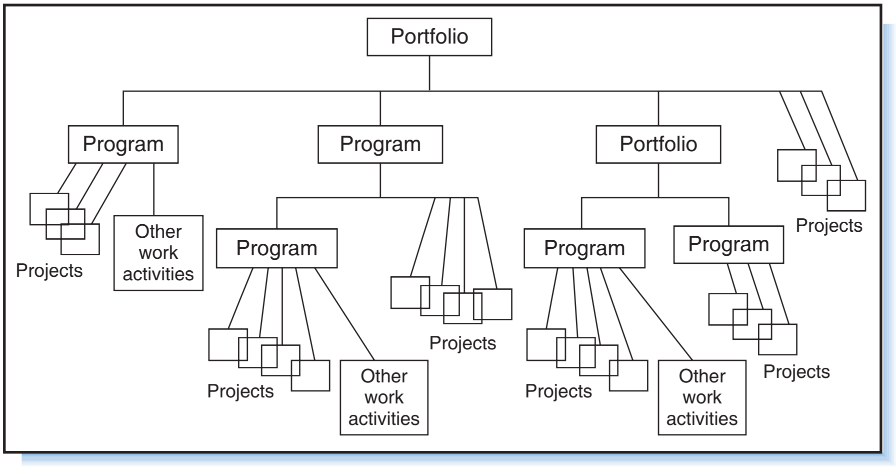


Figure 19.1
Portfolios, programs, and projects.

line, business unit, market, or geographical area of operation. Any program or project that contributes to or falls within a particular theme is added to the portfolio; thus, most organizations would have several portfolios.

As shown in Figure 19.1, a portfolio can consist of programs, projects, other work activities, and even other portfolios. Unlike projects in a program, projects and other elements in a portfolio are *not necessarily* interdependent. They are grouped in the portfolio for the purpose of better managing them as a whole and prioritizing and allocating resources among them to best achieve organizational goals.

Almost by definition, any organization that manages and allocates resources to more than one project *has a project portfolio*—whether or not its managers recognize it.[2] Organizations familiar with the concept of a project portfolio commonly conform to a process called project portfolio management; briefly, this involves two steps: (1) creating portfolios—defining "themes" around which to form portfolios and criteria for including projects and programs in each portfolio, and categorizing current and proposed projects and programs into particular portfolios, and (2) managing portfolios—assessing proposed projects and programs to decide whether each should be approved, put on hold, or rejected; prioritizing approved projects based on the risk involved and contribution to strategic objectives and allocating resources so priority projects get adequate funding; and tracking and managing projects and programs collectively in order to maximize the return on the investment made.

Example 19.1: Portfolios of a Brazilian Mining Company

A mining company in Brazil classifies each of its projects into one of four portfolios:

- *Compliance* projects—projects required to conform to legislation. These projects *must* be done and thus have very high priority and enjoy preference in the allocation of funds and other resources.
- *Environmental and social responsibility* projects—include, for example, projects to treat mine effluent water, to provide roads and supply fresh water to local communities, and to construct sewerage treatment plants.

- *Stay-in-business (SIB)* projects—projects to (a) *maintain* equipment and processes on current operations and (b) *improve* current operations, processes, and equipment.
- *Growth* projects—projects to expand the business; includes projects to develop new mines and develop *new* processes and products.

Senior management distributes available funds among the portfolios, while portfolio managers advise senior management on how to allocate those funds.

The most rudimentary form of portfolio management is simply to track projects underway and under consideration. The organization has two lists: one for "active" projects, another for "potential" or on-hold projects. Simple as it might appear, creating and maintaining such lists in the absence of a portfolio management process is not trivial, since managers routinely start projects without registering them and don't keep lists of all current and proposed projects.

Academics, consultants, and software firms have proposed many approaches to project portfolio management, and both the PMI and the UK Office of Government Commerce have developed portfolio management standards and certifications.[3] Software is often used to manage data, facilitate analyses, and streamline reporting. The breadth of the subject fills books; hence, treatment here is limited to a survey of some common principles and approaches.

Process for successful projects[4]

Successful projects and programs depend upon two things: choosing the *right projects* and doing those *projects the right way*. The two happen in a process that involves senior managers, business unit managers, and project managers:

- ***Strategic management: focus the organization***. Senior managers articulate the vision and mission of the organization, define strategies, set budgets, and allocate resources to business units. Some examples of contrasting strategies are to be the low-cost or technology leader, be innovative or imitative, or pursue mass or niche markets.
- ***Portfolio management: choose the right projects***. Business unit managers develop strategies, goals, and initiatives consistent with the corporate mission and strategies. Each goal or initiative becomes the theme for creating a portfolio and setting specific criteria, which become the basis for selecting projects from proposals generated internally or by customers.
- ***Gating methodology: nurture or get rid of projects***. Business unit managers assess each project as it moves through gates by comparing its performance to other projects' performance and gating criteria. Important but struggling projects are allocated more resources; poorly performing or mediocre projects are put on hold or cancelled.
- ***Project management: do the projects right***. Project managers guide projects using principles and practices of project management as described throughout this book.

Project portfolio manager

Portfolio management requires roles for decision-making and a clear structure. The project portfolio manager is charged with oversight of the project portfolio. Her aim is to achieve organizational objectives through the portfolio's investment in programs and projects; thus, she has an important role in guiding the organization in the right direction and consequently has a much broader and longer-term business perspective than project and program managers.

Working with the project review board (described subsequently), the portfolio manager's role is to:

- Ensure projects and programs align with strategic objectives and initiatives.
- Assess proposed projects and programs in terms of potential benefits, required resources, and risk.
- Approve or recommend projects that can achieve strategic objectives within acceptable risk and resource constraints.
- Cluster related or interdependent projects and programs into portfolios.
- Prioritize programs and projects based upon contribution to strategic objectives, resource requirements, and risks.
- Develop a resource plan and allocate resources to programs and projects.
- Seek an investment optimum by designing a mix of programs and projects to exploit synergies among them and provide balance in terms of risk, size, duration, and so on.
- Monitor, review, and assess projects at phase gates for business impact and business justification.
- Report assessment results and recommendations to senior executives.
- After projects are completed, assess and report the extent to which they delivered benefits as claimed in the business case.

Aspects of the PPM's role may appear similar to a project or program manager's; however, the PPM has greater authority. Each project manager champions and may fight for his project's existence, but the PPM looks at the project's overall benefits to the organization and may recommend scaling back or terminating a project or even a program.

Ideally, the PPM is experienced in project management and program management; more important, however, is that she understand the organization's business environment (e.g. markets and competitors), capabilities, competitive edge, and strategies, and interact well with executives and senior stakeholders.

In some cases, the PPM function becomes a responsibility of the PMO; when PPM becomes the major function of the PMO, the office is referred to as a project portfolio management office (PPMO) or project portfolio office (PPO). Usually the PPM is physically located in a PMO or PPMO. PMOs are discussed in Chapter 18.

See Chapter 18

The role of the PPM and PPMO is merely to provide advice and support to senior-management decisions. A senior executive or, in the case of major projects, the company board, makes the final decisions. Many a PPM has been fired for untactfully opposing the decisions of senior managers.

Project review board

The portfolio manager shares responsibility for project selection and portfolio management with the *project review board* (a.k.a. portfolio management team, project governance board, steering committee, project council). PRB membership typically includes the portfolio manager, chief financial officer (CFO), chief risk manager (CRM), chief human resource officer (CHRO), director of the project management office or project portfolio management office, and chief technical officer (CTO)—the last being someone from IT, engineering, or product development. For each project proposal, the CFO weighs the costs and financial benefits, the CRO assesses the risks, the CHRO assesses the human resource requirements, the CTO assesses the technical benefits and difficulties, and the PMO director compiles documentation required for selection and gating decisions.[5] The portfolio manager typically chairs the PRB and has final say over project additions or deletions in the portfolio.

For research and engineering projects, the PRB will include a group of technical "peer reviewers" who independently appraise and rate proposals according to scientific or technical merit, success likelihood, and competency or capability of the proposal originators. If they all assign low scores to a proposal, the project is rejected. If all assign high scores, the project is approved—provided others on the PRB also approve it and funds and other key resources are available. When funding is tight, few projects are approved, regardless of high scores. When it is abundant, even mediocre-rated projects might be approved.[6]

19.2 Framework for project selection and portfolio management

In organizations where projects are generated internally, the portfolio management process is used to evaluate proposals and approve projects; in those where projects are generated externally (contractors), it is used to determine to which RFPs the company should respond.

Projects differ with regard to resource requirements, risk, cost, and strategic value, so choosing the right projects is not easy. Since most projects represent investments, many of the methods used in project portfolio management derive from methods in investment management. Just as an investment portfolio can reduce monetary risk by, say, investing in multiple currencies (pound, euro, yen, or dollar), a project portfolio can reduce risk by incorporating projects from multiple business sectors.

Selection process

An organization that routinely faces project selection decisions should follow a consistent and objective process for assessing and comparing project proposals. The process should use a set of *measurable* criteria that reflects the organization's strategic goals and initiatives.

The project evaluation and selection process and its relation to other aspects of portfolio management are shown in Figure 19.2. In Phase I, each project is independently evaluated and screened; in Phase II, all projects are compared, and a subset is approved.[7] The framework largely also applies to programs—to selection of programs as well as to the projects that constitute them.

Phase I

Phase I starts with a *pre-screening stage* to eliminate clearly deficient project proposals; this corresponds to the "pre-project" or FEL-1 stage discussed in Chapter 4. To pass this step, a project must be justified in terms of organizational survival or growth.[8] Survival projects are necessary for the health and continued viability of the organization. Growth projects, though not essential for survival, expand or take advantage of opportunities for the organization. The justification is documented in a business case report that confirms the project is compatible with organizational strategies, worthwhile, and viable (expected benefits exceed expected costs). A project also needs a champion and sponsor who support it. Projects lacking justification, support, or sufficient information upon which to make a decision are rejected. Sometimes a simple checklist with a small number of criteria is employed, and each proposal is rated as excellent, good, poor, and so on. Proposals falling below a "threshold" composite rating are automatically rejected.

See Chapter 4

Proposals that pass pre-screening are subjected to *analysis* using quantitative and qualitative models and scoring methods. The analysis might rate or value the proposal in terms of diverse criteria such as "link to strategic objectives," "financial value," or "compliance to constraints," which lead to a more detailed, verified business case (sometimes called a "bankable business case"). This analysis is included in the FEL-2 process discussed in Chapter 4.

See Chapter 4

In order to be considered and approved for Phase II and possible funding, a proposal must exceed a minimum cutoff value or score; such is the purpose of *screening*—to determine which projects meet minimal requirements for benefits, risk, or other specific criteria.[9]

Phase I restricts the pool of projects entering Phase II to only the "right" projects and generates information for portfolio selection decisions in Phase II. To discourage project proposals that are frivolous or

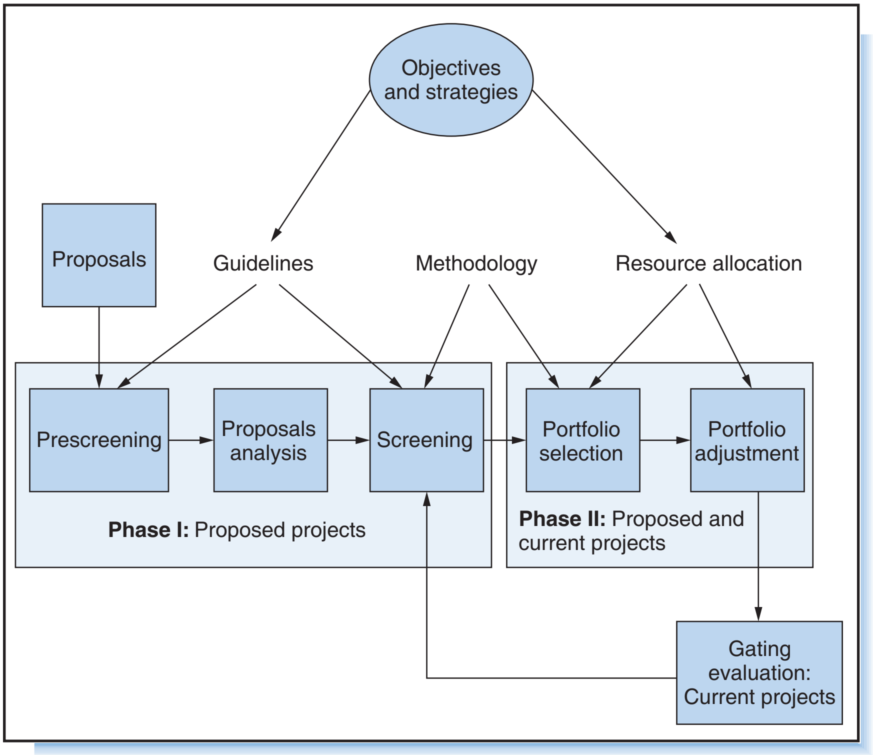


Figure 19.2
Project analysis, selection, and portfolio management methodology.

Source: Adapted from Archer N and Ghasemzadeh F. "An integrated framework for project portfolio selection." *International Journal of Project Management*, 17(4); 1999: 207–216.

clearly subpar, RFPs and project initiation procedures should clearly specify the minimal requirements for project approval.

Phase II

The first step of Phase II is *portfolio selection*, wherein projects approved in Phase I are reviewed together with existing projects to determine which combination of them would constitute the "best" portfolio. Projects are compared in terms of scores from the proposal analysis or, for existing projects, measures of their current status and performance. All projects, proposed and existing, are compared against each other using the same criteria.

Phase II is not a single event but an ongoing process. Existing projects are evaluated, periodically or at the end of each stage of the execution phase, for expected business impacts, risks, performance, and costs using the *gating process*. Those in trouble and not meeting minimal requirements are terminated outright. The remaining ones are pooled with new projects and all are rank-ordered for reconsideration about continuation, reduced or increased support, or cancellation. This *portfolio balancing* step helps ensure that high-priority projects receive resources and funding. Because objectives, opportunities (new strategies, RFPs, and proposals), threats, resources, and the external environment periodically change, so will the portfolio: new projects are added, while some current projects are accelerated, delayed, or cancelled. The gating process is discussed more fully later in the chapter.

Funnel and filter

Whether doing work externally under contract or internally to develop new products or processes, every company needs projects for survival and growth; ideally, it encourages proposals for as many innovative projects as possible and has many proposals, RFPs, and initiation requests to choose from. But a common problem is that companies approve and then attempt to execute *too many projects at once* and beyond the capability of available resources. For example, a key resource (such as an engineer) can only work on two or three projects concurrently, yet companies might try to stretch resources over twice that number. To avoid this problem, a good selection process should make sure that only the "right" projects are selected and pursued at the right time. Hence, the selection process can be likened to a *funnel* into which many proposals flow, and a *filter* through which only the best emerge. This is illustrated in Figure 19.3. The trick is to design the process with a funnel mouth wide enough to take in many proposals but a filter fine enough to screen out bad proposals yet provide a constant flow of high-quality projects.[10]

19.3 Methods for assessing individual projects

Project selection is based upon analysis of individual projects. Each analysis incorporates assumptions, some that later might prove to be wrong; for this reason, the analysis should always be thoroughly documented and include the stated assumptions. Among the most common analysis methods are financial models and scoring models.

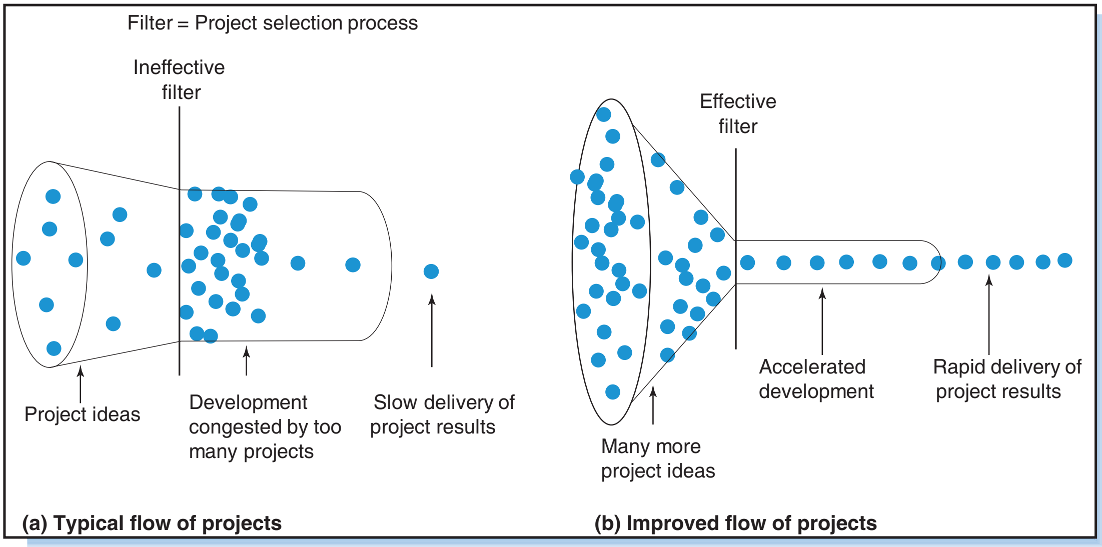


Figure 19.3
Project selection process as a funnel and filter.
Source: Concept adapted from S. Wheelwright and K. Clark, *Revolutionizing Product Development*, New York: Free Press, 1992.

Financial models

See Chapter 10

See Chapter 11

Financial models measure project proposals in terms of economic or financial criteria such as net present value (NPV), internal rate of return (IRR), return on original investment (ROI), payback period, and life-cycle cost (discussed in Chapter 9). One common such model is expected commercial value (ECV), an application of decision-tree analysis (see Appendix to Chapter 11). This model, illustrated in Figure 19.4, considers the costs, earnings, and success likelihood of the development and launch of a new product.[11] Suppose the product's development cost is \$10M, launch cost is \$1.5M, NPV for the future stream of earnings is \$50M, and probabilities for success are 80 percent in development and 60 percent in the market. Then,

$$\text{ECV} = [(\$50)0.6 - \$1.5\text{M}]\ 0.80 - \$10\text{M} = \$12.8\text{M}$$

Generally, the higher the ECV, the more preferred the project.

Another financial model is benefit/cost (B/C) ratio, which weighs the benefits of a project against its costs. A simple example is:

$$\text{B/C} = \frac{\text{Estimated revenues} \times \text{probability of success}}{\text{Estimated cost}}$$

Values in the numerator and denominator are expressed in the same form, either as annualized or present value amounts. For example, if estimated annual revenue of the project is \$100,000, estimated annual cost is \$25,000, and probability of success is 50 percent, the resulting ratio is 2.0. Thus, for each dollar spent on the project, two dollars in benefit would be expected in return. B/C can also be computed for other forms of benefits.[12] For instance, in the ratio

$$\text{B/C} = \frac{\text{Value of benifits}}{\text{Capital recovery cost} + (\text{Operating cost} + \text{Maintenance cost})}$$

the "value" can be cost savings. Suppose, for example, renovation of a factory and installation of new equipment will provide an expected present worth savings of \$6M for a present worth cost (facility renovation, equipment installation, and annual operating and maintenance expenses) of \$3M. The B/C ratio for the project is 2.0.

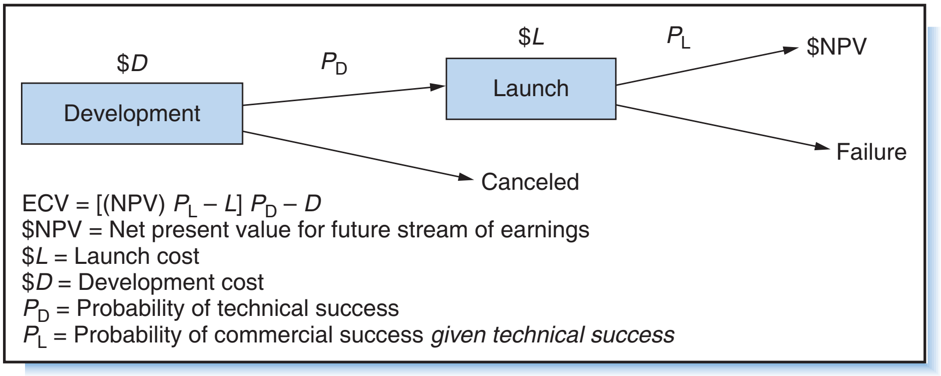


Figure 19.4
Model for computing expected commercial value.

Of course, the accuracy of the ratio depends on the accuracy of values for *all* relevant costs and benefits, including "hidden" or external ones such as impacts on the society, economy, and environment.[13] Hidden costs and benefits can be difficult to identify and measure and often exceed by far the more obvious costs and benefits. In the renovation example, suppose after the project begins, the factory electrical system is discovered to be out of code and need replacement, and the flooring is determined to be unsound and in need of reinforcement, or environmental regulations change, requiring new equipment to clean up smoke and liquids discharged from the factory. Not anticipating these costs would result in an inaccurate and overstated B/C ratio.

The main weaknesses of financial models are overreliance on *estimates* for costs, savings, future streams of earnings, probabilities, and so on; lack of data to estimate these values during project conception; and project supporters' tendency to understate costs and overstate benefits. Another weakness is sole reliance on one (financial) criterion and neglect of other criteria of equal or more importance; NPV, for example, does not measure the strategic value of a project or the extent to which, say, a project would contribute to the goal of "expanding market into Europe." Many companies focus primarily on financial models, even though financial models on their own are insufficient for assessing project success.[14] Methods that supplement financial models are discussed in the following sections.

Scoring models

Scoring models rate projects in terms of multiple criteria that, besides quantifiable measures, include non-quantifiable ones such as market risk, customer enthusiasm, or fit with company goals—whatever criteria are thought important and discriminate between projects.

In the simplest scoring models, a project is rated on each criterion according to a scale (say, 5 = excellent, 4 = good, 3 = adequate, 2 = poor, 1 = bad), and scores for all the criteria are summed to yield an overall project score. Weighted ratings are used when some criteria are considered more important than others.

Table 19.1 illustrates a scoring method that includes probabilities and weights. On the left are the scoring criteria, followed by five columns ("Very Good" through "Very Poor") that give *the expected probability* that the project will fit the criteria. For example, the probability that the long-range outlook for the project will be "Very Good" is 80 percent and will be "Good" is 20 percent. The way these probabilities are obtained depends on the information available and can range from gut feeling to sophisticated quantitative analysis. For example, the score in the table for "Risk level acceptability" can be opinion-based or derived from analysis of risk impacts and probabilities, explained in Chapter 11. As with all analyses, the more data available and more experienced the scoring team, the more accurate the estimates.

See Chapter 11

Numbers in the Expected Rating column in Table 19.1 are calculated as the sum of the probabilities times the score. The Expected Rating for long-range outlook for the product, for instance, is 0.8(4) + 0.2(3) = 3.8.

The next column, Weight, reflects the relative importance of the criteria (a criterion weighted 10 is considered twice as important as one weighted 5); sometimes the weights are set to total to 100, as shown. The next column, Weighted Expected Score, is the Weight multiplied by the Expected Rating. For the long-range outlook of the product, the Weighted Expected Score is 3.8 × 10 = 38.

The bottom of Table 19.1 shows the Total Weighted Expected Score (sum over all criteria), 336.8 out of a possible maximum 400. This score is used to screen the proposal in Phase I or rank-order it with other projects in Phase II.

One limitation of scoring methods is that they ignore the resources needed to implement projects. Big projects tend to get more attention and score higher than small projects, but they consume more resources and shut out other projects, even important ones. This limitation can be offset by simultaneously considering both a project's required funds or resources and its score or rating, as in the cost-effectiveness method, described later.

Table 19.1 Project weighted scoring model.

Criteria		Very Good 4	Good 3	Fair 2	Poor 1	Very Poor 0	Expected Rating	Weight	Weighted Expected Score
Long-range outlook	1. Product	0.8	0.2				3.8	10	38
	2. Market	1.0					4.0	10	40
Meets objectives	1. ECV	0.8	0.2				3.8	5	18.8
	2. ROI		1.0				3.0	6	18.0
	3. Image		0.6	0.4			2.6	4	10.4
Fits strategy	Phase 1	0.8	0.2				3.8	10	38
	Phase 2	1.0					1.0	5	5
	Phase 3	0.6	0.2	0.2			3.4	5	17
Goal contribution	Goal A	0.2	0.8				3.2	10	32
	Goal B	1.0					4.0	5	20
	Goal C		0.2	0.2	0.6		1.6	4	6.4
Risk level acceptability		0.7	0.3				3.7	10	37
Competitive advantage		0.9	0.1				3.9	8	31.2
Compatibility with other		0.2	0.7	0.1			3.1	8	24.8
	Total							100	336.8/400

Sources: Adapted from Cleland D. in *Project Management: Strategic Design and Implementation*, 3rd edn. New York. NY: McGraw-Hill; 1999; reprinted in Dye L. and Pennypacker J. (eds). *Project Portfolio Management*. West Chester, PA: Center for Business Practices; 1999, pp. 3–22.

19.4 Methods for comparing and selecting projects

Proposed projects that have survived Phase I are compared with current and other proposed projects in Phase II to determine which combination of projects constitutes the best portfolio. The result will be to add some new projects to the portfolio and to drop some current projects.

In their review of project portfolios in product development, Cooper et al. found that project selection approaches tend to aim at the following goals.[15]

- Maximize the value or utility of the portfolio.
- Achieve balance in the portfolio.
- Fit the portfolio to the organization's objectives and strategic initiatives.

Value or utility

Value or utility methods select projects with the highest "value" or usefulness as determined from financial models or scoring methods.

Single-criterion methods

These methods rank-order projects according to a single value or utility measure (e.g. ECV from model in Figure 19.4 or score in Table 19.1), and the highest-ranked ones are selected, subject to resource availability. A minimum-value threshold can be applied for screening proposals, such as rejecting those with a B/C ratio of less than 1.5, score of less than 50 percent maximum (200/400 in Table 19.1), or IRR of less than 8 percent (called the *hurdle rate*).

Other valuation methods, beyond our scope, include mathematical programming techniques to select the combination of projects that maximizes the portfolio value subject to project dependencies, limited resources, and other constraints.[16]

Of course, computed estimates of financial value are based upon *assumptions* about the values of the input variables, the validity of which is always open to question. In a *sensitivity analysis*, the values of input (independent) variables are altered to determine the effect on the project's estimated financial value (dependent variable); in other words, the analysis tests how sensitive the estimated financial value is to changes in the input variables (what happens to ECV if, e.g. costs rise 30 percent or the exchange rate increases 10 percent). By measuring the effect of changes in each or a combination of input variables on the calculated financial value, the *range* of values for input variables that yield an "acceptable" project financial value is determined. A project whose financial value is sensitive to even small changes in input values is considered risky.

The obvious drawback of single-criterion methods is reliance on a single value to rank-order projects, which can be risky, because underlying estimates of costs, benefits, probabilities, and so on are often fraught with inaccuracies. Also, the methods tend to be laden with assumptions that, if incorrect or overlooked, can lead to erroneous conclusions. Rank-ordering of projects according to B/C, for instance, assumes that all the projects are comparable, even though often they are not. Project A with a B/C of 3.0 would be ranked ahead Project B with a B/C of 2.0 even if Project B had a benefit of $2 million and Project A had a benefit of only $200,000.

Multiple-criteria methods

A project can be valued in many ways, although it might be valued high on one criterion but valued low on another. To overcome the conundrum of which criterion to use, there are methods that employ

Table 19.2 Multiple criteria rank-ordered list.

Project	Strategic Fit		ROI		Risk		Ranking	
	RATING	Rank	%	Rank	Risk	Rank	Weighted ranking	Rank order
A	4 (best)	1	5 (worst)	4	4 (worst)	4	15	3
B	0 (worst)	4	30 (best)	1	2	2	16	4
C	2	2	25	2	2	2	12	1
D	2	2	12	3	1 (best)	1	13	2
Weight	**3**		**2**		**1**			

multiple criteria.[17] For example, Table 19.2 rates each project for three criteria: Strategic Fit (subjective rating 0–4; 0 is poor fit with strategy, 4 is perfect fit), ROI, and Risk (subjective rating 0–4; 0 is no risk, 4 is high risk). Project scores for each criterion are compared and the projects ranked. For example, in Table 19.2, Project A is ranked 1 for Strategic Fit because it scored highest of the four projects (note projects are ranked the same when their scores are tied). Project A is ranked 4 for ROI because of the lowest ROI value, and it is ranked 4 for Risk because it scored worst in risk. The Weighted ranking is computed by using the following weights: 3 for Strategic Fit (most important), 2 for ROI, and 1 for Risk (least important). For example, for Project C, the weighted ranking is $2 \times 3 + 2 \times 2 + 2 \times 1 = 12$. Since this is the lowest numerical value, Project C ranks best and will enjoy the highest priority.

By accounting for multiple criteria and allowing additional criteria to be added as desired, this method somewhat ensures that “good” projects (in terms of the financial or scoring criteria used) are retained as candidates for selection. A limitation of this and all value methods is that they alone do not guarantee that the projects constituting the portfolio will be “balanced” or aligned with organizational objectives and strategies.

Example 19.2: Assessing Climate Change Adaptation Options Using Multicriteria Analysis[18]

Glaciers everywhere are melting, including in mountainous regions where the melt threatens mountain villages with landslides, and lowland cities and crops with flooding. As part of its National Adaptation Programme of Action, the Himalayan country of Bhutan assessed its vulnerability to these climate-change threats and ways to adapt to them. An expert task force team representing agriculture, biodiversity, forestry, natural disasters, infrastructure, health, and water resources identified and ranked possible adaptation projects using multiple criteria.

The team began by identifying the most likely and severe climate-related hazards and sectors at highest risk; these included:

- Increased glacial lake outburst floods, landslides, and flash-floods
- Most vulnerable sectors: agriculture and hydropower
- Most vulnerable communities: the rural poor.

The team considered 17 adaptation options, then shortened the list by assessing each option for:

- Severity of climate change effects addressed by the option
- Cost effectiveness

Table 19.3 Results of the ranking of prioritized adaptation options.

Criteria	Estimated cost	Human life/ health saved	Arable land, water supply, and so on saved	Essential infrastructure and monuments saved	Summary weighted score	Initial rank	National (N) Regional (R) Local (L) Multiplier	Adjusted ranking
Weight	0. 20	0.33	0. 27	0. 20			N +15% R +/- 0% L -15%	
Option								
(1) Disaster Management Strategy (Food Security and Emergency Medicine)	0.71	1.00	0.75	0. 25	0.7245	2	N 0.833175	1
(2) Landslide Management & Flood Prevention	0.56	0.75	0.75	0.50	0.662	4	R 0.662	4
(3) Weather Forecasting System to Serve Farmers and Agriculture	0.81	0.75	0.50	0. 25	0.5945	5	N 0.683675	3
(4) Artificial Lowering of Thorthomi Glacier Lake	0. 26	1.00	0.75	1.00	0.7845	1	R 0.7845	2
(5) Flood Protection of Downstream Industrial and Agricultural Area	1.00	0.75	0. 25	1.00	0.715	3	L 0.60775	5

- Level of risk by not adapting this option
- Fit with country goals such as overcoming poverty and enhancing adaptive capacity.

Table 19.3 shows five of the shortlisted options, ranked 1 to 5 according to the following criteria:

- Estimated project cost
- Human life and health saved or protected
- Arable land with water supply (for agriculture/livestock) and productive forest (for forestry) saved
- Infrastructure (hydropower plants, communication systems, industrial complexes) and monuments (cultural sites, religious sites, main tourist attractions) saved.

To arrive at the ranking, the task force team divided into three subteams, each assigned scores to the criteria for each project. Those scores were combined and standardized on a scale from 0 (no impact) to 1.00 (high impact), as shown in Table 19.3. The team then computed a summary weighted score based on the four criteria (for example, for Option 1, disaster management: 0.71 × 0.2 + 1.00 × 0.33 + 0.75 × 0.27 + 0.25 × 0.2 = 0.7245). It then adjusted the weighted score for geographical impact of the projects (15 percent increase for projects with national impact; 15 percent decrease for those with only local impact). The initial ranking, adjusted score, and final ranking are shown in the last three columns of Table 19.3.

Based upon the study results, Bhutan received funding from international sources for the two highest-ranked projects, disaster management and lowering of Thorthomi Glacier Lake.

Portfolio balance[19]

Wise investors avoid taking on too much risk. Rather than put all their eggs into one basket, they diversify and try to balance investments, for example, to pair projects that are high gain, high risk with ones that are low gain but low risk. Despite enticing opportunities for large profits or other rewards, few real estate developers, pharmaceutical companies, software developers, or others put all their resources into projects, markets, or products where outcomes are highly uncertain. They seek to balance projects that are gambles with projects that are safe bets.

A way to display this balance is with a “bubble chart.” In Figure 19.5, each “bubble” represents a project; the *x*-axis represents the project reward or expected benefits; the *y*-axis the likelihood of project success. The reward axis can be an interval scale (e.g. values for ECV, NPV, etc.) or ordinal scale (e.g. high, low); similarly, the likelihood axis can be interval (0–100 probability) or ordinal (low, high). The sizes of the bubbles represent the relative sizes of the projects based on, say, funding or resources.

Product-development organizations label the four quadrants in the chart according to the kinds of projects one finds—pearls, oysters, bread and butter, and white elephants.

Pearls are the projects that every company wants—high likelihood of success and high reward; but in reality, all companies are strapped with projects in the other quadrants as well. Oysters have lower success likelihood because of technical or other risks but are worth pursuing because of the high potential reward. The aim is to find pearls in the oysters; most oysters do not contain pearls, but you don’t know that until you look.

Bread-and-butter projects are the most common: rewards are low to moderate, but the success likelihood is high. Too many bread-and-butter projects, however, detract resources from the pearls and oysters and reduce future business opportunities.

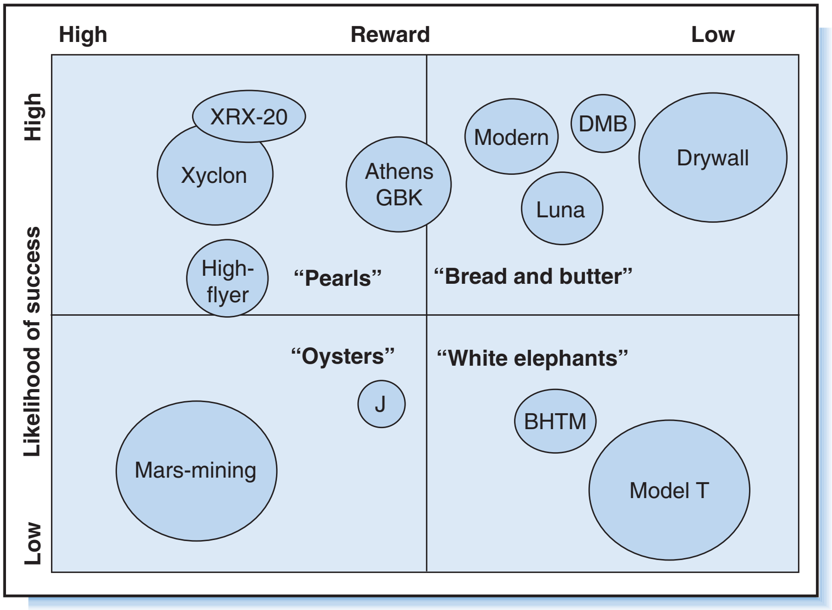


Figure 19.5
Bubble chart showing likelihood of success, reward, and uncertainty range.

White elephants are projects with low likelihood of success *and* low payoff. You have to wonder why a company would retain any projects in this category. Fact is, having spent money and effort on a project, companies feel they *should* continue; they stay committed to the projects because of funds already spent.[20] A more prudent approach is to consider funds spent "sunk costs" and irrelevant to deciding each project's future. It sometimes takes courage to cull a white-elephant project from the portfolio, especially when it was the idea of an influential manager.

The bubble chart can be modified to reveal other kinds of information. In Figure 19.5, for example, the size and shape of each bubble respectively reflect uncertainty about the likelihood of project success and the reward; the larger or longer the bubble, the greater the uncertainty.[21]

Like other assessment methods, the drawback of bubble charts is heavy reliance on estimates or guesses of likelihoods, rewards, costs, and so on. Also, they do not show the projects' rank ordering or priority using criteria other than reward and success likelihood (e.g. which is better, "Highflyer," "Xyclon," or "Mars-mining"?) or how projects *should* be distributed across the quadrants. Nonetheless, assuming the project selection team knows the balance it is seeking, such charts can be useful for deciding which projects to analyze more carefully and which to ignore. Conceptually, at least, every organization has a "threshold" line above which projects are accepted, below which they are rejected.

Another way to select projects is according to how well they fit organizational goals and strategies. Starting with the organization's mission, strategic initiatives, and objectives, top management decides on the categories (themes) of projects that best align with them.

Projects are typically categorized according to one of the following:[22]

- Strategic goal (e.g. defending the product base, growing the base, diversifying products, etc.)
- Product line (product A, B, C, etc.)

- Project type (R&D, capital improvement, process improvement, etc.)
- Geography (Toronto, California, Panama, Central America, etc.)
- Business unit (marketing, manufacturing, product development, etc.).

Further examples are the five headings in Table 19.4. Associated with each category is an allocated funding amount ($12.5M, $8.5M, $10M, etc.), which is the total budget available to all projects in that category. In a small company, the categories might be consolidated into one portfolio and managed as a single portfolio group or into a program and overseen by a program manager. In a large company, *each category* would be a *separate project portfolio* overseen by its own portfolio manager and PRB.

Companies routinely undertake more projects than they can handle. For example, in Table 19.4, the totals at the bottom of the columns indicate that projects in all but the second category require funding in excess of the allocated funding. To decide which projects to include in the portfolio, the PRB rank-orders the list of projects (using methods described earlier) and, starting at the top, selects projects until funds run out. Supposing the projects in Table 19.4 are rank-ordered, the underlined projects represent the cutoff. In the last category, for instance, Project S is the cutoff, and Projects A1 and E1 will not be funded.

A project that has been approved is admitted to the portfolio, but its ultimate execution depends on the availability of key limited resources. Someone, somewhere (perhaps the PMO) keeps track of the allocation of key limited resources, and only when resources become available can a project be scheduled to begin. A systematic procedure for allocating resources to multiple approved projects based on the Theory of Constraints is described in Chapter 8.

See Chapter 8

Deciding on the categories and the funding for each is top management's responsibility. Such decisions presumably are based upon consideration of organization mission, strategies, and objectives, although sometimes the allocation is debatable. The mission of NASA, for instance, is to support research and development in aeronautics, manned spaceflight, and unmanned space exploration, although at times, the overwhelming share of NASA funding goes to manned spaceflight programs, which leaves little remaining for unmanned space exploration and even less for aeronautics research. This has led critics to charge that NASA's skewed funding allocation does not support the agency's full range of purported objectives.

Cost-benefit grid

A method well suited for prioritizing and selecting projects according to several criteria is Buss's cost-benefit grid.[23] Suppose two important criteria are financial benefits and project cost. The PRB reviews each project's proposal and rates it (high, medium, or low) according to financial benefits and cost. The outcome is displayed on a three-by-three grid. When several projects are rated this way, the result looks like Grid A in Figure 19.6, which shows the ratings for 12 projects.

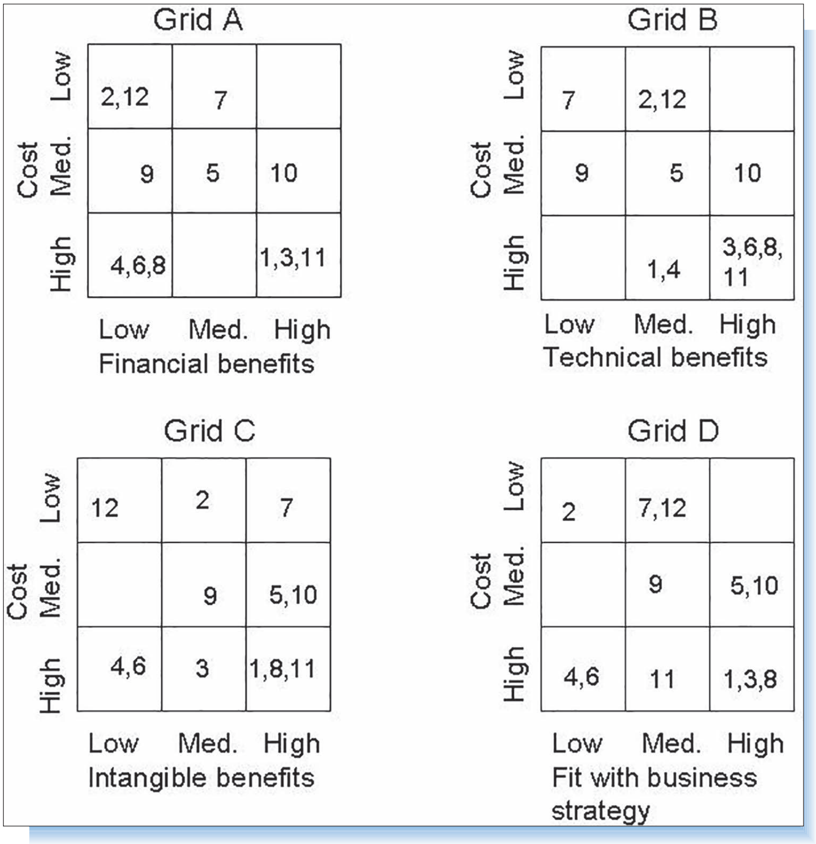
After reviewing the grid and reaching agreement on the relative positioning of the displayed projects, the team repeats the procedure for additional criteria, such as technical benefits, intangible benefits, fit with company business strategy, and so on, and plots the results on other grids (Figure 19.6).

How are intangible benefits assessed? First, the team agrees on the intangible benefits it wants to consider, such as company image, customer satisfaction, or strategic fit. Teams having members with different perspectives—that is, some who see projects in terms of financial return, others who see them in terms of technical capabilities or strategic benefits—are usually better at identifying intangibles than teams where everyone thinks alike. Given the list of intangibles, the team chooses a scoring method. If, for example, there are six intangible benefits and each is scored 1–5, then a project's maximum possible score for intangibles will be 30. To locate a project in the grid, scores are converted into simple categories, for example, ≥20 is High, ≤10 is Low, in between is Medium.[24]

Table 19.4 Projects rank-ordered within categories.

Asian Operations $12.5M		European Operations $8.5M		OEM Product Line Development $10M		Domestic Product Line Development $8M		Process Improvement $7.2M	
Project E	3.2	Project B	0.2	Project A	3.4	Project D	2.2	Project C	2.2
Project G	1.4	Project F	2.2	Project H	0.8	Project J	1.2	Project I	0.8
Project O	0.6	Project N	0.4	Project L	1.7	Project M	0.1	Project K	1.2
Project Q	3.7	Project P	1.5	Project R	3.1*	Project T	1.3	Project S	2.7*
Project W	2.3*	Project U	1.3	Project CI	1.6	Project V	0.2	Project AI	0.7
Project BI	1.8	Project X	0.6	Project GI	1.1	Project Y	0.8	Project EI	1.2
Total	13.0**	Project FI	1.9*	Total	11 y**	Project Z	1.2*	Total	8.8**
		Total	8.1			Project DI	2.2		
						Project HI	0.2		
						Total	9.4**		

* Cutoff project.
** Required funding exceeds allocation.



Grid A

Cost	Low	Med.	High
Low	2,12	7	
Med.	9	5	10
High	4,6,8		1,3,11

Financial benefits

Grid B

Cost	Low	Med.	High
Low	7	2,12	
Med.	9	5	10
High		1,4	3,6,8, 11

Technical benefits

Grid C

Cost	Low	Med.	High
Low	12	2	7
Med.		9	5,10
High	4,6	3	1,8,11

Intangible benefits

Grid D

Cost	Low	Med.	High
Low	2	7,12	
Med.		9	5,10
High	4,6	11	1,3,8

Fit with business strategy

Figure 19.6
Buss's cost-benefit grids, ratings for 12 projects.

A rank-ordered list is created from the completed grids. Projects in the lower-right cells would be placed at the top of the list and those in the upper left at the bottom. But besides location in the grids, the rank order also depends on organizational priorities. In Figure 19.6, projects 1, 3, 8, and 11 appear in the lower right in three of the grids, yet if the organization's top priority is financial benefit, then project 8 would be ranked lower and might even be rejected. Final selection will also depend on each project's size and available funding and resources, as described earlier.

The main advantage of the grid method is clear exposition of the comparative benefits of projects as determined by the collective judgment of the team. For this and all team assessment and selection methods, ideally, team members represent a broad range of perspectives (technical, product/market, financial, environmental, etc.).[25]

Although the grid method might seem to rely too much on subjective judgment and too little on formal analysis, the team might in fact use formal analysis methods and quantitative models to arrive at their ratings. (As mentioned, however, quantitative methods often rely on estimates that are little more than guesses, making them no more accurate than subjective methods—despite creating false perceptions to the contrary.)

Cost-effectiveness analysis

Cost-effectiveness analysis is similar to the cost-benefit grid method but uses numerical values for costs and benefits. The term "effectiveness" refers to the degree to which a project is expected to fulfill project requirements; it is interchangeable with terms such as *benefit*, *value*, *utility*, and *performance*. As with those terms, assessing effectiveness involves consideration of multiple factors. In assessing commercial aircraft projects, for instance, effectiveness would account for some combination of aircraft passenger capacity, weight, range, speed, fuel efficiency, and maintainability, which are interrelated in complex ways.[26] One method for deriving a single measure incorporating multiple factors is to rate the factors subjectively (but using results from quantitative analysis and advice from technical experts), weigh the ratings, and add them up—similar to the weighted scoring model illustrated in Table 19.1. The factors chosen for the analysis represent significant ways to distinguish between projects, and the projects are assumed identical in all other important respects.

The method does not rank the projects but suggests which ones should be dropped from consideration and allows tradeoff analysis of the remaining projects. For example, Figure 19.7 shows the three projects from Table 19.5 and five other projects. Projects *j*, *h*, and *m* (in the shaded area) fall below the minimal effectiveness threshold of 75 and would be dropped from consideration. The line connecting the uppermost points (*j*, *A*, *B*, *n*, *C*)—called the "efficient frontier"—represents the *maximum effectiveness level* attainable for a given cost (or minimum cost for a given effectiveness level). Project *k* is below this line, which means it is inferior to at least one other project in terms of both cost and effectiveness and should also be dropped. Only projects *A*, *B*, *n*, and *C* are worthy of further consideration.

A maximum effectiveness line with a positive slope indicates that increasing project cost is justified by increasing effectiveness. But the *degree* of slope matters too: Project *C* is only marginally more effective than Project *n* but costs a lot more, suggesting that it is probably not worth pursuing.

As mentioned, project selection relies on imperfect information about costs and benefits. While the models in this chapter provide "objective" ways to sort through the maze of facts, figures, and issues associated with project selection, rarely are final decisions based solely upon them; fact is, human instincts, emotions, and ulterior motives also play a role in project selection.

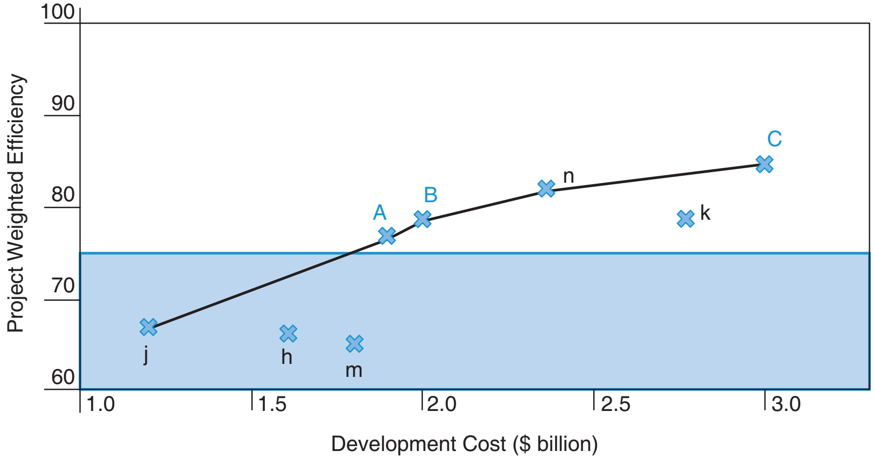


Figure 19.7
Effectiveness versus development cost for eight projects.

Table 19.5 Cost-effectiveness data analysis.

		Project A		Project B		Project C	
Factors	W(weight %)	E	WE	E	WE	E	WE
Speed	10	95	9.5	80	8	85	8.5
Range	15	70	10.5	80	12	75	11.25
Efficiency	20	75	15	75	15	85	17
Comfort	15	70	10.5	85	12.75	85	12.75
Capacity	20	70	14	90	18	95	19
Loaded mass	15	90	13.5	60	9	70	10.5
Maintainability	5	75	3.75	85	4.25	80	4
Total WE			76.75		79		83
Cost			$1.8B		$2.0B		$3.0B

19.5 Integrating the gating process and portfolio management[27]

Portfolio management includes selection of new projects and periodic review of current projects. The portfolio manager and PRB must decide when to start each newly approved project—immediately or later—and whether each current project should be sustained, changed, or terminated. Projects exceeding deadlines or expected costs, not meeting requirements, or no longer suited to changing company objectives or the environment are reconsidered. In order to reallocate funds and other resources appropriately, underperforming or no-longer-necessary projects are cancelled to make way for essential or more promising projects. In many companies, periodic project review happens through a gating or stage-gate process.

As mentioned, money and effort already spent on a project should be considered a sunk cost that should not be taken into account when deciding how to proceed in the project. It is, however, often difficult to cull a white elephant—often for fear of being criticized for having wasted the money in the project. A sign of an effective portfolio management process is that periodically, projects *do* get cancelled.

Some projects, however, for example, in construction, reach a point of no return where after cancellation, cost is too high. This emphasizes that projects should not be allowed to proceed to execution in the absence of a strong case, based on reliable estimates.

Gating and portfolio management augment each other, but the two processes are very different. In gating, at the end of each project phase, sub-phase, or milestone, the project is assessed based on its performance, estimated business impact as of that stage, and external factors. The assessment does not consider the project's impact on organizational resources or objectives or other projects.

In contrast, portfolio management looks at all projects in the portfolio and compares them in terms of benefits, costs, and resources. This involves considerable effort and, consequently, might happen only three or four times a year—maybe less. Since companies are usually involved in many projects and proposals at any given time, each arriving at a decision gate at a different time, it is not feasible to compare all projects in a portfolio every time one of them reaches a gate.

Also, the two processes tend to use different decision criteria: whereas gating typically permits a project to continue as long as it conforms to plans, expectations, and the business environment, portfolio management allows it to continue only if it compares favorably to other projects. In addition, the two processes usually involve different teams: decisions in the gating process are made by middle-level managers and customers; in portfolio management, they are made by the portfolio manager and PRB.

Nonetheless, ideally the two processes and teams assist each other: gating weeds out marginal projects so the portfolio has none that are underperforming, and portfolio management weeds out projects that do not contribute to company objectives. Further, the PRB assists managers in the gating process by sharing its rank-ordered listings and noting any changes in company strategy and objectives. Gating managers consider this information and sometimes kill projects that ultimately would have been killed by the PRB anyway.

19.6 Summary and discussion

Portfolio management is the process of choosing and managing those projects that best achieve organizational objectives subject to resource constraints. Portfolio management, in combination with strategic management, the gating process, and project management, helps ensure that the organization selects the right projects and does those projects right.

Project selection and portfolio management happen through a multistage process of pre-screening, analysis, and screening of new-project proposals and then ranking, selecting, and ongoing review of approved new and existing projects. Top management establishes the high-level criteria for project selection decisions, but actual project selection and portfolio management rest with the portfolio manager and PRB.

This chapter reviewed a variety of methods for rating, screening, and comparing projects in terms of benefits, costs, risk, resource requirements, and strategic objectives. Yet the methods covered do not account for everything. Project dependency is an example: when Project B depends upon Project A, then Project A's approval might depend on the importance of Project B, and, of course, Project B's approval will depend on whether Project A has been approved.[28] A separate but related matter is selection of parallel projects—such as in new technology development—so as to increase the likelihood that at least one will achieve a breakthrough.

Given the variety of methods to analyze, rate, and select projects, the question is: Which is best? In practice, no one method stands head and shoulders above the rest, but it is not necessary to choose just one method. In fact, the methods described should be used in combination. For example, projects first divided according to strategic categories can then be judged by the benefit–cost grid method; the best of these can then be ranked and selected subject to available resources. Or projects prioritized using financial, scoring, or cost-effectiveness approaches can be checked for portfolio balance on bubble charts and then judged with the grid method. Using multiple selection methods helps ensure that the projects selected are the "right" ones.

Review Questions and Problems

1. What are four or five main features of project portfolio management?
2. What is a project portfolio? How do project portfolios differ from programs?
3. Is it poor practice to do the easiest projects first ("pick the low-hanging fruit")?
4. Compare the following; for each, state the focus and how it relates to projects:
   - Strategic management
   - Portfolio management
   - Gating methodology.
5. What are the responsibilities of the project portfolio manager?

6. What are the responsibilities of the project review board? Who are the members of the PRB?
7. "Some projects you simply have to do. You have no choice." Give examples of projects where you have no choice.
8. What is the purpose of *pre-screening* in the project selection process? How does it differ from project *screening?*
9. Explain portfolio selection. What kinds of projects does it consider—current, proposed, or both?
10. How would spare capacity influence project selection decisions? What should you do with spare capacity?
11. Projects W, X, Y, and Z are each being screened according to four criteria: potential return on investment, *lack of* technological risk, environmental "friendliness," and service to community:
    - Project W: return, high; lack of risk, medium; environment, medium; service, low.
    - Project X: return, medium; lack of risk, high; environment, medium; service, low.
    - Project Y: return, medium; lack of risk, medium; environment, high; service, high.
    - Project Z: return, medium; lack of risk, medium; environment, high; service, low.

    Create a scheme for screening the projects, assuming equal weight for all criteria. Which project comes out best, which worst?
12. For the previous four projects, assign scores of high = 3, medium = 2, and low = 1. Assume the criteria are weighted: potential return on investment = 0.3, lack of technological risk = 0.3, environmental "friendliness" = 0.3, and service to community = 0.1. Now which projects come out best and worst?
13. Compare the ECV and B/C methods for evaluating projects.
14. What is the expected commercial value of a project involving the launch of a new product with an estimated development cost of $15M, launch cost of $0.8M, and NPV for the future stream of earnings of $45M if the probabilities for success are 70 percent in development and 50 percent in the market?
15. A project has three phases—concept, development, and launch—that are expected to cost $5M, $15M, and $4M, respectively. The likelihoods of success for the three phases are 0.5, 0.8, and 0.7, respectively. If the estimated NPV of future earnings is $90M, what is the ECV for the project? (Answer: $11.1M.)
16. In the previous example, what else must be considered if the stream of earning were in euros instead of dollars?
17. In Problem 15, suppose the likelihood of project success is $0.5 \times 0.8 \times 0.7 = 0.28$.
    - What is the B/C ratio for the project?
    - Which measure makes the project look more attractive, ECV or B/C? In your opinion, does the project merit approval?
18. Project A and Project B have the same overall cost of $4M. Project A's likelihood of success is 95 percent; Project B's chances are 50 percent. Project A is expected to generate $11M revenue but will incur $5M maintenance costs. Project B is expected to generate $8M revenue and efficiencies that would *save* $5M in expenses. Applying the B/C ratio, which project would you recommend?
19. What advantage do scoring models have over financial models in terms of assessing the value or utility of projects?
20. What are the drawbacks of financial models? Of scoring models?
21. What are the three main approaches to comparing and selecting projects?
22. What is the drawback of ranking projects using single-criterion methods?
23. Top management has decided to reallocate funds among the five categories of projects listed

Project D Factors	E
Speed	80
Range	90
Efficiency	95
Comfort	85
Capacity	95
Loaded mass	90
Maintainability	80
Cost	$2.5B

in Table 19.4 as follows: $13M, $8M, $7.5M, $10M, and $7.8M, respectively. What are the cutoff projects in each of the five categories?

24. Explain how cost–benefit grids can be used to rank-order projects.
25. Discuss similarities and differences between bubble charts and cost–benefit grids.
26. Suppose Project D is added to the projects in Table 19.5 and has been rated for effectiveness as shown in the table subsequently:
    Compute the total weighted effectiveness using the weights in Table 19.4. How does Project D compare to the others in Figure 19.7?
27. Once a project has been approved and admitted to the project portfolio, how is it monitored thereafter? Under what circumstances might the project be cancelled?
28. Describe the differences between the gating process and portfolio management. What are the difficulties in integrating the two processes? How might the difficulties be overcome so that portfolio projects can also be gated projects?

Questions About the Study Project

1. Does the organization have a portfolio management process? If so, describe the key steps in the process and the managers and others who participate in the process. In your opinion, is the process effective? What are its strengths and weaknesses?
2. Does the organization have portfolio managers or PRBs (governance boards, project steering committees, etc.)? Describe their roles and modus operandi.
3. Describe the organization's project analysis and selection process. What kind of analysis and selection models and methods are used?
4. How are projects compared and rank-ordered? Who makes approval and funding decisions?
5. Does the organization have a gating process? Describe the gates, assessment criteria, and list who participates at each gate. In your opinion, is the process effective?
6. If the organization has both portfolio management and gating processes, discuss the relationship between the two and the manner in which they are integrated.
7. If the organization has a PMO, discuss the PMO's role in portfolio management and the gating process.

CASE 19.1 PROPOSED CEMENT FACTORY FOR PCS COMPANY

See Chapter 4

Note, for this case you might wish to review the front-end loading (FEL) process in Chapter 4.

The first sentence in the executive summary of the draft business case reads, "The proposed cement factory would be the perfect answer to top management's goal to grow PCS's product base while remaining a low-cost producer of building materials." Geological work performed as part of the feasibility study had pointed to a site containing high-quality limestone—a key resource in the production of cement—that could be exploited very economically. The site, already owned by PCS, was underutilized and could suitably house a new plant located right next to the proposed limestone pit. It afforded ample and cost-effective access to all essential logistics and resources, including other materials needed for the manufacture of high-quality cement.

The business case and feasibility study also indicated a high return on investment for the project—well above the hurdle rate set by the company for a new project to be considered for inclusion in its project portfolio. Given the company's competency in cement production, the technical and production risks were assessed as low.

Everything seemed in order, and the team proposing the project was optimistic that approval of the next phase of the proposed project (FEL-2) would be a mere formality. They presented the draft business case to the PMO for finalization and to top management for authorization of FEL-2. To their surprise, the PMO director insisted that the team must make all assumptions explicit and do a sensitivity analysis before he would even consider carefully reading the business case. He pointed out that the current high cement price as assumed in the feasibility study was the result of a booming Chinese construction industry that could decline significantly in the foreseeable future. Another member of the PMO added: "And what if assumed costs rise and we can't stick to the proposed budget, as was the case with several of our recent projects?"

QUESTIONS

1. Explain why a business case should take into account alternative scenarios for the important variables.
2. List topics or issues that are not mentioned in the case but should be considered before the project gets the go-ahead.

CASE 19.2 SELECTING PROJECTS AT GALACTIC MINING, A

Jim LaPlas, the CEO of Galactic Mining, compiles a list of seven projects to investigate the feasibility of mining 7 of Jupiter's known 79 moons. All the projects passed the initial screening assessment. He hands the list to Judy Patel, the manager of the project portfolio office, and requests her to rank the projects according to priority. As Judy leaves Jim's office, he specifically comments on the importance of profitability.

The following information is available about the seven projects:

Project Europa

Although the risk is low, this project provides an excellent ECV (expected commercial value, a criterion that takes net present value, development cost, and probabilities of technical and commercial success into account). Europa, however, does not fit the current strategy well.

Project Adrastea

Although both the ECV and the risk are moderate, compared to the other six projects, it fits rather poorly with the current strategy.

Project Himalia

This project fits the current strategy well, is not risky, but does not provide an exciting ECV.

Project Thebe

With a good strategic fit and moderate risk, the ECV of this project is better than that of Adrastea and Project Himalia.

Project Metis

With an excellent strategic fit and a relatively low risk, Metis unfortunately promises a poor ECV.

Project Ganymede

Ganymede offers a reasonable ECV with an excellent strategic fit and low risk.

Project Callisto

With an ECV slightly better than that of Ganymede and just worse than that of Europa, Callisto has a very low risk and an excellent fit with the current strategy.

ASSIGNMENT AND QUESTIONS

1. Compile a list, ranking the projects in order of priority, from No. 1 to No. 7. First, do this individually and then discuss with a group of people who also ranked the projects individually.
2. Discuss the possibility of prioritizing the projects solely on financial criteria.
3. What role do you think biases and internal politics would play in selecting projects?
4. Discuss the role that availability of resources should play in decisions about the sequence in which the projects should be commenced. (Consider money, key personnel, and other important resources).
5. Suggest a way to proceed to reach consensus on the priorities. Indicate stakeholders that should be involved.

CASE 19.3 SELECTING PROJECTS AT GALACTIC MINING, B

Judy sees this assignment (see Case 19.2) as an opportunity to test a scoring technique that she recently proposed. The technique requires that for each project a score be assigned for the strategic fit and the risk, and that the specific ECV be calculated.

The following score values are to be used:

- For risk: moderate risk = 4; low risk = 3; very low risk; not risky = 2
- For strategic fit: excellent = 4; fits well = 3; good fit = 2; does not fit well = 1; poor fit = 0.

The calculated ECVs for the projects are as follows (the *higher* the score, the more desirable the project):

Project	ECV
Metis	2.3
Adrastea	3.5
Thebe	3.1
Himalia	2.6
Europa	6.4
Ganymede	4.6
Callisto	5.3

The scoring technique first ranks the project according to each criterion and then calculates an aggregate ranking.

ASSIGNMENT AND QUESTIONS

1. Use Judy's technique to numerically score each of the projects according to strategic fit, ECV, and risk. Then numerically rank the projects based on the scores, assigning projects with the same scores the same rank. (For example, on ECV, Europa is ranked 1, Callisto 2, and so on; on strategic fit, Metis, Ganymede, and Callisto are all ranked 1, Himalia is ranked 2, etc.) Then, for each project, compute the average rank based on the ranks for the three criteria. Finally, based on the average ranking scores, rank-order the projects.
2. Discuss the relative results.
3. Discuss the role the scoring technique could play regarding biases and internal politics.
4. How should preferences and biases of executives be handled?
5. How should resource availability be taken into account?
6. A turbulent environment may lead to a change in strategy. How should such a change be handled?
7. Discuss any possibilities you see of further refinement or optimization of the ranking list (consider quantitative techniques, etc.).
8. Repeat the ranking, but besides strategic fit, risk, and ECV include a fourth criterion: public image of project (4 = high, 0 = none). Assume the projects are rated as follows on public image (numbers in parentheses are ranking on list):

Project	Public image
Project Metis	0 (5)
Project Adrastea	1 (4)
Project Thebe	4 (1)
Himalia	3 (2)
Project Europa	4 (1)
Project Ganymede	2 (3)
Project Callisto	3 (2)

Include this ranking with the rankings for strategic fit, risk, and ECV, and re-compute the final rankings for the projects based on all four criteria.

Notes

1. Cooper R., Edgett S. and Kleinschmidt E. Portfolio management in new product development: Lessons from leaders, phase II. *Research Technology Management*; November–December 1997: 43–52, reprinted in Dye L. and Pennypacker J. (eds). *Project Portfolio Management*. West Chester, PA: Center for Business Practices; 1999, pp. 27–33.
2. Sommer R. Portfolio management for projects: A new paradigm. *Proceedings of the Annual Project Management Institute Seminars & Symposiums*. Newtown Square, PA: Project Management Institute; 1998; reprinted in Dye and Pennypacker. *Project Portfolio Management*, pp. 55–59.
3. Project Management Institute. *The Standard for Portfolio Management*, 4th edn. Newton Square, Pennsylvania: PMI; 2017 and Office of Government Commerce. *Management of Portfolios*. Norwich, UK: The Stationary Office; 2011.
4. This section adopted from Cooper et al. Portfolio management in new product development: lessons from leaders, phase II, pp. 34–5; and Bridges D. Project portfolio management: ideas and practices. In Dye L. and Pennypacker J. (eds), *Project Portfolio Management*. West Chester, PA: Center for Business Practices, pp. 97–116.
5. Levine H. Project portfolio management: A song without words? *PM Network*; July 1999.
6. Davidson Frame J. *The New Project Management*. San Francisco, CA: Jossey-Bass Publishers; 1994, p. 190.
7. Archer N. and Ghasemzadeh F. An integrated framework for project portfolio selection. *International Journal of Project Management* 17(4); 1999: 207–216.
8. Sommer. Portfolio management for projects: A new paradigm; and Bridges. Project portfolio management: Ideas and practices.
9. Bridges. Project portfolio management: Ideas and practices.
10. The concept of project selection as a funnel is analogous to *product* selection as described in Wheelwright S. and Clark K. *Revolutionizing Product Development*. New York, NY: Free Press; 1992.
11. Method described in Cooper et al. Portfolio management in new product development: Lessons from leaders, phase I. *Research Technology Management*; September–October 1997, 16–19, reprinted in Dye and Pennypacker. *Project Portfolio Management*, pp. 97–116.
12. Shtub A., Bard J.F. and Globerson S. *Project Management: Processes, Methodologies, and Economics,* 2nd edn. Englewood Cliffs, NJ: Prentice Hall; 2005, pp. 182–183.
13. Ibid., pp. 186–187.
14. See for example Voss M. and Kock A. Impact of relationship value on project portfolio success: investigating the moderating effects of portfolio characteristics and external turbulence. *International Journal of Project Management* 31; 2013: 847–861; also, Killen C., Hunt R. and Kleinschmidt E. Project portfolio management for product innovation. *International Journal of Quality and Reliability Management* 25(1); 2008: 24–38.
15. Mathematical programming approaches for project portfolio optimization are described in the literature in operations research. For an example, see Dickinson M., Thornton A. and Graves S. Technology portfolio management: Optimizing interdependent projects over multiple time periods. *IEEE Transactions of Engineering Management* 48(4); 2001: 5l8–527.
16. Method described in Cooper et al. Portfolio management in. . .: Lessons from leaders, phase I.
17. Source: National Environment Commission, Royal Government of Bhutan. Bhutan National Adaptation Programme of Action; 2006, http://unfccc.int/resource/docs/napa/btn01.pdf, accessed May 28, 2019.
18. Cooper et al. Portfolio management in. . .: Lessons from leaders, phase I. Bubble charts are easily created with commercial software (Google the term "bubble chart" for examples of methods and products).
19. Meyer W.G. The effect of optimism bias on the decision to terminate failing projects. *Project Management Journal* 45(4); August–September 2014: 7–20.
20. Cooper et al. Portfolio management in. . .: Lessons from leaders, phase I.
21. Method described in Cooper et al. Portfolio management in new product development: Lessons from leaders, phase II.
22. Frame. *The New Project Management*, pp. 181–185; Buss M. How to rank computer projects. *Harvard Business Review*; January–February 1983.
23. Buss. How to rank computer projects.
24. Frame. *The New Project Management*, p. 185.
25. Overview of method as presented in Shtub et al. *Project Management: Engineering, Technology, and Implementation*, pp. 127–130.

26. This example, like others in this chapter, is a much-simplified illustration. Assessing options for development of large-scale systems such as aircraft involves engineering studies to assess alternative configurations and design details, plus economic analysis of development, procurement, operating costs, and projections of unit sales. See Jenkinson L., Simpkin P. and Rhodes D. *Civil Aircraft Design*. London: Arnold; 1999.
27. This section adopted from Cooper et al. Portfolio management in new product development: Lessons from leaders, phase II; and Nelson et al. Building on the stage/gate: An enterprise-wide architecture for new product development.
28. On selection of dependent projects, see Dickinson et al. Technology portfolio management: Optimizing interdependent projects over multiple time periods.

Chapter 20

International project management

Consider three recent projects:

1. General Electric divided the development project for a new cardiac monitoring device between two teams, one in Milwaukee, one in Bangalore. The hardware development work was done by the US team, the software work by the Indian team. The manager coordinating the teams was based in Milwaukee but made frequent trips to Bangalore. The project required continual back-and-forth exchange of people, equipment, software, and information.
2. Bechtel, a US corporation with divisions worldwide, oversaw the construction of a complete industrial city in Saudi Arabia. As prime contractor, it managed and coordinated on-site work, materials acquisition, and major systems provided by subcontractors from Europe, the United States, and Saudi Arabia. The Bechtel project manager remained on-site during most of the project but traveled globally to meet with Bechtel senior managers and contractor associates.[1]
3. Boeing Commercial Airplane Division is the principal designer, systems integrator, and final assembler for the 787 commercial aircraft, but virtually all of the design and manufacture for the plane's major components and subsystems—wings, fuselage sections, engines, and instrumentation—is done by contract suppliers in Japan, Canada, Spain, Italy, and the United States. Oversight and integration of suppliers and other Boeing divisions contributing to the program are handled by Boeing's program management office in Washington State.

The obvious commonality among these projects is that they are "international" or "global" in scope. Unlike single-country, domestic projects where most or all stakeholders and project work are confined to one country, stakeholders in these projects are cross national and cross cultural, and project work happens in different countries.

20.1 International projects

International projects have become ubiquitous as more companies establish divisions, seek customers, and outsource work to suppliers and contractors in different countries. Thanks in large part to lower costs and increased capacity of global air and sea transportation; enhanced communication technologies fueled by the Internet; and emerging business and technological capabilities in nations such as China, India, and Brazil, companies seek out and execute projects everywhere.

While such projects are enticing because of the benefits and opportunities that come with operating on an international scale, they are at the same time vulnerable to considerable risk. Regardless of the scope or end-item, a project that is "global," "international," or "overseas" automatically inherits more issues and greater risk than one that is not. And regardless of the issues and problems that the manager of a domestic, one-country project faces, the manager in an international project automatically faces an "extra layer" of issues. That extra layer touches most everything about management—leadership, interpersonal relations, stakeholders, procurement, communication, work definition, estimating, risk management, and work tracking and control. Language, local customs, transportation, and infrastructure—all of little or no concern in a home-country project—become potential showstoppers in an international project.

20.2 Problems managing international projects[2]

Each new international project poses a new set of unknowns. To illustrate, think of an international project as analogous to a play with actors, scripts, sets, and props. Actors are the project stakeholders and social networks, scripts are the social institutions that guide and constrain peoples' behavior, set is the project's work site, and props are the project technologies. Just as the actors, scripts, sets, and props differ in every play, so do the stakeholders, institutions, site location, and technologies differ in every international project. Such differences expose the project to potential mistakes and oversights in organizing, planning, and execution.

Table 20.1 lists aspects of an international project that tend to make planning and undertaking it more difficult; some are "explicit"—somewhat easy to pinpoint and account for in project plans and estimates, others are "tacit"—more difficult to isolate and address. In general, the more "unknown" the

Table 20.1 Unknowns in an international project.

1. Local institutions and culture
    a) Language (explicit)
    b) Norms, social customs, attitudes traditions (tacit)
    c) Laws, rules, rights, sanctions (explicit)
2. Local stakeholders—laborers, managers, consultants, suppliers (tacit)
    a) Skill, experience, motivation
    b) Reputation, honesty, integrity
    c) Who knows who; who has knowledge, resources, and connections
3. Local natural environment (explicit)
    a) Site environment—soil, ground slope, vegetation
    b) Regional environment—climate-weather, geography, seismic activity
4. Local technology (explicit)
    a) Infrastructure—roads, buildings, communication
    b) Available tools and systems—GPS, equipment, hardware, software, materials

Note: "Local" refers to people and factors situated at the location or region of the project or that become activated in the local context, including international NGOs, associations, and other organizations that play a role in "promulgating environmental, technological, occupational, and legal" rules and regulations to the local level.3

host country and its people are to the project manager and team members, the harder it will be for them to plan and execute the project. Hereon, "host" refers to the place where the project is executed, "home" to the native country of the contractor, developer, or project manager. Ignorance about the unknowns makes it difficult to anticipate problems, set priorities, and act appropriately. It is why international projects often have trouble meeting schedule, budget, or requirement commitments.

20.3 Local institutions and culture

Stakeholders in international projects encompass different cultures and use different languages that influence communication, attitudes, behavior, work practices, decision patterns, and, ultimately, project performance. Additionally, they are guided or restricted by regional or national laws, regulations, and rules.

Culture

Culture refers to the set of values, beliefs, behaviors, and attitudes that members of a group, organization, country, or region tend to share. Among many ways to measure culture is an oft-cited study by Hofstede of IBM employees in over 50 countries. The study identified five dimensions of culture.[3]

- Power distribution (PD). The extent to which the less powerful members of a culture accept or expect that power should be unequally distributed, versus feeling that power should be equally distributed. People from high PD countries tend to hold superiors or leaders in high regard and not question their directives or actions.
- Individualism (IND). The extent to which members of a culture believe they are expected to look out for themselves versus believing they are part of and looked after by the group to which they are loyal.
- Achievement orientation (ACH). The extent to which roles are distributed along gender lines: "masculine," which implies assertive, tough, and achievement orientation, versus "feminine," which implies a more relationship, helping, or quality-of-life orientation. People from high-ACH countries care more about earnings and signs of success; those from lower-ACH countries care more about sharing, cooperating, and caring for others.
- Uncertainty avoidance (UNA). The extent to which members feel uncomfortable with uncertain or ambiguous situations and need to take steps to impose order and structure, versus accepting uncertainty or ambiguity, "going with the flow." People from low-UNA countries are more comfortable with ambiguity and feel *less* uncomfortable in the absence of detailed plans and formalized team roles and responsibilities.
- Long-term orientation (LTO). The extent to which members look to long-term benefits and deferred results or gratification, versus seeking immediate or short-term results and gratification.

Hofstede's research showed considerable differences in these dimensions by country: Table 20.2 gives some results. Larger values imply the tendency to accept unequal power distribution, be individualistic, seek achievement, and be masculine, more comfortable with uncertainty, and long term–oriented; smaller values imply the opposite.

For a project with team members in different countries, differences in these dimensions might merit attention. For example, a project team with members located in the United Kingdom, United States, and China might expect differences in terms of PD, IND, UNA, and LTO. According to the table, team members in China are more likely to accept authority differences than those in the United States and the United Kingdom; they are also likely more willing to "blend" into the team and not want to be singled out as individuals than members in the United States or United Kingdom. US team members will

Table 20.2 Hofstede's cultural dimensions: representative results.

Country	PD	IND	ACH	UNA	LTO
Brazil	69	38	49	76	65
China	80	20	66	30	118
Denmark	18	74	16	23	*
India	77	48	56	40	61
Israel	13	54	47	81	*
Japan	54	46	95	92	80
Poland	68	60	64	93	32
Russia	93	39	36	95	*
Spain	57	51	42	86	*
United Kingdom	35	89	66	35	25
United States	40	91	62	46	29

* No data

possibly be slightly more comfortable with uncertainty or ambiguity than their colleagues in the United Kingdom or China, and members in China will likely be less influenced by short-term gains and incentives than those in the United Kingdom or United States. Any of these might lead to members' different responses to management expectations.

One danger with findings like this is the temptation to generalize, even though, of course, people are unique and don't necessarily fit the average. Some have criticized the findings for a number of reasons, including methodology and basic assumptions.[4] Nevertheless, the fact remains that people in different regions and countries *do differ*, which can be challenging when they have to work together. While the challenges might be significant even among workers from different developed nations, they are exacerbated when the workforce combines members from developed countries and developing countries (a.k.a. emerging economies).

Like any challenge, the solution starts with airing of differences, and that might happen as part of a team-building session. As described in Chapter 17, one purpose of team building is opportunity for members to acknowledge their differences—in this case, their values, belief systems, and expectations—and to develop team guidelines that bridge those differences. Besides team building, the project manager should seek to strengthen interpersonal relationships, trust, and mutual respect, all of which tend to reduce stereotyping and build team cohesion.

Of note is that national culture sometimes matters less to people than the culture of their profession or personal interests. This says, for example, that an Indian software engineer might feel more in common with an American software engineer than with his average fellow Indians.[5] A project manager might take advantage of this affinity by developing "communities of practice" to overcome cultural differences and build team unity.

Language

When project stakeholders speak different languages, conversations and shared project documents such as scope, requirements, budgets, and contracts must be translated. The challenge is to make sure that every translation faithfully reflects the content and intention of the original message.

Even projects wherein ostensibly everyone uses the same language face difficulties. For example, the same English words when used in America, the United Kingdom, South Africa, Australia, and India may have different meanings; add to that slang, vernacular, idiomatic terms, and poor diction, and the result is the message gets "lost in translation." For example, "tell the English to walk on the pavement and they will walk on what the Americans call the sidewalk; tell the Americans to walk on the pavement, they will walk down the middle of what the English call the tarmac."[6] US managers often say it is more difficult to communicate with the British than with the French.

The best practice in international communication is to *always* use the simplest, most concise wording and phrasing. Before sending out important messages and documents, ask several people to interpret them. Napoleon did something like this: before issuing military orders, he always had a corporal read them, reasoning that if someone of low rank could understand them, then certainly so would his officers.[7]

Often locals will claim to understand English when in fact their grasp of it is poor at best. When they pepper their responses with "yes, yes, yes," it is a sure bet they don't understand what's being said. Verbal directives should always be followed up in writing.

The manager of an overseas project should learn at least enough of the local language to conduct simple daily transactions. Besides facilitating communication, doing so shows respect for people of the host country, who are appreciative of foreigners' (perhaps awkward) attempts to communicate in the local language.

Managers sometimes create a glossary of project terms, which can be extensive and even include pictures. For the project to develop the Anglo-French Concorde supersonic airplane, a special French–English project dictionary was created.

Formality

Whereas business associates in North America tend to address one another—subordinates, immediate superiors, and even senior managers—by first name, most everywhere else in the world they use some variant of sir, mister, or madam. Such formality extends to the way people introduce themselves, communicate ideas, make commitments, and give and receive business cards. The workplace code of behavior may discourage kidding around and other forms of informality. Formality pertains to documents, too: while in-country proposals and contracts are commonly faxed, emailed, or verbally communicated, such practices in international projects are problematic because they pose questions regarding the country where agreements are made or contracts concluded and hence whose contract law and court of law applies.

In some areas of the world, practices of little import elsewhere are raised to a high art. In Japan, for example, the exchange of business cards is an essential part of business etiquette and constitutes what amounts to a business card "ceremony."

Attitudes about age

Many cultures associate wisdom with age. Older people automatically garner greater respect, reverence, and credibility than younger managers, regardless of experience. Managers in senior positions are always older (and usually male), and they tend to ignore or avoid anyone much younger than them. In meetings, older managers do most of the speaking, and younger managers avoid contradicting them—even when they disagree.

Social behavior

In Middle- and Far-Eastern countries, most relationship building and even formal business happens after-hours at social gatherings. What is considered proper conduct is dictated by local norms although, generally, any sign of inebriation, fraternization, careless or too-casual dress, or sharing of personal details about family or friends is considered inappropriate. Behavior that would be considered suitable or even expected elsewhere—like bringing a spouse to a gathering or talking to another's spouse—could be embarrassing and potentially ruin a business relationship.

Of course, offensive behavior and dress should always be avoided, although what is considered offensive varies by country. In the Middle East, a woman's head should be covered in public, and men and women are not supposed to greet each other by shaking hands. People in Rome tend to dress more smartly than, say, in US cities, and a tourist from the United States who would not draw any attention at home might come across as somewhat slovenly in Rome. When working in Rome (or Beijing or Mumbai), a good rule of thumb is to adopt some of the local customs of dress and behavior (assuming they do not violate a personal or universal code of ethics).

This applies to all kinds of behavior, including gift giving, which in many countries is considered a suitable way to show gratitude but in other countries is prohibited. Certain gifts are considered acceptable, others not, and discretion is necessary to avoid violating laws or local customs of etiquette.

Food and drink

Newly arriving expatriates (workers coming from outside the country) often will scan local menus looking for familiar items—not knowing that the foods listed won't be the same as back home (although home-based or well-known restaurant franchises provide greater reliability and sometimes welcome familiarity). Nonetheless, the more local foods you eat, the better: natives always appreciate outsiders who eat and enjoy at least some of their foods.

Meat portions in Europe and Asia tend to be small—miniscule by US standards. Meat and martinis might not be on the menu—or on any menu anywhere in the country—and to even ask about them is utterly inappropriate. The rule of thumb concerning food and drink—but applicable to everything about local customs—is to be respectful, polite, and accepting, even when the customs do not suit your taste or predisposition.

Attitudes about time

In some Western countries, punctuality is everything. Time is viewed as a limited resource, and being punctual ensures it is never wasted. People who dither or are late are considered rude and inconsiderate of others' time! But in the Middle and Far East and most of Africa, the concept of time is viewed differently: more important than doing things punctually is to make sure they are done right. If it takes time to prepare a plan and then revise it, and revise it again, so be it, even if the schedule slips. A Western manager accustomed to filling every minute with work will be annoyed by the many "time-wasting" gatherings organized by his Asian or Middle-Eastern business associates; they, in turn, will be insulted by his angst to get on with business and will question his motives and loyalty to them.

Holidays, weekends, vacations

Every country has its own non-work holidays. The United States has seven national public holidays. Most European countries have nine to 11 national holidays, with many additional regional holidays. A project that involves participants from, say, four countries with five different national holidays could conceivably face 20 days of holiday downtime. The Ramadan and Chinese New Year holidays affect the schedules of many projects. Even when different counties share the same holidays, exact dates may differ. The Christmas holiday runs in the United States December 23 through January 2, but in Russia and some Eastern European countries, it is December 31 through January 8—sometimes later. In the southern hemisphere, the summer holidays fall in December and sometimes halt project work for most of the month. The "weekend" in many parts of the world is Saturday and Sunday, but in the Middle East, it is Friday and Saturday. While these differences create problems for some projects, they offer opportunities to others by enabling work to continue at different places around the world 7 days per week.

Vacation time off also varies by country and region. Whereas in the United States, 2- or 3-week vacations are standard, Australian law prescribes 4 weeks, as does the European Union—usually the whole month of August. Some countries mandate by law 6 weeks of vacation plus 6 weeks more for sick leave.

Labor time

What constitutes a "usual" workday and workweek also varies by country. French law mandates and enforces a not-to-exceed 35-hour workweek, and Chinese law specifies a five 8-hour-day workweek. Labor laws are not always enforced, but no project manager in any country should gamble on violating them.

Social norms also matter. If the local culture dictates the "work day" is between 6 a.m. and 2 p.m., the manager of a 9-to-5 project will probably see her local workforce falling asleep around 3 p.m.

Layoffs

In the United States, when a project ends and there is no follow-up work, the employees are commonly terminated. In other countries, however, termination is *not* automatic, especially for workers who served 12 continuous months on a project. What is a manager to do with these employees? In many European countries, labor laws dictate whom an employer can lay off and how the employer must go about it. According to David Pringle of the *Career Journal Europe*, layoff decisions by German employers must conform to social criteria that sometimes force them "to retain staff that is older, have large families, and might find it very difficult to get new jobs."[8] French employers often must "give detailed reports on the progress of staff-cutting programs to state authorities."

Laws, contracts, rights

The law in effect for a project is the law of the host country, not of the home country of the developer or contractor—although US contractors working overseas must confusingly also comply with US law, and the trick is to not violate the laws of either country. The Foreign Corrupt Practices Act, for example, prohibits US contractors from participating in bribery, even though the practice is rather common in many parts of the world.

In countries like China, rules are not always enforced, and local contractors and customers might tell you just to ignore them (of course, risking the possibility that at any time the rules *could* be enforced). A safe practice is to verify whatever the locals say about the law and never do anything illegal.

Because of differences in language, formalities, terminology, regulations, and laws, international contracts take longer to finalize than domestic contracts. Getting the wording and terminology right on contracts is extremely important, and even the littlest details (like initialing changes and pages) matter. The project manager should be involved in contract negotiations from the beginning and—this is essential—have access in the host country to her own legal counsel or sound legal advice.

To minimize confusion about contract terminology, the International Chamber of Commerce has created a list of International Commercial Terms, or "Incoterms," described on its website as "standard trade definitions most commonly used in international sales contracts. . . (and) at the heart of world trade." Usage of Incoterms in contracts helps clarify expectations and "goes a long way to providing the legal certainty upon which mutual confidence between business partners must be based."[9]

The contractor must be sure to include stipulations and actions in the contract to protect its intellectual rights and be prepared to take action should it discover that its ideas, products, or technology are being pirated.

Litigation, payment, meeting contract terms

See Chapter 12

Contracting in international projects is a topic unto its own and beyond the scope of this book. While some companies employ standard-format project contracts (e.g. FIDIC or NEC; see note 10, Chapter 12), some large companies prepare their own contracts. In general, contracts should be designed to avoid legal disputes, which in the international arena can be a nightmare—messy, slow, expensive, and sometimes corrupt. They should specify that any legal disputes would be litigated in a neutral country, that is, in neither the host nor the contractor's home country. US contractors often specify England.

Each contract should provide stipulations to ensure that the customer will receive its deliverables and the contractor its payment. This would seem customary even in single-country, domestic projects, yet because of the extreme difficulties of litigation in international projects, the stipulations must be such as to remove even the slightest chance of problems. The contract might impose severe penalties for failure to meet schedules or requirements and offer strong incentives to exceed them (such incentives assume that the contractor is in the position to perform work to meet requirements—which is not always the case in developing countries).

To protect the contractor, the contract might specify a large first payment followed by payments upon meeting frequent time-phased targets. Frequently, payments are delayed, not by the customer but because international funds transfer usually requires approval by an agency of the host country, which can take 60 days. Sometimes payments to foreigners must be made via tax agents, further complicating the payment process.

Ordinarily, contractors should never perform work for unsecured payment after project completion. In many countries, including China, the system for managing credit and receivables is not very good, and customer creditworthiness is difficult to ascertain.

Politics

National and local political stability and the government's position regarding the project are potential risk factors. Radical labor strikes, political reform, overthrow of the government, local military intervention, and terrorism are clearly situations that threaten a project. While phenomena such as labor strikes are rare in countries such as the United States, they are common elsewhere. But such events rarely materialize at short notice and without warning signs. A contractor in an international project must have reliable people in the host region to monitor these signs and keep the project manager informed.

It should be obvious from this discussion that international projects are fraught with problems absent in single-nation projects. The following example illustrates additional problems—plus what happens when cross-cultural teams ignore the mixing of their norms and customs for the benefit of the overall project.

Example 20.1: The Chunnel Project[10]

The initial construction phase of the 32-mile (51-km) Channel Tunnel between Britain and France was managed almost as two separate projects—one starting from Britain, the other from France, both racing to see which would reach the halfway mark first. Competition, it was felt, would speed things up. But the project teams represented two different cultures, and the competition between them only aggravated the differences and exacerbated problems.

For starters, ideally contracts are written in one language and governed by one legal system, but the Chunnel project had *two* contracts, one in English, one in French, and neither had precedence over the other. Although the contracts were purportedly based on principles common to the two legal systems, legal approaches to health, safety, trade unions, and taxation differed significantly, and a panel appointed to resolve disputes often faced the situation of having to make tough decisions.

The two countries also differ with regard to standards concerning, for example, train engines and cars, railway width, voltages, and signaling systems, although, clearly, in every case, there would have to be only one standard in each instance. It was decided that where a difference existed between the standards of the two countries, the higher standard should prevail—though it was not always obvious which standard that was (e.g. the best way to pour concrete).

Decisions by a democratic government can require substantial deliberation, but decisions by *two* democratic governments require even more deliberation. Simply deciding whether to increase the railcar door width from 600 mm to 700 mm took 9 months.

20.4 Local stakeholders

Contractors[11]

Project teams operating in foreign countries are often required to hire local contractors. Although subcontracting to local contractors can reduce costs for labor and relocation, it can increase costs for training and supervision. Sometimes lower labor cost equates to lower productivity, which translates into needing more workers and erasing any potential savings. (Many countries like India, however, have low labor costs yet productivity as high as in Western nations.) A local contractor who is familiar with the local customs and bureaucracy can sometimes cut through red tape and avoid hassles that would stymie a contractor from the outside.

Selecting a local contractor goes beyond the usual criteria of skill, experience, resources, and financial stability. One consideration is the quality of the contractor's communications as determined by language and culture. Another is the contractor's familiarity with common business practices. Practices that in most countries are taken for granted (e.g. RFPs, proposals, SOWs, change controls, and status reporting) may be unfamiliar to a local contractor and challenging for it to adopt. Also important is the contractor's ethical reputation ("ethical" as defined according to Western standards, not local standards). Although perhaps difficult to undertake, a due diligence review of the contractor's business history, reputation for honesty, and political connections is nonetheless a necessity.

Customers and supporters

Good relations with customers and supporters is always important but even more so in international projects. In general, whereas Westerners tend to first set contractual agreements and then build relationships, Easterners build relationships first and then reach agreements. Regardless of the professional track record of the project manager and his company, local businesses, subcontractors, vendors, and potential customers are apt to withhold agreement, collaboration, or support until they feel they know the project manager personally. Building personal relationships and trust with business colleagues and associates is fundamental to the business process.

Example 20.2: How to Ruin a Business Relationship[12]

Negotiations between a US company and a firm in India to finalize the contract on a promising project began with a series of informal meetings. Soon after arriving in India, the American project manager sensed that his customers were unnecessarily dragging their feet, so he tried to urge them along. But the more he tried, the more the Indians doubted his motives and the less they trusted him. As is their custom, they had planned to delay serious talks until after becoming acquainted with the American—a trust-building process intended to occur during a few days of after-hour dinners and social gatherings. The project manager, however, was expecting serious talks to begin soon after his arrival and conclude after no more than a few days. Because most of the project work was to be done in the United States by a US team—and only later to be transferred to the customer's site in India—the project manager hadn't bothered to familiarize himself with Indian social customs; in other words, he blew it. The negotiations failed, and the manager flew home without a contract.

20.5 Geo-national issues

Many issues regarding international projects arise from the simple fact that the stakeholders are dispersed across different nations and geographic regions.

Currency and exchange risk

Economic swings that alter exchange rates and relative currency values put project costs, revenues, and profits at risk. For example, on December 6, 2015, the South African Rand traded at R14.35 per US$; by December 12, it traded at R15.89; and by January 12, 2016, R16.16. For any South African project that depended on imported items, this exchange rate change could have posed serious consequences.

To protect the value of its contracted work, a contractor should require payment in terms of its home currency (e.g. US dollars for an American contractor), although it must be said that most all international contracts are concluded in US dollars. Customers are likely to agree to this for short-duration projects, though not necessarily for longer projects because of the greater risk of a significant change in exchange rates. Of course, the matter is moot unless the host government grants the customer the legal right to pay for the project in foreign currency.

Example 20.3: Impact of Change in the Currency Exchange Rate

A French contractor agrees to do a project in France for an American customer. The contractor estimates the project will cost €900,000 and, so as to earn a nice profit, prices the project at €1,000,000. To accommodate the American customer, the contract price is set in dollars. At the time of contract signing, the exchange rate is $1.3 per euro; hence, the price specified on the contract is US$1,300,000.

Many months later, the project is completed, and the work ends up costing €900,000 as predicted. The customer pays the agreed price of $1,300,000, but the exchange rate has changed and is now $1.4 per euro. That being the case, the payment equates to $1,300,000/1.40 = €928,571. Instead of a tidy €100,000, the contractor profits only € (928,571 − 900,0000) = €28,571. An alternative way of looking at this is to say that the increased $/€ rate led to an increase in the dollar expense of the project [from €900,000(1.3) = $1,170,000 to €900,000(1.4) = $1,260,000]. Either way, the contractor made less profit.

One way to reduce exchange risk is to lock in to the contract today's price for a payment that will not occur until later. Called *hedging* of expected foreign currency transactions, this protects the future cash flow against negative currency fluctuations. The locked-in forward price reflects the difference in interest rates between the customer's and contractor's countries.[13]

Offsets[14]

Foreign contractors on large government-funded projects are often subject to requirements concerning spending in the host country called *offsets* or *counter trade*. For example, the contractor might be required to spend a percentage of project cost on local labor, locally supplied materials or products, local airlines and transportation services, and local subcontractors. Offsets like these that are tied directly to project activities are called "direct offsets." Another form, called "indirect offsets," requires the contractor to contribute to non-project endeavors such as business enterprises or improvements to roads, communications, or other infrastructure, with the purpose of reducing the net amount of payments going outside the country. The value of the offset can range from a few percent to more than the full cost of the project. Sometimes the trick is for the contractor to satisfy the offset requirement yet still make a profit.

Offset requirements are specified in the RFP, and sometimes a contractor wins the job based primarily on the offset plan as described in the proposal. In essence, the offset is the deal-clincher, exceeding in importance the principal work of the project.

Export/import restrictions

The export/import of certain US technology, software, and hardware are regulated by government agencies such as the US Departments of Commerce, State, and Agriculture. Early in the project, systems designers and project planners must identify items that are essential for the project but are restricted or prohibited from import/export; these items will have to be substituted with non-restricted alternatives.

Time zones

Project stakeholders located in different time zones might have no overlapping normal business hours, and messages between them might take days to read or respond to. Avoiding communication delays is largely a matter of planning, such as scheduling work hours in the zones so as to allow 2–3 hours overlap and ensuring easy accessibility of the project manager and other key participants via cell phone messaging and email during critical stages of the project.

In projects that require frequent travel across multiple time zones, jet-lagged managers and team members need more time to get up to speed.

20.6 Project manager

Typical problems in an international project:[15]

- Team members need travel visas
- Someone on the project team does not have a valid passport
- Someone on the team needs health tests and inoculations before heading to the project site
- Someone gets sick or injured at the project site
- Someone gets arrested for a local traffic violation.

At times like these, the first place people go is to the project manager, expecting her to be able to handle the predicament personally or know where to get help. While dealing with such issues, the project manager must continue to deal with project-related problems both on-site and back home.

The project manager must be largely self sufficient. Faced with unique challenges and often without support from nearby associates and family, the project manager must be adaptable to the local environment and able to resolve problematic situations that would perplex or immobilize a lesser person. A sense of humor helps, as does prior work experience in international projects.

Sensitivity and acceptance

The project manager must understand local norms and customs and be able to develop trusting relationships with business associates and customers in the host country. The local staff, contractors, and laborers might not know what to expect from, or how to deal with, foreign managers. To gain their trust, the project manager must be able to show respect for and acceptance of their culture. Sometimes she does this in subtle ways, like emulating aspects of their social customs, eating local popular foods, or wearing forms of local dress.

Every culture a new experience

Each project in a new country or region requires new learning and familiarization; experiences from one culture or country cannot be generalized to others. For example, although local laborers might *appear* unmotivated or lacking in creativity, the reality might be that they simply do not know what they are supposed to do and require careful instruction and explanation. The project manager must employ whatever motivational sources work best. Sometimes it is a simple matter of adjusting the workday hours to conform to local biological clocks!

Nor should it be assumed that, because a process or method succeeded in one country, it will do so in another, or that local laborers and suppliers will automatically accept the process or method. Making assumptions without considering the local sentiments and attitudes can create resentment and resistance among local staff.

The project manager might need to adjust her leadership style according to the culture. For example, people in Hofstede's high-power distribution cultures might need or expect more coaching than those from low-power distribution cultures.

Among the challenges of managing a cross-cultural team are being aware of and dealing with biases when appraising team members. In general, the tendency is to appraise people from one's own culture more highly than those of other cultures. The project manager needs to ask: if this person were from my own culture, would I assess her the same?

Ideally, everyone in the project, but especially the project manager, possesses skills to bridge cultural differences. Such skills include:[16]

- Understanding how cultural perspectives influence work and collaboration
- Understanding how national, functional, and organizational culture affects working style, team interactions, and peoples' expectations
- Sensitivity to the business practices of different countries and regions.

On hand, fully engaged, fully in charge

Ideally, the project manager is in the middle of everything, managing the project not from a remote office but at the project site. She is always or frequently on hand to see what is happening and discuss problems with local managers, staff, and workers. She is fully committed to the project and remains at the site until the project is completed and the customer has signed off.

Members of the team witness the project manager making decisions that affect the project and them personally. The project manager must be in constant touch with her team and available to assist them when they need help—not only with project decisions but with documents, currency, housing, and medical assistance. In this way, she earns their gratitude, respect, and commitment. When the project manager works with a virtual team and cannot be on-site, she must remain engaged through frequent emails, instant messaging, on online conferences, lest project members perceive that she is out of touch.

Local project manager

In situations where the project manager cannot be on site, day-to-day responsibility for the project should be delegated to someone else whom workers see as visibly engaged and fully in charge, a *local project manager*. Thus, each subproject in a global project will have two project managers, the global project manager who plans and coordinates from the home office and travels among sites and the local project manager who is responsible for on-site, detailed planning and daily management. The local manager reports to the global manager, and the responsibilities and authority of the two are clearly delineated and understood by the project team.

At time of hiring, the local project manager should be informed about expectations, responsibilities, and performance targets and then periodically reminded. Hiring and training a good local project manager is not easy, so when a problem arises, she should be given every opportunity to work it out. If the problem is serious and thought to be getting worse, the global project manager should "parachute in" either herself or a trusted person to assess the situation and offer assistance. Only when the situation is deemed hopeless should the local project manager be replaced. But that can cause a 6-month delay as the replacement manager settles in and attends to family and other (survival) issues.

20.7 Local representative[17]

Every international project needs someone in the host country to mediate with local laborers, unions, and government officials; keep the project manager informed about local matters; and help resolve cultural and regulatory issues. This person—the *local representative*—is responsible for:

- Representing the project manager and company to the customer, and vice versa.
- Keeping the project sold to customers and supporters.

- Arranging for in-country services (hotel and car reservations, local communications, interpreters, office staff and space).
- Arranging meetings with government officials, attachés, and consulates.
- Educating the customer about home-country government requirements, for example, the transfer of technology and technical knowledge.
- Helping arrange local housing for project personnel.
- Assisting in locating local subcontractors.
- Informing the project manager about in-country politics and economy.

Qualifications of the local rep include thorough knowledge of the project—its mission, scope, technology, management, and team, and the contractor company—its officers, products, and services. If the contractor is performing several projects in the host country, the local rep should be familiar with all of them.

The local rep must thoroughly know the culture and social customs of the host country and, ideally, be fluent in the local language. It is not necessary that he be a native of the host country, but it is necessary that he be sensitive to and comfortable with local customs and culture. Also, the local rep must be committed to the project and not eager to race off as it nears completion.

When the project has a local project manager, ideally that person also serves as the local rep unless, however, the local project manager is not familiar with the local culture, customs, and stakeholders, in which case she should have a local rep.

One way to secure a local rep is by partnering with a local company for a portion of the project work. In effect, the partner becomes the local rep. Qualifications of the partner combine those described in Section 20.4 with capability to perform the contracted work, ability to communicate, and ethical reputation.

20.8 Top management, steering committee, and project management office

Practically everything associated with an international project is more difficult to do and takes longer. Sustained backing and support from top management is crucial, yet when a project is far away, experiencing problems, and taking too long, it is easy for managers back home to lose interest. To avoid that, top management should create a steering committee to guide the project and assign the PMO a role to help manage it.

Steering committee[18]

The steering committee for an international project includes senior managers and sponsors from both company headquarters and the host country/region of the project. For a global project composed of multiple project sites, the manager in charge of the overall project (i.e. the global project manager) is also on the committee. The purpose of this "executive" or "global" steering committee is to establish a governance framework to coordinate and fund the project. If the project comprises subprojects at multiple sites, the committee also sets global goals and coordinates work and resources among the subprojects.

Each subproject should also have its own "local" steering committee. This committee is composed of local sponsors and managers and, for a global project composed of multiple project sites, the local project manager. The committee plans and executes details of the project and handles problems originating at the project site or host country. Serious issues that it cannot resolve are forwarded to the executive committee.

Role of project management office[19]

Besides those described in Chapter 18, the functions of a PMO for international projects include:

- Identifying people to serve as project managers for international projects.
- Assisting senior management in assessing and selecting international projects.
- Accumulating lessons learned from international projects and incorporating them into templates, checklists, and training materials.
- Following up on issues and problems identified by management that require coordination among multiple international projects.
- Managing files and documentation for international projects.
- Providing support and mentoring for overseas project managers.
- Scheduling forums for managers of international projects to share experiences.
- Providing training and education about language, culture, protocol, laws, and so on pertaining to each international project.

In general, project personnel departing for overseas should be well informed about the project and aware of what to expect. After they arrive, they should not have to worry about what to do, where to go or stay, or whom to see; such worries detract from their ability to work on the project. The PMO and executive steering committee share responsibility for these matters, arranging for training and coaching, travel and living arrangements, securing a local project rep, and numerous other matters, big and small.

20.9 Team and relationship building

The project manager kicks off the international project with a team-building session for key members from the project team, including local managers and staff. The purpose of the session is to develop a common purpose and shared expectations, identify likely or possible problems, and develop project guidelines to avoid problems. The guidelines address familiar matters such as collaboration, conflict management, and role assignments but also problems unique to international projects such as coordination across countries and time zones and cross-cultural, language, and social factors that could hamper communication and decision-making.[20] A useful exercise to build cultural adaptation is for each participant to express how much he assumes people from other cultures are willing to adapt to his culture and how much he is willing to adapt to theirs.

The project manager should also meet with each local subcontractor to discuss issues that might arise and to prepare a plan that would prevent or mitigate them. During the meeting, they determine which tasks they will do individually and which together. Ideally, a large portion of the work packages (20–30 percent) will be performed jointly by teams from both the host and the home countries. This will encourage local workers to take ownership in the project yet allow the contractor to retain control over the work.

Beyond building relationships with local project team members, the project manager must develop relationships with stakeholders in the host country. Should the project become embroiled in serious problems, having personal ties with local and national government, trade, and labor officials, and vendors will come in handy. To this end, it is important that the project manager make time to attend social events with local officials and celebrate local holidays and cultural events.

20.10 Project definition

An international project cannot be approached in the same way as a domestic project. Many potential issues of little or less consequence in a domestic project, such as different or unfamiliar culture, laws, business practices, social customs, and politics, must be identified and dealt with.

Where to start

How do project managers learn what they need to know for each international project? Here are common ways:[21]

- *Look at examples of similar projects* done in the country by your company or others and try to learn what they did. Seek out project managers with experience in the host country or region and ask for advice.
- *Hire a credible consultant or freelance expatriate* to provide guidance and serve as a cultural intermediary with local stakeholders. Seek out those who have project experience and have developed a social network and local connections in the host region.
- *Ask trusted guides, professionals, and international advisory groups* for advice about local politics, norms, customs, business practices, and the economic environment. Even though they might not be familiar with the business or technology of a particular project, they will know about local labor, resources, and laws.
- *Attend formal training programs* devoted to coping with foreign stakeholders, institutions, and environments.
- *Start with a small pilot project* in the country to allow time to become familiar with the culture and laws before committing to larger, more risky projects.
- *Create a culture risk management team* to identify potential cross-cultural and cross-national issues and steps to reduce or avoid them. The membership of this team should mirror the national and ethnic groups of the project stakeholders.

Customer requirements

Most projects begin with a list of customer needs and wants, which the contractor later expands and converts into a list of technical requirements. In a multilanguage project, this process is complicated because the customer's list must be translated into the contractor's language, then the contractor's list must be translated back into the customer's language for approval. The process can be lengthy, although, typically, Western managers are eager to get it done as quickly as possible. But non-Western managers, taking a different stance, often prefer to hold off on defining the details and first build relationships and establish areas of agreement. The attitude is, not to worry, disagreements over details are inevitable but will eventually be worked out. In this regard, key responsibilities for the project manager are to build trust and establish areas of agreement with key parties involved in the project. These responsibilities must not be delegated to someone in business development, sales, or marketing, as often happens in domestic projects.

Scope and statement of work in global projects[22]

For a global project that consists of subprojects at multiple international locations, the project global steering committee prepares the scope statement, SOW, and a preliminary plan specifying the countries or regions of the subprojects. The plan identifies goals, strategies, targets, costs, and so on for each country and subproject, although only in the form of estimates, proposals, or suggestions.

The local project manager, local sponsor, and local steering committee for each subproject then review the preliminary plan and expand it into greater detail to account for their knowledge of the region and site. Also, they make suggestions to the global steering committee about the subproject's purpose, goals, benefits, and costs. The process is repeated for every subproject, resulting in the information illustrated in Table 20.3.

Because of differences in culture, norms, and languages, subprojects that start out with almost identical purpose, scope, and SOW often end up varying substantially. To accommodate differences in purposes, goals, and so on (Table 20.3, rows 1–8), the global steering committee adjusts the scope and SOW (rows 9 and 10) for each subproject. In the course of back-and-forth iterations between the global and local steering committees, the scopes and SOWs of the subprojects and the global project (row 11) are mutually adjusted for compatibility.

The intended outcomes of the process are that:

1. Local project managers and teams are involved in and become committed to their subprojects.
2. Each local sponsor agrees to the goals and scope of the subproject and promises support.
3. The scope, goals, and SOW of the subprojects conform to local customs, regulations, and laws.
4. Stakeholders at the global and local levels are in agreement.
5. Goals, scope, and SOW of the subprojects align with those of the global project.

Work definition and work breakdown structure[23]

Work definition must account for the many factors that distinguish an international project from a domestic project. One approach is to start with a generic WBS template for the technical part of the project and then expand it to include international factors. The starting template for the technical WBS lays out the first-level breakdown of activities or end-items, general areas of work, and resources needed, and might not look much different than for a one-country, domestic project. Then, each first-level activity is assigned to one team member who will be responsible for managing it (presumably the person who knows the most about the activity). This person, who might be the local project manager, subdivides the activity into detailed task definitions with estimates for resources, time, and cost.

Table 20.3 Project plan to account for local (subproject) and global project scope and SOW.

	Sub-project in Country A	Sub-project in Country B	Sub-project in Country C
1. Purposes			
2. Goals			
3. Strategies			
4. Cost			
5. Schedule			
6. Benefits			
7. Issues			
8. Risks			
9. Scope			
10. SOW			
11. Goals, Scope, and SOW of global project			

Thus far, the work-definition process is not much different than for a domestic project. In an international project, however, as activities are broken down into greater detail, matters relevant to the locale begin to surface. It is at the lower levels of the WBS where an international project becomes truly unique. Although a generic kind of project repeated in each of several countries might look the same in terms of high-level technical activities, subprojects in different countries look quite different at lower work levels because of differences in culture, institutions, geography, and so on. Local or international issues identified in each work package (e.g. as listed in Table 20.4) must be addressed with detailed tasks within work packages or by additional work packages.

In addition to the WBS process described previously, another way to discover and address issues in an international project is to create a separate cross-cultural/cross-national WBS devoted entirely to international issues (Figure 20.1, right). The WBS is created by a special "culture risk team" with the sole purpose of identifying and dealing with cultural/international issues. The first-level breakdown of the WBS might consist of the following work packages:[24]

1. Identify important international and local issues and factors in the project.
2. Assess risks associated with these issues and prepare plans to address them.
3. Provide support for overseas personnel on the project.
4. Provide team-building and relationship-building support.
5. Manage knowledge obtained for this and other international projects.

As Figure 20.1 illustrates, the two WBSs provide a dual-pronged approach to help ensure that no important international issues are overlooked. Any redundant matters that appear in both WBSs are simply consolidated.

One way to keep track of all the detailed tasks and work packages in a global project is with a summary matrix, shown in Table 20.5. The matrix reveals which tasks are unique to certain subprojects and countries and which are common among many or all of them. It also suggests places where knowledge gained from one subproject might be used in others and helps ensure that important tasks or issues are not overlooked.

Table 20.4 Issues in international projects.

- Team members speak different languages.
- Expatriate team members need vaccinations, passports, visas, and so on.
- Expatriate team members need local room, board, transportation.
- Local team members lack knowledge and skills about project work.
- Local communication infrastructure is poor.
- Project leader lacks prior international experience.
- Expatriate team members lack knowledge about the local culture and host country.
- Local team members are unfamiliar with business practices of the contractor.
- Work status might be difficult to determine.
- Project will at times require people from the home office with critical skills.
- Local transportation infrastructure is poor.
- The business needs of the local office differ from those of the home office.
- Project will depend on vendors who do not have strong presence in the country.
- Business processes in the host country differ from those in the home country.
- Technology or material requires export licenses and import approvals.
- Project or task startup is dependent on success of another project or task.
- Team members might be pulled off project due to other higher-priority needs.

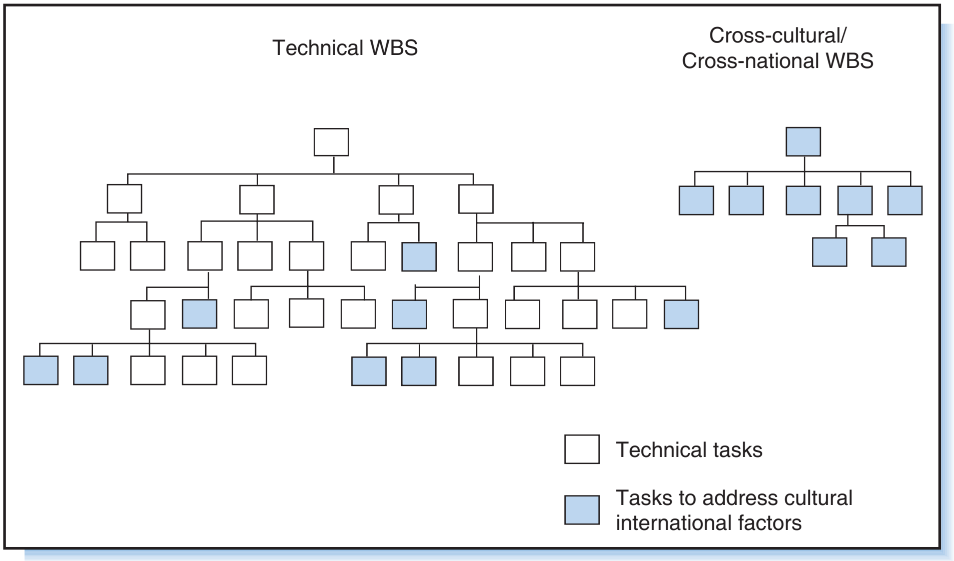


Figure 20.1
WBSs for an international project.

Table 20.5 Summary matrix of tasks versus subprojects.

Tasks	Subproject in Country A	Subproject in Country B	Subproject in Country C
Technical Tasks			
Survey		X	X
Site development		X	X
Site construction		X	X
System implementation	X	X	X
System test	X	X	X
Training	X	X	
Tasks Addressing Local Issues			
Labor		X	X
Subcontractors		X	X
Permits	X		X
Customs	X		X
Time zone	X	X	
Language	X		X

Approach adapted from Seward J. *Managing a global project*, pp. 3–4, ETP The Structure Programme & Project Management Company, accessed September 9, 2005, www.etpint.com/globalproject.htm.

Work packages and responsibilities

Since, in general, smaller work packages are easier to track and control than larger ones, the technical WBS should ultimately be subdivided into small packages of short duration and measurable outcomes. Early in the definition process, however, such a detailed breakdown will neither be possible nor—because of the many unknowns—desirable. Nonetheless, once the project is underway and the picture of pending activities becomes clearer, the unknowns fade and the work can be defined in greater detail. As with phased project planning, the WBS and plan are continually reviewed, and the immediate, upcoming work packages are subdivided into detailed, short-duration tasks, ideally of no more than 2 weeks each.

While the WBS is being created, so is the responsibility matrix to show all parties working on or supporting the project—customer, subcontractors, and others, both at home and at the project site/host country—and their responsibilities.

Resources, schedule, and budget[25]

Any estimates for resources, time, and cost based upon domestic experience must be revised when applied to overseas projects. Planned resources must be adjusted for differences in equipment and labor productivity levels, and schedules and budgets adjusted for the time and costs for communication (fax, phone, courier, translators), travel (air fares, car rentals, taxi and limo fares), and local arrangements (conferences and services). The budget must include fees and costs for insurance, licenses, governmental reviews, local housing, overseas work salary incentives, automobile, daycare, schooling, security, and medical care. Expenses and lead times for obtaining passports and visas and transporting managers, workers, and replacements in accordance with the project schedule must also be accounted for.

Besides the factors already mentioned, adding to time and cost in international projects are shipping preparation, transport between countries, customs inspection and clearance, and transportation in the host country. Transport time in the host country depends on the quality of roads and on available airport, harbor, trucking, and other local services. If the only available transport to or from the project site departs only once a week, missing it by a minute could result in a week's delay. Any material or equipment to be brought in from the United States but deemed as "transfer of technology" must first be approved by the Department of State, which can take months. The fluctuation of exchange rates and the effects should also be anticipated by forecasting the impact of an exchange rate change on the estimated project cost at completion. All of these extra activities make international projects, *ceteris paribus*, more costly, lengthy, and risky than domestic projects.

Example 20.4: Added Time and Cost of an International Project

A contractor working on an overseas project encountered bad weather that fouled the equipment and stopped the project. Back home, the contractor simply would have brought in other equipment more appropriate for the weather, but in the host country, that equipment was not available and had to be imported.

Problems associated with international transport of the equipment (export licensing, shipping schedules), local transport (local roads and hauling services), and local bureaucracy (customs inspection and import regulations on equipment) substantially added to the project's time, cost, and risk. A solution that would have been relatively straightforward in a domestic project became a lengthy, costly, and risky proposition in the overseas project.

The skills and work ethic of local professionals and laborers must also be factored into time estimates and schedules. Owing to language differences, the productivity of a local engineer might be considered equivalent to only half that of, say, an American engineer and would be compensated for by extending the project's engineering work schedule. On the other hand, if lower labor costs of local engineers would allow hiring several of them to replace one American, then extending the project schedule might not be necessary. But rarely are such tradeoffs easy to determine in advance.

Example 20.5: Productivity in International Projects

One of the authors has worked with American, Canadian, and German engineers in projects in South Africa. Despite their professional competency, in all cases, these engineers needed significant time before they became as productive as the local (South African) engineers due to factors such as time to "settle in," lack of personal networks, lack of knowledge about local companies and processes, poor understanding of the cultural environment, and communication problems. These put expatriate (non-South African) engineers at a disadvantage and reduced their productivity, at least initially, and restricted them from working at their full potential. As a consequence, expatriate engineers were given only technical assignments, whereas South African engineers with similar qualifications and experience were given assignments that included management responsibility.

Training

Cultural adjustment is a two-way street. Often, much preparation goes into training and coaching expatriate managers and staff in the culture, traditions, and regulations of the host country. Typically overlooked, but sometimes as important, is training local managers and staff in the culture, common business practices, and technical procedures of the contractor and the home country. For training of locals, the strategy and setting must be carefully designed, since the Western mode of classroom lecture–discussion is not very effective in some cultures.

20.11 Project monitoring[26]

The project manager must make certain that every local subcontractor understands her expectations regarding communication and progress reporting. She should require that the local project manager and team leaders submit weekly task updates, which can be simplified by posting project plans and updates on the Internet. Assuming that technical work packages have been defined so as to be of relatively short duration—no longer than 2 or 3 weeks—the project manager will be able to readily discern from weekly reports whether they have been completed or are on schedule or behind.

When a local subcontractor starts to fall behind or miss requirements, the project manager needs to step in and take a more direct role in managing the subcontractor's work; if that is not possible, she should assign a local person to assist the subcontractor. International litigation can be a big hassle, so it is better to first try to coach a subcontractor into getting back on track rather than resorting to legal action.

A project manager who cannot be on site must rely heavily on telephone and teleconferencing to communicate with local workers. Good practice is to precede all such communication with written documentation and directions so local workers will know what to expect and how to prepare, and then follow up with any written directives or action plans. This will help reduce misunderstandings among parties, which is common in international projects.

The project manager of an international project must make her presence known. If she cannot always be on site, then she should make frequent visits—unannounced. Nowhere is the value of site visits and visibility more important than in international projects.

20.12 Communication

Communication plan[27]

See Chapter 13

An international project should have a communication plan. In addition to the contents described in Chapter 13, the plan must address the difficulties that arise from differences in languages and time zones. The plan should identify important contact persons (Who's Who) in the host country, home country, and elsewhere. Everyone—domestic and foreign project staff and subcontractors—must understand the required reports and written communication and the content and format of each. Foreign contractors and local project staff might not be familiar with "common" project documents and have to be taught why they are important, how they will be used, and how to prepare them.

When the project involves multiple languages, a common "working" language should be adopted for all or specific portions of the project. Those not familiar with the working language should be given accelerated language lessons. Everyone working on the project and using the common language should be reminded to speak slowly and use simple terms and no slang. The project newsletter should be published in multiple versions for the different languages of the key project stakeholders.

Meetings

The communication plan should include a tentative schedule for all formal reviews and milestone meetings and describe the meetings' formats, expected content, advance preparations, time limits, attendance policy, and who will lead. Since formal meetings in international projects can be difficult to schedule, require much preparation, and expose people to cultural gaffes or imbroglios, the fewer of them, the better. *Before* formal meetings, the project manager should meet with local customers or officials to report any major problems; no one should first learn about big problems or be shocked by what they hear in a meeting.

The primary means for tracking status and identifying problems should be one-on-one communication and frequent *informal* meetings, convened as needed, the time and place to be determined by urgency and purpose, for example, alternate weeks if everything is okay, more often if not, and at the site experiencing problems or issues. Attendance should be restricted to meeting contributors and those who would benefit from being there. As with domestic projects, the project manager should be the person who takes meeting notes and formally writes them up and distributes them.

See Chapter 17

The team in an international project might be dispersed across multiple locations around the globe—for example, a distributed or virtual team—and most meetings occur via electronic meeting technology or audio or web conferencing. All the recommendations for "virtual meetings" in Section 17.8 in Chapter 17 apply to international projects, but with the addition of a few more. In the interest of building personal relations and team trust, every meeting should begin with casual conversation. The project manager should allow a few minutes each meeting for members to talk about their families, hobbies, interests, and so on, especially before a holiday for local members to explain the holiday and its customs. It's not so important that members know much about each other, but rather that they show they *care enough about each other* to want to hear about their personal lives and holidays.

Setting time for virtual meetings can be problematical. Says Cohn, "It's not the distance, it's the time difference."[28] Cape Town and San Francisco are roughly equidistant from London (9,700 km versus 8,600 km), but the former is 2 hours ahead of London, while the latter is 9 hours behind. Scheduling London–Cape Town calls and meetings will pose few problems; scheduling London–San Francisco meetings, that's something else! Meetings held during mealtimes should be avoided, although what's "mealtime" varies around the world. In North America, dinner is around 6 p.m.; in Europe, India, and elsewhere, 8 or 9 p.m. is more common.

When time differences are big, the project manager should try to share the pain in scheduling meetings.[29] Chicago and Mumbai are 10.5 hours apart and allow no convenient meeting times for teams in both places. The solution is to rotate meeting times—sometimes 8 a.m. Chicago time (6:30 p.m. in Mumbai), sometimes 8 a.m. Mumbai time (9:30 p.m. in Chicago). The rule should hold even if Chicago is the project home office with 30 people and Mumbai is a satellite team with only six people. Rotation reduces perceived "power" differences among members and helps build trust and respect. If the project has people dispersed around the world, the number affected can be minimized by requiring only a few members or a representative from each place to participate in the meetings (again, rotating times). This alternative is never as good as everyone participating (just as virtual meetings are never as good as face to face), but compromises are sometimes necessary.

To raise awareness of differences, the project manager should distribute a guide to all team members showing for every member their country; time zone; and the times, days, mealtimes, and holidays when they say they cannot or prefer not to meet.[30]

20.13 Risks and contingencies

See Chapter 11

International projects are fraught with risks, though often they are subtle or hidden and visible only by seeing the project from the perspectives of the different cultures and countries of the project stakeholders. Any standing risk policies of the contractor or customer (described in Chapter 11) should be applied in a consistent manner across all projects in all countries. In other words, a company's risk tolerance as expressed in the risk policy should remain the same, no matter the project or country.

As discussed in Chapter 11, risk analysis begins during project conception and definition by imagining different scenarios about what could go wrong. Project risk is associated with level of uncertainty: the less certain you are about something, the greater the risk. In an international project, much of the uncertainty relates to ignorance about local culture, customs, language, institutions, infrastructure, and stakeholders; thus, an important strategy for reducing risks in an international project is *learning*: the more you know about these matters, the better you can identify and mitigate the risks.

Another strategy, however, is to decrease the amount of learning necessary, especially learning about how to deal with local regulations, laws, and resources. This is done in the following ways:[31]

- *Outsource activities that are heavily restricted by local regulations*. Purchasing land, obtaining permits, hiring locals, and moving materials through customs are risky because they require knowledge about local laws and customs. By hiring knowledgeable subcontractors to assume these activities, the burden of responsibility (and much of the risk) is shifted to the subcontractors.
- *Perform technology-intensive work at home*. Rather than dealing with the uncertainties of local labor, materials, and infrastructure, do much or all work on major hardware and software deliverables at home, reserving for abroad only the on-site assembly and installation.
- *Sign contracts under international law or third-country law*. Rather than learn the intricacies of local laws and depend on local lawyers, finalize all contract agreements according to international law or a neutral country where the laws are familiar. This practice is mandatory in countries where local laws are unclear or enforcement unpredictable.

Most companies employ a mix of the previous—they learn about and deal with some aspects of the host country and culture themselves but avoid having to learn about and deal with others. The mix depends on the kind of project. In general, the more a project requires the contractor to be "imbedded" in a foreign country, the more she must learn about the country, its laws, and culture. Contractors such as Fluor and Bechtel that perform large construction projects are *heavily* imbedded in the local environment because the projects take years, have large scope, and rely somewhat on local resources. Hence, the firms and managers must learn about the country or region of the project, which they do by hiring local contractors, local laborers, and expatriates who know the country thoroughly. They also methodically manage all knowledge gained about the host country. At the same time, they reduce their need to learn about *everything* by, wherever possible, prefabricating deliverables at home, outsourcing to local suppliers and contractors, and hiring local representatives to deal with local stakeholders, and freelance expatriates to manage technology and contracts.

Of course, the project manager of an international project who must be on site is always "imbedded" in the host country—even when the contractor (his employer) is not. Although knowing the local practices, ways, and protocols might not matter to his firm, it does matter to the manager who has to live and work in the host country for the duration of the project. Of all the ways to reduce the risks in an international project, perhaps the overall best is to learn and adapt to the local customs, laws, infrastructure, and social norms and build trusting relationships with the leaders, subcontractors, laborers, and officials of the host region.

20.14 Summary

A project that is international in scope automatically inherits more issues and greater risk than one that is not. These issues touch most everything about project management—leadership, interpersonal relations, stakeholder involvement, communication, planning, risk management, and tracking and control.

The project manager must be able to work with local subcontractors, suppliers, customers, business associates, and officials. Often these stakeholders withhold effort, collaboration, or support until they feel they know the project manager personally. Thus, gaining personal familiarity and building relationships is a fundamental aspect of managing international projects. Besides "domain competency" over technical aspects of the project, the project manager must be self-sufficient, adaptable in unfamiliar environments, and able to understand and respect local culture and customs.

When the project manager cannot always be on site, she should appoint a local project manager to handle detailed planning and daily management. Even when she can be on site, she should appoint a permanent "local representative" to keep her updated on local matters, mediate with local stakeholders, and help resolve local issues.

Each global project should have an executive steering committee to oversee governance and funding, set goals, and coordinate work among subprojects at different sites. Each subproject should have a local steering committee to plan and execute local details and handle local problems.

Definition and planning for an international project require identifying the many issues and unknowns associated with culture, country, laws, people, and so on and accounting for them in project plans, schedules, and budgets. Managers and others familiar with the local environment must be consulted and involved in preparing detailed plans. The project might have two WBSs, one for technical aspects of the project, the other for cultural or international aspects. The fact that most everything involves greater effort, time, and cost must be factored into plans, schedules, and budgets.

The project manager must provide firm goals and direction to local managers and subcontractors. Ideally she is on site; if not, she makes frequent visits, unannounced.

Many risks in international projects stem from ignorance about local and international customs and conditions; thus, one of the best ways to reduce risk is to learn about local customs, laws, infrastructure, and social norms and to build trusting relationships with local stakeholders.

Review Questions

1. Consider the analogy of an international project to a play. In international projects, who are the actors, what are the scripts, what are the sets, and what are the props?
2. What are the four main categories of "unknowns" in an international project?
3. In the previous list of unknowns, which are "implicit" and which are "explicit"? Why are implicit unknowns potentially more problematic for the project manager?
4. Describe each of Hofstede's five cultural dimensions. How is awareness of these dimensions relevant to project management?
5. Consider two countries you are familiar with. Compare and contrast them in terms of the following: Hofstede's five cultural dimensions, language, formality, gift giving, attitudes about age and about time, food and drink, holidays and time off, and customary labor time.
6. Why might worker layoffs following the project cause legal problems for the contractor or employer?
7. For an overseas project, whose laws prevail, the host country's or the home country's?
8. What are "Incoterms"?
9. What legal problems are associated with contracts in international projects? What steps should be taken to avoid them or to deal with them should they arise?
10. How can the project manager know in advance of impending political or labor/union problems in the host country?
11. What are some benefits of hiring local contractors in an international project? What are the drawbacks and difficulties?
12. Describe the role of informal gatherings and social events in building trust.
13. Describe ways a contractor can protect against rising costs or falling prices resulting from fluctuating exchange rates.
14. What is an "offset"? What is the difference between indirect and direct offsets?
15. Name some forms of export/import restrictions. In what ways can they impact an international project?
16. A project involves team members in New York and Rome. Discuss how you would accommodate the 6-hour time difference to maximize communication and coordination between them.
17. In global projects that include subprojects at multiple sites, who is responsible for day-to-day oversight of each subproject at each site?
18. Can it be assumed that a technology or process that proved successful in a project in one country will automatically be successful in an identical project in another country? Explain.
19. Who should be trained in the cultures, traditions, and regulations of the home or host country, the managers and staff who will be going to the host country to work on the project, or the local managers and subcontractors who will be working on the project for a contractor that is based overseas?
20. What are the responsibilities and qualifications of the local representative?
21. What is the role of the project steering committee (or governance committee or review board) in an international project? What is the difference between the global and local steering committees?
22. What is the role of the PMO in an international project?
23. What are ways to build teamwork and encourage cooperation between members of the project team from the home country and host country?
24. What are ways to build relations with local vendors and officials? Why are these relations so important?

25. How can the project manager learn about the host country and potential risks related to culture and environment in the project?
26. Discuss the process of developing the scope and SOW for subprojects in a multisite, multinational global project.
27. Describe the WBS for identifying the unique issues of an international project. How is the technical WBS of an international project similar to or different than the technical WBS for a single-country, domestic project?
28. Name some of the issues that the WBS in an international project might have to address.
29. Describe the purpose and content of the summary matrix in Table 20.5.
30. Comment on the size of work packages in an international project. How are work packages tracked and controlled?
31. List some factors that must be taken into account in estimating resources, time, and cost for an international project and in establishing budgets and schedules for the project.
32. What special issues should the communication plan for an international project address?
33. What are some strategies for handling risks in international projects?

Questions About the Study Project

If your investigation project was a global or international project, or involved customers and/or contractors overseas, consider the following questions.

1. What did the contractor and/or project manager have to do in this project that differed from a typical domestic project?
2. Discuss aspects of the country, culture, language, and social behavior of the host country that challenged the project manager.
3. How did the project manager and staff learn about the culture and traditions of the host country? In your opinion, were they knowledgeable and well prepared to work in the host country?
4. What difficulties were encountered that stemmed from the international nature of the project? Could they have been avoided through better planning?
5. Discuss the following roles, as appropriate: of the local project manager, of the steering committee, of the PMO.
6. How did the project manager identify special issues related to the international nature of the project and account for them in planning the project?
7. What adjustments did the project manager have to make in estimating the resources, time, and cost of the project to account for differences in countries supplying labor and materials to the project?
8. What strategies were employed to identify and reduce project risks?

CASE 20.1 MOZAL PROJECT—INTERNATIONAL INVESTMENT IN AN UNDEVELOPED COUNTRY[32]

Mozal is a $1.4 billion project launched in 1998 to construct a 250,000 tons per annum (tpa) large, modern, state-of-the-art aluminum smelter in Mozambique (Figure 20.2). The idea of such a project at first seemed preposterous. Construction of such a facility would require international financing and stable supplies of raw materials and labor, but Mozambique was one of the world's

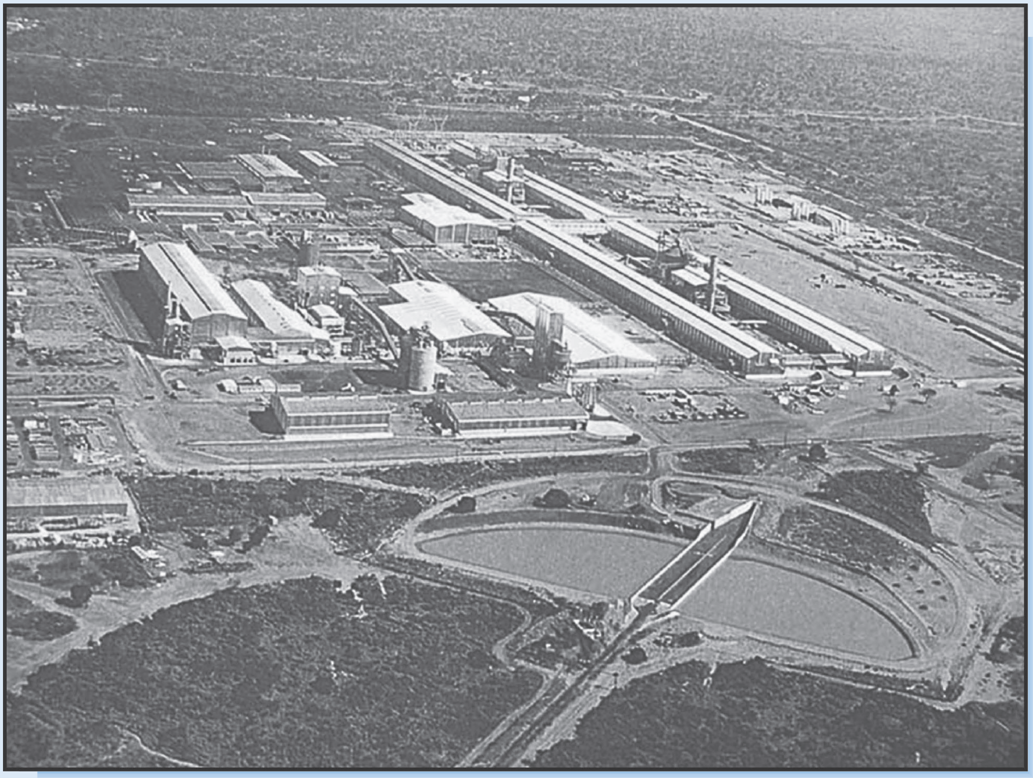


Figure 20.2
Mozal aluminum smelter.
Source: Photo courtesy of BHP Billiton.

poorest nations with an infrastructure in ruins after two decades of civil war. Yet the project was a success, completed months ahead of schedule and well under budget. It is worthwhile to see how that happened.

Mozal's primary promoting and controlling shareholder was Gencor, a large South African mining firm (later a part of BHP) that had recently completed the world's largest (500,000 tpa) smelter, called Hillside, in Richards Bay, Republic of South Africa (RSA). In 1995, Gencor sent a multinational team of South African, Canadian, and French specialists from the Hillside project to search for a site for another smelter.

Mozambique

The team chose Mozambique for several reasons (Figure 20.3). Its capital, Maputo, offered a suitable (though run down) harbor for importing alumina and exporting aluminum, plus abundant low cost (though largely unskilled) labor. Also, the South African power utility, Eskom, saw an opportunity to extend its power grid into Mozambique. The grid would provide the Swaziland region with reliable power and, later, be the conduit to supply hydropower from the Zambesi River in Mozambique to the RSA.

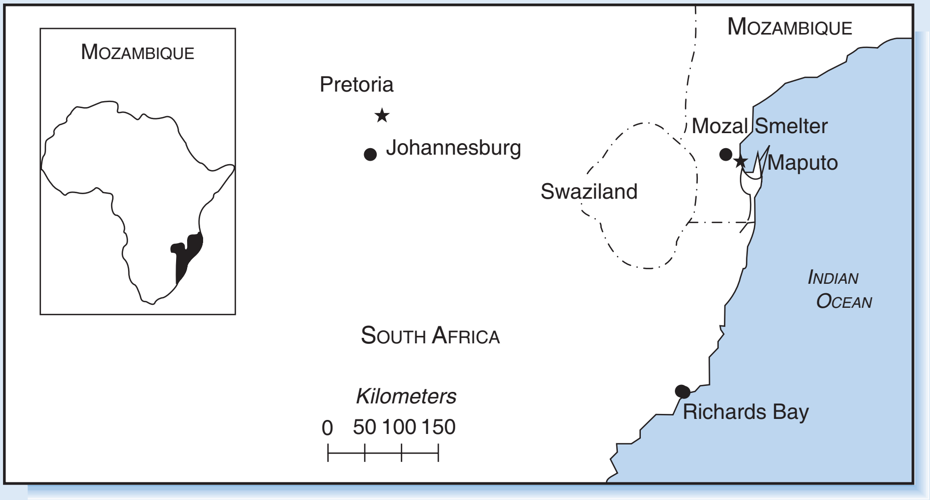


Figure 20.3
Mozal Smelter location and surroundings.

Mozambique's government was receptive to Mozal, since the project would provide impetus to its industrialization policy. Mozal would become the first enterprise to qualify as an enterprise in the Industrial Free Zone, giving its supporters tax and duty exemptions. In addition, since Mozambique is an Asian-Pacific-Caribbean country under the Lome Agreement, aluminum produced there would enter the European Union duty free. After a visit to the Hillside smelter, Mozambique's prime minister championed the project and facilitated the regulatory and bureaucratic changes necessary for it to proceed.

The site chosen for the smelter lay in an undeveloped area 17 km from the harbor. To clinch the project, Gencor agreed to finance all related infrastructure work, including developing the harbor facilities, against repayment over time through taxes and harbor revenue offsets. Key members of the Mozal team relocated to Mozambique, enabling them to build relationships with stakeholders throughout local government and the community.

Financing

Another sponsoring shareholder for the project was the Industrial Development Corporation (IDC), a development bank of the RSA government created to identify investment opportunities that promote economic stability. IDC agreed to provide low-cost financing, export credit, and guarantees to South African manufacturers and contractors. The International Finance Corporation (IFC), a member of the World Bank Group that promotes sustainable investment in developing countries, also agreed to finance the project after being convinced that it was commercially viable, environmentally sound, and offered important benefits to the region. All major cash inputs and outputs were set in US dollars to minimize currency exposure.

Risk Mitigation and Go-Ahead

Costs for produced aluminum were anticipated to be in the bottom 5 percent of industry capacity, and its commercial case surpassed Gencor's investment criteria. The only major risk in the project was Mozambique. In May 1997, the governments of Mozambique and the RSA signed an agreement pledging to honor and protect cross-border investments. After private discussions with influential interest groups in Mozambique, the IDC and IFC decided to seek an influential international shareholder to share in the risk. In 1997, Mitsubishi Corporation, the Japanese conglomerate, signed on, and in May 1998, the project was given the go-ahead.

Construction

Construction at the Mozambique site posed major challenges. The locals speak Portuguese, but the expatriate managers, supervisors, and the computer software use English. Some basic engineering work was done in Canada and France; some specialized equipment was designed and manufactured in Japan and France. Most of the planning, coordination, detailed design, and preparation of material took place in the RSA.

Road and rail links connected Mozal to Richards Bay, RSA, where material and equipment arrived from overseas for transport to the project site. At one stage of the project, it became clear that Mozambique agents were having trouble processing the 60 to 80 trucks of equipment and materials that crossed the border daily. But the project director had built good relationships with key stakeholders, including Mozambique's president, and convinced them to allow the Mozal team to assist in managing the border post.

The project employed many experienced workers from the Hillside project, although thousands more unskilled workers had to be hired. Schools were set up to train them in construction and increase awareness of safety and the risks of HIV infection. To combat malaria, the area surrounding the site was continually sprayed, and full-time on-site clinics set up that would eventually handle over 6,000 cases. For residents displaced by the project, new farming land was allocated and cultivated, and a development trust established to provide for local schooling and other community needs. Before contractors could access parts of the site and service corridors, land mines laid during the civil war had to be cleared. Construction of cross-country power supply lines and, consequently, commissioning of the smelter were threatened by major cyclonic floods. Heavy-lift helicopters were needed to fly in large pylons prefabricated offsite and to string power cables.

One goal of the project was to maximize local content. An estimated $75M was spent in the local economy. At peak construction, 70 percent of the 9,000 people employed at the site were Mozambicans.

QUESTIONS

1. Summarize the issues and factors that posed risks to the Mozal project. Which of these arose from the international nature of the project?
2. What actions led to successful completion of the project despite the risks?
3. The team began searching for a suitable site in 1995, but the project was not launched until 1998. Discuss the kind of work required during the pre-project phase of a high-risk international project such as Mozal and the importance of that work.
4. Discuss the social responsibilities relating to projects in developing countries such as Mozambique.

STUDY ASSIGNMENTS

1. You are the newly appointed director for the proposed Mozal project. The feasibility study is complete, and you must convince the international sponsors and lenders to commit to the project. Develop a presentation to a special board of stakeholders asking for the go-ahead to commit $1.4 billion to the project; address their expectations and how you will deal with the perceived risks.
2. The project has received the go-ahead and you now face the reality of mobilizing your team and starting work in a foreign country. What special project challenges can you expect, and how will you go about laying the foundations for success?
3. What do you see as the criteria for evaluating the success of this international project?

CASE 20.2 SPIRIT ELECTRONICS' PUERTO RICO OFFICE[33]

Spirit Electronics Company, a US firm, is building an office branch in Puerto Rico. Susan Marcie of the construction management firm Weller & Waxhall is managing the project; this is her first non-US project. She visited the project site and met with the person who would be the local project representative. In preparing the budget, she sought bids from vendors in the United States and Puerto Rico. Bids received from US firms seemed extremely high; this plus the fact that labor laws in Puerto Rico require that some jobs be performed by local vendors led Susan to select mostly Puerto Rican vendors.

Spirit wanted the project completed within 30 weeks. Since cost bids from the vendors were slow to arrive, Susan prepared a budget using her firm's cost-estimating spreadsheet and standardized costs. Spirit's budget review process takes 4 weeks and, she thought, the quicker the budget is approved, the sooner the project can begin. The project budget for $690,457 was approved.

As project planning progressed, issues arose since the project was in Puerto Rico:

- Permits are required from both city and state (the United States requires only city permits).
- Labor insurance is required at 5 percent of construction cost (not required in the United States).
- Unusually high city taxes for construction work.
- High furniture cost (much higher than in United States).
- High security cost due to risk of theft (higher than in United States).
- Work shut down due to state holiday (December 22 through January 15).

These plus other smaller issues raised the estimated cost to $1,250,998. Spirit threatened to cancel, but Susan was able to negotiate with vendors and reduce the cost to $987,655, to which Spirit agreed.

Susan knew that in overseas projects, extra time must be included in the schedule to account for unknowns. She proposed delaying the target completion by 8 weeks, but Spirit objected. She was able to create a schedule to meet the original target date by paying the government an additional $20,000 to rush the permits.

As the project progressed, Susan had to respond to several issues:

- Long lead times for custom-made fixtures (6–8 weeks). Susan asked contractors to order the needed fixtures as early as possible.
- Millwork for cabinets and shelving, which usually must be done on site after walls are completed and exact room dimensions known. To avoid this, the building design was changed so millwork could be premade.
- Long lead times on permits (3–16 weeks). She submitted drawings and permit applications far in advance, noting the dates when permits were needed.
- Disorganized furniture installation vendors. Susan made the vendors create a plan (from which she estimated 8 weeks completion time) and then held them to it.
- Local labor pool dichotomy: extremely high cost (five times more expensive than in United States but able to reliably meet expectations) or extremely low cost (uncertain ability to do quality, on-time work). Typically Susan hired the first.
- Added cost and time for imported materials due to import tax and shipping costs and 6 weeks for government inspections. To avoid delays, Susan arranged for local storage space and shipping of materials far in advance of need.

- Language differences between US and local team members (site superintendent, IT personnel, carpenters and laborers). For tasks requiring coordination between these members, Susan extended the duration times.

QUESTIONS

1. In managing the project, how did Susan explicitly address the fact that it was an "overseas" project?
2. How might she have pre-identified issues that ultimately required her to redo the budget? How might she have anticipated other issues that emerged later?

Notes

1. Jubail City—2: SR 200bn Industrial Hub in the Making. *Zawya*, www.zawya.com/story.cfm/sidZAWYA20050321123628, accessed June 12, 2006.
2. Adopted from Orr R. *Strategies to Succeed in Foreign Environments*. Collaboratory for Research on Global Projects, Stanford University. CIB W92 International Symposium. Construction Procurement—The Impact of Cultural Differences and Systems on Construction Performance (Las Vegas, February 8–10, 2005, 3), http://crgp.stan-ford.edu/publications/conference_papers/RyanVegas.pdf, accessed April 10, 2007.
3. These descriptions are simplified, and each dimension has much broader ramifications than implied here. See Hofstede G., Hofstede G.J. and Minkov M. *Cultures and Organizations: Software of the Mind*, 3rd edn. New York, NY: McGraw-Hill Education; 2010.
4. McSweeney B. Hofstede's model of national cultural differences and their consequences: A triumph of faith—a failure of analysis. *Human Relations* 55; 2002: 89.
5. Carmel E. *Global Software Teams: Collaborating Across Borders and Time Zones*. Upper Saddle River, NJ: Prentice Hall; 1998.
6. Turner J. *Handbook of Project-Based Management*. New York, NY: McGraw-Hill; 1998, p. 483.
7. Murphy O. *International Project Management*. Mason, OH: Thompson; 2005, p. 23.
8. Pringle D. Finding ways around rigid labour laws. *Career Journal Europe*, www.expatica.com/actual/article.asp?subchannel_id=157&story_id=10562, accessed May 8, 2006.
9. International Chamber of Commerce. *Policy and Business Practices, Incoterms 2000*, www.iccwbo.org/policy/law/id315/index.html, accessed April January 1, 2007.
10. Lemley J. Managing the Channel tunnel—lessons learned. *Tunneling and Underground Space Technology* 10(2); 1995: 9–11, www.ita-aites.org/applications/30th/PDF/TUST_95_v10_n1_5-29.pdf, accessed December 2, 2007; Anbari F. (ed). *Case Studies in Project Management: The Chunnel Project*. Newton Square, PA: Project Management Institute; 2005.
11. Murphy. *International Project Management*, p. 63.
12. Adapted from Mathew M. *Doing Business in India: A Cultural Perspective*, www.stylusinc.com/business/india/cultural_tips.htm, accessed September 25, 2006.
13. Tools for Hedging Foreign Exchange Risk. *Study.com,* https://study.com/academy/lesson/tools-for-hedging-foreign-exchange-risk.html, accessed October 28, 2019.
14. Murphy. *International Project Management*, p. 63.
15. Lientz B. and Rea K. *International Project Management*. Amsterdam: Academic Press; 2003, p. 49.
16. Duarte D. and Snyder N. *Mastering Virtual Teams*. San Francisco, CA: Jossey-Bass; 2006, p. 134
17. Murphy. *International Project Management*, pp. 65–66.
18. Lientz and Rea. *International Project Management*, pp. 44–45.
19. Ibid., p. 56.
20. Ibid., pp. 71–72.
21. Orr. *Strategies to Succeed in Foreign Environments*, p. 5.
22. Similar approaches discussed Lientz and Rea. *International Project Management*, Chapter 2.
23. Lientz and Rea. *International Project Management*, Chapter 2.

24. Grove C., Hallawell W. and Smith C. *A Parallel WBS for International Projects*. Professional Knowledge Center, Grovewell LLC; 1999, www.grovewell.com/pub-project-wbs.html, accessed January 25, 2006.
25. These and other considerations discussed in Murphy. *International Project Management*, pp. 72–73, 88, 91–94, 178.
26. Lientz and Rea. *International Project Management*, pp. 124–128.
27. Ibid., pp. 155–170.
28. Cohn M. *Succeeding with Agile*. Upper Saddle River, NJ: Addison-Wesley; 2010, p. 375.
29. Ibid., p. 377.
30. Duarte and Snyder. *Mastering Virtual Teams*, p. 68.
31. Orr. *Strategies to Succeed in Foreign Environments*, pp. 6–7.
32. Personal communication, Rob A. Barbour, former chairman, Mozal.
33. Case adapted from Carta K., Cisek A., Cho L., Farr B., Hobbs M. and Kim C. *Sprint Powered Workplace*. Graduate School of Business, Loyola University Chicago; February 2007.

Appendix A

Request for proposal for Midwest Parcel Distribution Company

Following is the RFP for the proposed LOGON system sent by Midwest Parcel Distribution Company (MPD) to contractors perceived as most capable of meeting the requirements. Only partial entries are shown to minimize the length of the example.

(Note: Reference to "Appendix" is for a hypothetical appendix attached to the RFP, not to any appendix in this book.)

Introduction

You have been selected by Midwest Parcel Distribution Company as potentially capable of meeting our requirements for a new system. You are invited to submit a proposal to supply the hardware, software, and support services for the system described in this request for proposal.

Section 1 background

MPD seeks to award a contract for the design, fabrication, installation, test, and checkout of a transport, storage, and database system for the automatic placement, storage, and retrieval (PSR) of standardized shipping containers. The system, called the Logistical Online system (LOGON), will be installed at MPD's Chicago distribution facility . . . (*Additional discussion of the Chicago distribution facility, projected future needs, and purpose and objective of the LOGON system*).

Section 2 statement of work

The contractor shall be responsible for furnishing expertise, labor, material, tools, supervision, and services for the complete design, development, installation, checkout, and related services for full operational capability for the LOGON system. All necessary testing of systems and subsystems designed and installed by the contractor, as well as of current facilities to ensure compatibility with the new system and with local, state, and federal requirements, will be performed by the contractor.

The LOGON system must meet performance requirements, be compatible with existing structural and utility limitations of the facility, and be compliant with packaging and logistical standards and codes as specified in Section 6: Technical Information . . . (*Additional discussion of the services, equipment, and material to be provided by the contractor and a list of specific end-items.*)

Exclusions

Removal of existing PSR equipment will be performed under separate contract and is the responsibility of MPD. Removal will be completed in time for the new system to be installed . . . (*Discussion of services, equipment, and material provided by MPD or other contractors and for which the contractor is NOT responsible.*)

Scheduled Delivery Date

LOGON system is to be fully operational on or before April 30, 2025. All hardware, software, and support services necessary for full system operation will be supplied and/or completed by April 30, 2025. Site installation will initiate no later than November 30, 2024.

Subcontractors

With the proposal, the contractor shall submit a list of subcontractors and work to be assigned to each. Subcontractors will be subject to MPD approval prior to placement of a contract.

Cost and contract

Price of contract will not exceed $15 million. Contract will be fixed price with a penalty charge of $10,000 per day for failure to meet the operational completion date of April 30, 2025.

Section 3 proposal content and format

Proposal will include the following sections and conform to specific instructions as follows.

Proposal table of contents

1. Cover sheet (use Form I provided in Appendix)
2. Executive summary
3. Statement of work
    a. Background statement of need
    b. Technical approach and distinguishing features
    c. Project plan and schedule (use Forms II through V provided in Appendix).
4. Budget and price (use Form VI provided in Appendix)
5. Project organization and management plan
6. Prior experience and key personnel
7. Attachments
    a. Signed statement of confidentiality (use Form VII in Appendix)
    b. MPD-supplied confidential information
    c. Letters of commitment for work contracted to third parties.

Specific Instructions

(*Details about the purpose, specific content, specific format, and approximate length for each of the sections listed above.*)

Section 4 proposal submittal

Submittal

Contractor will submit two (2) physical copies and an email copy of the completed proposal along with all MPD confidential information to:

Lynn Joffrey l.joffrey@mpdchicago.com
Administrative Assistant
Midwest Parcel Distribution Company
13257 N. Wavelength Avenue
Chicago, IL 60699, USA
(773) 773–7733

Deadline

Physical and email copies of the proposal must be received by MPD by 5 p.m. August 15, 2023.

Section 5 selection date and criteria

Selection and award date

September 5, 2023.

Selection criteria

Completed proposals received by the deadline will be evaluated by the following criteria:

1. Technical capability:
    a. Capability of system to meet performance requirements within limitations of existing facility, standards, and codes. (15%)
    b. User friendliness of system with respect to operation, reliability, and maintenance. (5%)
    c. Use of state-of-the-art technology to ensure system remains current into the next decade. (15%)
    d. System support services during contract period and available afterward. (5%)
2. Contractor's bid price. (25%)
3. Contractor experience and qualifications. (25%)
4. Project organization and management plan. (10%)

Section 6 technical information

Confidentiality

The attached technical data and any additional requested drawings, specifications, requirements, and addenda shall be treated as confidential and the property of MPD. Information provided in this RFP or requested from MPD will not be duplicated beyond that necessary to prepare the proposal. The original and all duplicates will be returned with the proposal. (See Form VII, Appendix.)

(Attached to the RFP are Appendices containing forms, agreements, and supporting technical data, standards, and performance requirements necessary for preparing and submitting a proposal.)

Supporting technical data

1. Technical data is attached in Appendix to this RFP:
    a. Technical performance requirements and standards for LOGON system
    b. Facility structural and utility specifications
    c. Facility floor plan.
2. For clarification and additional information, contact:
    Mr. Ed Demerest
    Project Director, Facilities
    Midwest Parcel Distribution Company
    13257 N. Wavelength Avenue
    Chicago, IL 60699, USA
    (773) 773–7733

Appendix B

Proposal for Logistical Online System Project

Submitted to Midwest Parcel Distribution Company from Iron Butterfly Company

1 Cover sheet

Form I: cover sheet

1. **Project Name:** Logistical Online System Project (LOGON) for the Midwest Parcel Distribution Company, Chicago distribution center
2. **Ref. Job No. 904–01**
3. **Contractor:** Iron Butterfly Corporation, Goose Rocks, Maine
4. **Name and Address of Contact:** Frank Wesley, Project Manager, Iron Butterfly Corporation, Robotics Applications Division, 150 Seaview Lane, Goose Rocks, Maine 715–332–9132, fwesley@ibuttc.com
5. **Proposal Contents Check-off**
    1. Cover Sheet
    2. Executive Summary X
    3. Statement of Work
        - A. Background Statement of Need X
        - B. Technical Approach and Distinguishing Features X
        - C. Project Plan and Schedule (Forms from RFP: II. Work packages; III. Deliverables; IV. Work schedule; V. Subcontractors) X
    4. Budget and Price (Project Price: $14,413,905)
        - A. Budget and Price (Form VI from RFP) X
        - B. Variations, Changes, Contingencies X
        - C. Billing and Payments X
    5. Project Organization and Management Plan X
    6. Qualifications and Key Personnel

  A. Company and Prior Projects X
  B. Résumés of Project Manager and Project Engineer X
7. Attachments (*provide as specified in the RFP or as necessary to substantiate assertions in the proposal*) X

2 Executive summary

Iron Butterfly Corporation of Goose Rocks, MN, is submitting this proposal for the design and installation of the LOGON system at Midwest Parcel Distribution Company's Chicago distribution center. Our proposed system integrates robotic and neural network technology to streamline parcel transport and storage and will complement MPD's existing distribution information processing system.

The *proposed system utilizes robotic drone transporters* to place and retrieve stored parcels. The *system will utilize neural network technology* and thus will actually learn where to place and retrieve parcels and gain in efficiency over time.

The significant benefits of the proposed system are:

- It can *readily accommodate the expected 20% increase in volume* anticipated by MPD.
- It can *be operated for about 10%* less than the annual operating cost of the current system.
- It can be *readily implemented in the existing facility* with no structural changes to the building and only minor changes to the electrical utilities.
- It is *easily expandable* in case the current facility is extended into the adjacent vacant lot.
- It can be *designed, installed, and made fully operational within 1 year* of contract agreement. Conversion can be done in three 2-month phases, each on only one-third of the facility. Hence, throughout the 6-month conversion, the *current facility will be able to operate at more than 60% capacity*.
- The *system hardware and software* are *durable and easy to maintain as* demonstrated by many 1,000s of hours operational usage of current systems by Iron Butterfly Company (IBC) customers.

IBC has 40 years of experience in the project management of the design and implementation of large warehousing transporter and storage systems. We have chosen highly experienced professionals as the project manager and the project engineer to oversee the LOGON project administration and technology. They will work closely with MPD to assure that the installed system satisfies the MPD needs identified in the RFP and feasibility study and as emerge during the project.

Creative Robotics Company of Newton, MA, is *IBC's partner in this project*. They will modify the robotic transporter drones for this project. CRC is the *industry leader in robotic drone technology* and has developed robots for NASA as well as the robotic drone transporters for all of IBC's installed robotic drone transporter systems.

Our price for the system is $14,413,905; we will hold this price fixed for the next 120 days. Iron Butterfly and Creative Robotics are fully committed to this project and guarantee its benefits. We invite you to contact us for more information and a formal presentation at your convenience.

3 Statement of work

A. Background statement of need

We recognize that MPD Company seeks a parcel storage, transport, and tracking system to replace the current system at its main distribution facility system in Chicago. The existing system is operating at capacity; the new system must be able to accommodate an expected 20 percent increase in parcel shipments over the next 7 years. Further, we recognize that the existing system utilizes a process that has become antiquated. MPD's objectives for the new system are to accommodate the expected growth; substantially improve the speed of parcel handling; increase utilization of existing storage facility space; enhance record keeping; and reduce the costs of labor, insurance, and shrinkage. The new system, to be called LOGON, will fully automate the process for placement, storage, and retrieval (PSR) of standardized shipping containers. MPD seeks a contractor to design, fabricate, and install the system, which is to include all hardware and software for transport and storage of parcels and the associated processing and storage of information for inventory and parcel tracking and control. This will be achieved with the deliverables listed in Form III and described in Section B.

We also recognize that removal of existing PSR equipment will be performed under a separate contract and that during system installation, MPD will arrange for alternative storage at other sites.

B. Technical approach and distinguishing features

Based upon analysis of information provided to us by Mr. Ed Demerest about MPD's Tulsa facility, which is considered a model facility, and data included in the RFP package, we conclude that the best approach for meeting MPD's needs and objectives is a system that uses robotic drone transporters, racks with standard-sized shipping containers and storage buckets, and a computer database for automatic placement and retrieval of parcels and record keeping. The new system will be derived from a combination of advances in robotic and drone technology, artificial intelligence, and application of existing technology. Our company has 40 years' experience in design and installation of parcel handling and associated information systems, including eight installed robotic drone systems for companies in North America and Europe. (Experience is explained in Section 6, Qualifications and Key Personnel.) While using advanced technology, the proposed system will incorporate features of existing MPD systems to avoid duplication of effort and provide a fully operational system in less than 12 months from start.

The proposed systems work like this:

Upon a parcel's arrival at the distribution center receiving dock, it is placed into one of three standard-sized parcel "buckets." The buckets are electronically coded as to item and shipping destination. This code is relayed to a master database from any of four terminal workstations located at the dock. The workstations are connected via a DEM-LAN network to a CRC Model 4000 server. The Model 4000 has 4-terabyte storage plus backup for retaining information about parcel description, status, location, and destination. The system tracks available remaining storage space, and, if needed, reallocates buckets for optimal space utilization. Allocation for space utilization relies on neural network technology, which enables the system to "learn" and improve its reallocations over time. The CRC 4000 will also provide reports about system status and performance as requested by management.

Parcel buckets are attached to a robot drone transporter that carries the bucket to a "suitable" vacant storage slot within a shipping container located on a rack. The computer determines which container has a vacant slot of sufficient size and containing parcels destined for the same or nearby destination as parcels in the transporter's bucket. The robotic drone transporter then conveys the bucket to the appropriate shipping container and unloads it into the vacant slot. Each slot in the storage rack has a tray on rollers that automatically extends to accept/yield incoming/outgoing buckets from arriving drones and then retracts. Shipping containers are stacked in seven rows of racks, three high (Items 2 and 3). The facility storage capacity is 400 shipping containers, each with 150 cubic feet storage capacity.

When a truck headed to a specific destination is to be loaded, the destination is keyed in at the dock terminal workstation, and the database system identifies all containers with buckets with parcels going to the same or nearby destinations. The system routes the robotic drone transporters to the appropriate containers for retrieval of the buckets. The trays with the outgoing parcels are extended for parcel retrieval by the drones. The system uses six robot drone transporters that operate independently and simultaneously. The drone transporters deliver buckets from incoming trucks and retrieve and transport them to the loading dock for placement into departing trucks. The longest specified delivery/retrieval time is 6 minutes. A seventh drone transporter will be included as backup.

(Discussion continues about features of the robotic system and neural network software, including the benefits and advantages over alternative designs.)

C. Project plan and schedule (Forms II to V from request for proposal)

Form II: work packages

1. Perform functional design of overall system.
2. Prepare detailed design specifications for subcontractors of robotic transporter, storage rack systems, and shipping and parcel containers.
3. Prepare specifications for the software for DEM-LAN and CRC 4000 system interface.
4. Prepare detailed modification drawings for robotic drone transporter units and storage rack system.
5. Prepare plan for system installation and test at the site.
6. Fabricate robotic drone transporter units and rack support subassemblies at IBC facility.
7. Perform preliminary functionality tests on seven robotic drone transporter units.
8. Perform structural and functional tests of storage rack systems.
9. Perform installation of all subsystems at MPD Chicago facility site.
10. Perform checkout of subsystems and final checkout of overall system at MPD facility site.
11. Codes and Standards. (*List of requirements and standards for local, state, and federal agencies, and measures for compliance.*)

Form III: deliverables

Hardware Group A
7 storage racks, 109 3 159 3 69, installed at site
Final structural, functional checkout of racks
400 shipping containers installed at site
1,000 size D43A parcel buckets
600 size D25B parcel buckets
600 size D12C parcel buckets
Final structural, functional checkout

Hardware Group B
7 robotic transporter units, each 20 pounds maximum load capacity, compatible with three sizes of parcel buckets, 6 minutes retrieval at farthest point, installed at site
Four-unit functional checkout
Integration checkout, Groups A and B

Software Group
DEM-LAN network, four CRC 2950 workstation terminals and CRC 4000 server, operating system software (CRC)
Vista-Robotic software (Creative Robotics)
Triad warehousing system; Mobius transaction processing (CRC)

Support

Two physical copies plus online copy, system operation/maintenance manuals
Robotic drone transporter/CRC 4000 integration
User training to competency
Final system checkout, user

Form IV: work schedule

1.	Commence basic design	May 2024
2.	Basic design review	July 2024
1.	Commence basic design	May 2024
2.	Basic design review	July 2024
3.	Process/track design approval	September 2024
4.	Computer system specs review	October 2024
5.	Hardware Groups A and B received	December 2024
6.	Begin installation at site	January 2025
7.	Finish installation of complete system 1/2	March 2025
8.	Final user approval	May 2025

Form V: subcontractors

1. Creative Robotics, Inc., Newton, MA, will supply the seven robotic drone transporters and necessary software.
2. Steel Enterprises, Inc., West Arroyo, OH, will supply and install the parts for the storage racks.
3. United Plastics Co., Provo, UT, will supply the shipping containers and parcel buckets.
4. CompuResearch Corp., Toronto, Ont., will supply terminal workstations, DEM-LAN network, and CRC 4000 computer neural network software, and installation of software and related hardware.

4 Budget and price (project price: $14,413,905)

A. Budget and price (form VI from request for proposal)

Task	Labor Cost	O/H @0.25	Material Cost	S/C	G/A @0.10	Total
Project coordination	800,000	20,000	20,000		12,000	852,000
Project design and development	260,000	65,000	51000		143,000	519,000
Basic hardware	684,000	171,000	54,100		90,910	1,000,010
Hardware design and Drawings	1,165,200	291,300	143,400		160,000	1,759,900
Software specs	150,400	37,600	23,300	116,000	32,730	360,030
Parts purchase	10,320	2,490	600	1,477,500	149,100	1,640,010
Drawings	703,000	175,750	121,200	0	100,000	1,099,950
Software purchase	6,080	1,520	2,000	2,550,000	72,720	2,632,320
Assembly	562,800	140,700	151,000	0	85,450	939,950
Test	343,000	85,750	117,000	0	54,580	600,330
Final installation and test	997,600	249,400	133,500	165,000	154,550	1,700,050
Totals	5,682,400	1,240,510	817,100	4,308,500	1,055,040	13,103,550
Price		profit	10%	1,310,355		14,413,905

B. Variations, changes, contingencies

(List conditions under which costs will change: change in the scope of work, cost of steel-fabricated materials, work stoppages for labor disputes, etc.)

C. Billing and payments

(Proposes the method for billing and payment.)

5 Project organization and management plan

Our company knows project management and has the experience, skills, procedures, and software to successfully perform this project. The project manager, Mr. Wesley, will be responsible for managing project work, including all client contact work, reporting of progress, adherence to contractual commitments regarding schedule and technical performance, and monitoring of budgetary expenditures (see Section 6, Qualifications and Key Personnel). The project engineer, Julia Melissa, will be responsible for specification definition and ensuring the system meets technical requirements. She will supervise preparation of design requirements and drawings and ensure fulfillment of system technical requirements at the site. Ms. Melissa has worked at IBC for 7 years and on IBC's three most recent robotic projects. The fabrication manager, Ira Block, will be responsible for managing materials procurement and assembly and related work at the IBC plant and coordinate assembly operations and give approval for assemblies prior to shipment to the MPD site. Mr. Block has worked with IBC for 9 years.

Within 1 month of contract signing, the project manager will prepare a project execution plan for MPD to review. Thereafter, he will present progress reports at monthly meetings with MPD staff. Written documentation will be provided in advance to MPD. The meetings will review expenditures to date, progress on work, and milestones and deliverables attained, all tracked by IBC's IRIS project management planning, tracking, and control system. Other formal meetings include a mid-project review meeting and a project summary meeting; plus others as requested by MPD or IBC.

(Additional sections address reporting and communication structure and risk mitigation.)

6 Qualifications and key personnel

A. Company and prior projects

Iron Butterfly Corporation has been in the business of designing and installing custom warehousing systems for 35 years. Among our customers are Nalco, Firebrand, Kraft, Abbott Laboratories, Cardinal Health, Swiss Guard, and Boeing. Our company has been ISO 9000 certified since 1996; we have also been certified as a Category A supplier for Grego Systems and a Class IIA supplier for Boeing's Commercial Aircraft Division. (*Author's note: this is a hypothetical example.*) In 2005, we received the Genie Design Award from IAWA. In 1998, we teamed with Creative Robotics Company to design the first fully automated robotic warehousing system, and in 2011, we installed the first operational drone transporter system at the 300,000 sq. ft. AIKEN distribution center in Hamilton, Ont. In 2014, we installed a similar system for Genteco Distributors at their 400,000 sq. ft. packaging center in Everett, WA. The robotic drone transporters are based on the standard industrial Model EZ, produced by Fancy Free Aerospace, Inc. The Model EZ has over 3 years and 350,000 hours of industrial service without major incident. The design of the Model EZ was modified for warehousing application by CRC president and MIT professor Dr. Sanjeev Rayu. (*Include a few sentences about Creative Robotics' experience, projects, and achievements.*)

So far we have installed a total of eight of these systems for satisfied customers.

(Additional paragraphs provide details of these systems: size and applications, cost of projects, names of customers, and information for contacting these customers.)

B. Résumés of project manager and project engineer

(Attach one-page résumé each for project manager and project engineer showing experience on related projects and relevant background—degrees, memberships, and certifications. Also include half-page résumés for one or two other key people in the project.)

7 Attachments

(*This section provides attachments as specified in the RFP or as necessary to substantiate assertions in the proposal*); e.g.:

1. Signed statement of confidentiality (use Form VII in RFP)
2. MPD-supplied confidential information
3. Technical data and analysis to support the proposed system
4. Letters of commitment for work contracted to third parties.

Appendix C

Project execution plan for logistical online system

Contents

Cover letter

Memorandum

Iron Butterfly, Corp.
Elegant design. Built to last.

To: SEE DISTRIBUTION Ref. Job No.: 904–01
From: Frank Wesley, Project Manager Date: January 3, 2024
Subject: Logistical Online System Project

Project Execution Plan

The Project Execution Plan for the Logistical Online System Project for the Midwest Parcel Distribution Company's Chicago distribution center has been modified to include your suggestions and approved by everyone in distribution. Copies of this document are herewith sent for use in the performance of contract requirements.

FW:es
Enclosure

Distribution:

Julia Melissa, Project Engineer
Sam Block, Fabrication Manager
Noah Errs, Quality Control Supervisor
Larry Fine, Software Manager
Sharry Hyman, Design Manager
Brian Jennings, Assembly Supervisor
Frank Nichol, Site Operations Manager
Emily Nichol, Assembly Supervisor
Robert Powers, Drawing Supervisor
Burton Vance, Purchasing Manager
Viola Chen, Contract Administrator

Logistical online system project execution plan

I Management summary

On September 5, 2023, the Midwest Parcel Distribution (MPD) Company awarded the Iron Butterfly Company (IBC) the contract for the Logistical Online (LOGON) System to be installed at MPD's Chicago distribution facility.

The project consists of designing, fabricating, and installing a parcel transport, storage, and database system, for automatic placement, storage, and retrieval of standardized shipping containers. The system uses robotic drone transporter units and a computerized database for automatic placement and retrieval of parcels and record keeping.

Iron Butterfly is the prime contractor and is responsible for the design of hardware and software, fabrication of component parts, system installation, and checkout. The major subcontractors are Creative Robotics, Inc. (CRI); Steel Enterprises, Inc. (SEI); United Plastics Co. (UPC); and CompuResearch Corp. (CRC). Iron Butterfly will provide overall project management between CRI, SEI, and UPC Corp. and related contract administration. The project manager is Mr. Frank Wesley, and the project engineer is Ms. Julia Melissa.

The project will commence with basic design on or before May 17, 2024, and final system approval by MPD Co. will happen on or before May 2, 2025. The principal subtasks are shown in Item 7.

The price of the contract is $14,520,000, fixed fee with limited escalation, based on a target final approval date of May 2, 2025. Total expenses, tabulated in Item 8, for labor, overhead, materials, subcontracting, and general/administrative are $13,140,270. The agreement provides for an escalation clause tied to inflation indices for material expenses for the steel rack support system. A penalty of $10,000 a day will be imposed on IBC for target completion overruns. Contingency arrangements in the agreement allow for reconsideration of the penalty in event of disruption of work for labor dispute with management.

II Project description

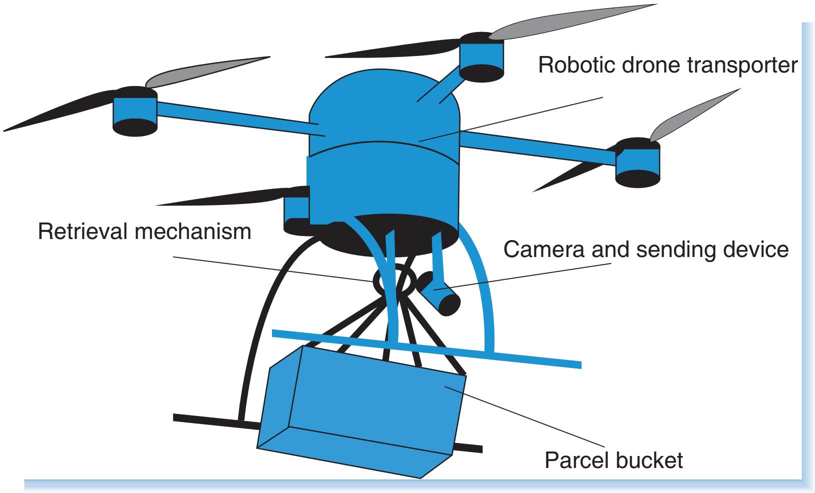
On September 5, 2023, IBC was awarded the contract for the LOGON System Project. The award followed a 1-month competitive bidding review by the MPD Company of New York. The system is to be installed at MPD Co.'s main Chicago distribution facility.

The project consists of designing, fabricating, and installing a parcel transport, storage, and database system (LOGON) for placement, storage, and retrieval of standardized shipping containers. The system will substantially improve the speed of parcel handling, increase the utilization of storage facility space, enhance record keeping, and reduce labor costs at the facility. Anticipated ancillary benefits include reduced insurance premium and shrinkage costs.

The system uses robotic drone transporter units, racks with standard-sized shipping containers and storage buckets, and a computerized database for automatic placement and retrieval of parcels and record keeping. The system works as follows:

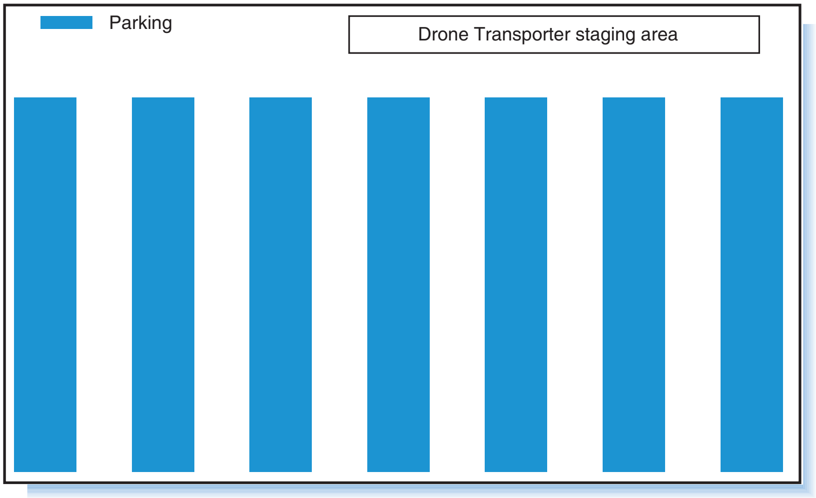
Upon a parcel's arrival at the distribution center receiving dock, it is placed into one of three standard-sized parcel "buckets" that are electronically coded as to parcel item and shipping destination. This code is relayed to a master database from any of four terminal workstations. The workstations are connected via a DEM-LAN network to a CRC Model 4000 server with 4 terabyte storage with backup to retain information about parcel description, status, storage location, and destination. The system keeps track of available storage space and reallocates buckets for optimal space utilization; upon request, it provides reports about system status and performance.

The parcel buckets are attached to a robotic drone transporter (Item 1). The drones are industrial Model EZ, produced by Fancy Free Aerospace, Inc., and modified by CRI for this application. Model EZ has been in use for over 3 years and 350,000 hours of industrial service with no accidents.



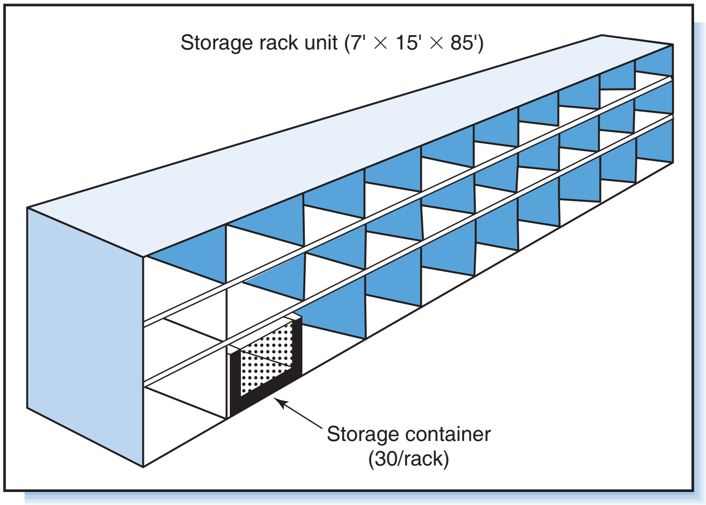
Item 1
Robotic drone transporter.

The transporter carries the bucket to a "suitable" vacant storage slot within a shipping container located on a rack in the facility. The computer determines which shipping container has a vacant slot of sufficient size and containing parcels going to the same or nearby destination as parcels in the drone transporter's parcel bucket. The transporter then conveys the bucket to the appropriate shipping container and unloads it into the vacant slot. Shipping containers are stacked three high in seven rows of racks (Items 2 and 3). The facility holds 400 containers, each with 150 cu. ft. of storage capacity.



Item 2
MPD site layout.

When a truck going to a specific destination is to be loaded, the destination is keyed in at the dock terminal workstation so the database system can identify all shipping containers with parcels going to the same or nearby destinations. The system then routes the robotic transporters to the appropriate shipping



Item 3
Storage rack assembly.

containers for retrieval of parcel buckets. The system has six robotic drone transporters that operate independently and simultaneously. The transporters retrieve the buckets and transport them back to the loading dock for placement of parcels into departing trucks. The longest retrieval time in the system is 6 minutes. The system will employ neural network technology that will enable it to improve on its ability to place and retrieve containers. A seventh drone transporter is provided for backup.

IBC is the prime contractor and is responsible for the design of hardware and software, fabrication of components, system installation, and checkout. The major subcontractors are CRI, which will supply the major components for the robotic drone transporters; SEI, which will supply the storage rack system; UPC, which will supply the shipping containers and parcel buckets; and CRC, which will supply the terminal workstations, DEM-LAN network, neural network software, and CRC 4000 computer, as well as software development support and installation of computer hardware.

During system installation, MPD has arranged for alternative, temporary storage at another facility and rerouting of most parcel traffic to its other sites.

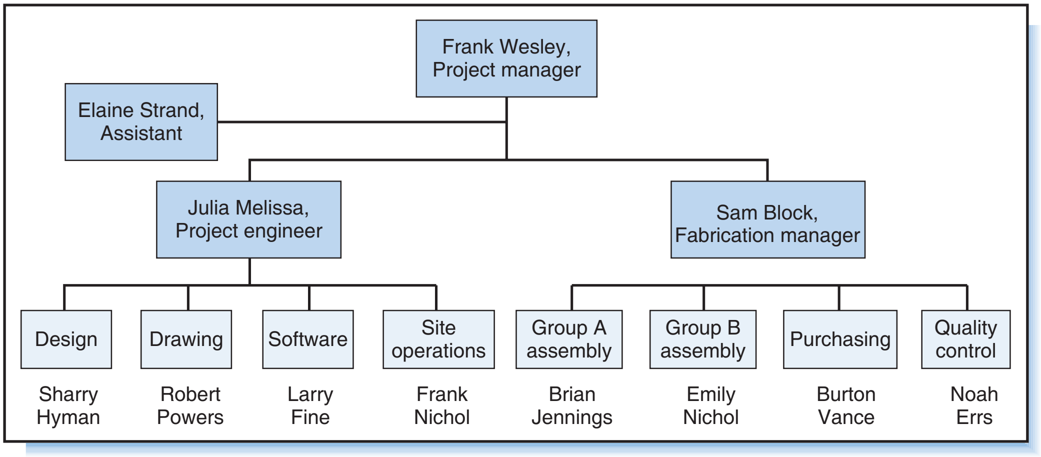
Design information about MPD's Tulsa facility will be utilized to try to initially move the project to an advanced stage. Remaining design work will use as much as possible of work that has been done already, without compromising confidentiality of clients, on previous similar projects.

III Organization section

III.1 Project administration

Correspondence on project matters will be between the project manager for IBC and the project director for MPD. Project personnel may correspond directly with the client or subcontractors for information, providing the project manager and project director with copies of memos and conversations.

The account number assigned to the LOGON project is 901–0000. Work packages and tasks will be assigned subaccount numbers at the time when work package instructions and schedules are authorized. A single invoice for the project accounts as a whole is acceptable for billing at monthly intervals.



Item 4
LOGON organization chart.

III.2 Project organization and responsibility

The organization of IBC for the performance of the LOGON project is shown in Item 4. Administrative and managerial responsibilities are summarized in Item 5.

The project manager, Mr. Wesley, is responsible for all client contact, reporting of progress, adherence to contractual commitments regarding schedule and technical performance, and monitoring of budgetary expenditures. He and his staff will report directly to Mr. Ed Demerest, vice president and project director for MPD Co.

The project engineer, Ms. Melissa, is responsible for establishing specifications and system delivery to meet technical requirements. She will supervise the preparation of design requirements and drawings, estimate quantities, check drawings and calculations, and ensure that system technical requirements are fulfilled at the site.

The fabrication manager, Mr. Block, is responsible for managing procurement, assembly, and related work at the IBC plant. He will ensure that delivered parts from subcontractors meet requirements, coordinate assembly of robotic drone transporters and storage rack subsystems, and sign off final approval for assemblies prior to shipment to the site.

III.3 Subcontractor administration

Key personnel at the four primary subcontractors CRI, SEI, UPC, and CRC are:

Bill Plante	Project coordinator, CRI
Terry Hemmart	Manager, manufacturing, SEI
Delbert Dillert	Customer representation, UPC
Lynn Duthbart	Systems engineering representative, CRC
Elmer Hyman	Customer representative, CRC

Changes to the respective agreements requested by a subcontractor or by IBC will be acted upon by the IBC project manager, Mr. Wesley, upon receipt of a written proposal from the subcontractor.

Correspondence with subcontractors concerning technical matters will be directed to the previously named first four parties or their substitutes. Software specifications–related work with CRC will

Responsibility code

P Primary responsibility
S Secondary responsibility
N Must be notified
A Must give approval

	Persons responsible																											
	Project manager																											
		Project engineer																		Fabrication manager								
			Design				Drawing					Software				Site operations						Assembly A				Assembly B			
Project task or Activity	F.W.	J.M.	S.E.H.	R.L.Q.	P.J.	D.V.R.	R.I.P.	O.E.M.	P.V.P.R.	D.M.N.	R.L.	L.S.F.	L.L.L.	J.R.S.	D.V.Q.	F.W.N.	J.M.M.N.	L.O.T.	A.U.A.	D.A.R.	S.O.B.	E.N.	G.G.F.	R.T.T.	B.V.L.	B.J.	T.T.Y.	H.R.D.	B.V.-Purchasing
Project coordination	P	S																			S								
Project development	A	P																											
Project design		A	P				A					N				A					N								N
H Basic design	N	A	A	P	S	S	N					N				N													
I Hardware design A			A		P	S																							
J Hardware design B			A	P		S						N																	
K Drawings B							A	S	P												N								
L Software specs		N	A									A	P	S	S														
M Parts purchase B		N																			A								P
N Parts purchase A		N																			A								P
O Drawings A							A			S	P										N								
P Installation drawings							A	P		S						N													
Q Software purchase		N																			A								P
U Assembly A		N																			N	A	P	S	S				
V Assembly B		N																			N					A	P	S	
W Test A		N														N					A	P							
X Test B		N														N					A					P			
Y Final installation		N														A	P	S	S										
Z Final test		N														A		P		S									

Item 5
Project responsibilities.

be coordinated by the CRC customer representative. Project telephone conversations between IBC and subcontractors shall be noted in handwritten memos and copies sent to the IBC project engineer.

Formal progress reports shall be prepared by the CRI project coordinator, the SEI manufacturing manager, the UPC customer representative, and the CRC systems engineering representative for presentation at weekly meetings to be held at IBC's Chicago office for the duration of scheduled involvement. Informal meetings will be scheduled as needed and may require attendance by other individuals as requested by the subcontractors or the project manager. The following minimum number formal meetings are included in the respective subcontractor agreements.

CRI	5 meetings
SEI	3 meetings
UPC	2 meetings
CRC	5 meetings (software development)
CRC	8 meetings (site system integration)

Subcontractors will provide information and perform services as follows:

1. CRI will perform all work associated with procurement, manufacturing, and component functional tests of parts and subassemblies according to specifications, plans, and drawings provided by IBC. Parts and components for seven robotic drone transporters will be delivered to IBC per the criteria and dates specified in the agreement.
2. SEI will perform all work associated with procurement, manufacturing, and functional tests of parts and subassemblies per specifications, plans, and drawings provided by IBC. Parts and components for the seven storage racks will be delivered to IBC per criteria and dates specified in the agreement.
3. UPC will perform all work associated with procurement, manufacturing, and component functional tests of parts and subassemblies per specifications provided by IBC. Plastic containers and parcel buckets will be delivered to the MPD Chicago distribution facility in quantities and according to dates specified in the agreement. One plastic container and one each of three sizes of parcel buckets will be delivered to the IBC facility for tests per the agreement.
4. CRC will perform all work associated with development, programming, and tests of LOGON system robotic transporter control and neural networking software and system database per specifications provided by IBC. Software will be delivered to the IBC facility per the agreement.
5. CRC will transport, install, and perform component and integration tests for checkout of five terminal workstations, DEM-LAN network, CRC 4000 server, NN software, backup system, and peripheral hardware per criteria and dates specified in the agreement.

IBC will provide overall project management of CRI, SEI, and UPC and related contract administration, and legal, accounting, insurance, auditing, and counseling services as may be required.

III.4 Client interface

Key personnel associated with the project for MPD Company are:

Ed Demerest	Project director, Chicago
Lynn Joffrey	Administrative assistant, Chicago
Cecil Party	Financial manager, Chicago
Mary Marquart	Operations manager, New York

Changes or modifications to the agreement requested by MPD or by IBC will be acted upon by the operations manager upon receipt of a written proposal from IBC.

Correspondence with MPD will be directed to the project director. Project telephone conversations between IBC and outside parties shall be noted in handwritten memos and copies sent to Ms. Joffrey.

Progress reports shall be prepared by Mr. Wesley, IBC project manager, for presentation at monthly meetings to be held at MPD Co.'s Chicago office. Other meetings may require attendance by other individuals as required by MPD or requested by Mr. Wesley. Mr. Wesley shall also convene a mid-project review and a project summary at the MPD New York office. Fifteen meetings are included in the agreement. MPD will provide information and perform services on the project as follows:

1. Perform all elements of work associated with vacating the site prior to the date in the agreement for commencing of system installation.
2. Provide surveys, design criteria, drawings, and preliminary plans prepared under previous agreements or received through requests for proposals for the LOGON system.
3. Provide design criteria, drawings, and plans prepared for the automated parcel storage and retrieval system at MPD Co.'s Tulsa facility.
4. Obtain all internal, municipal, state, and federal approvals as may be necessary to complete the project.
5. Provide overall project management between MPD, IBC, and CRC Corp., and legal, accounting, insurance, auditing, and consulting services as may be required by the project.

The contract administrator is the operations manager. Changes or modifications to the agreement with MPD, requested either by MPD or IBC, shall be subject to a written proposal by IBC to MPD's contract administrator through IBC's project manager.

The financial manager is responsible for approvals of monthly expense summaries provided by INC and monthly payment to IBC. MPD is responsible for securing the necessary support from electrical and telephone utilities for system hook up and for making available to IBC all criteria, drawings, and studies prepared for the Chicago site facility and the Tulsa facility automated system.

III.5 Manpower and training

No additional manpower requirements beyond current staffing levels are envisioned to perform services for this project. Five personnel from IBC's design group have been enrolled in and will have completed a robotics seminar before the project begins.

III.6 User training

Two systems operations manuals and 16 hours of technical assistance will be provided. Thereafter, ongoing operator training will be the responsibility of MPD.

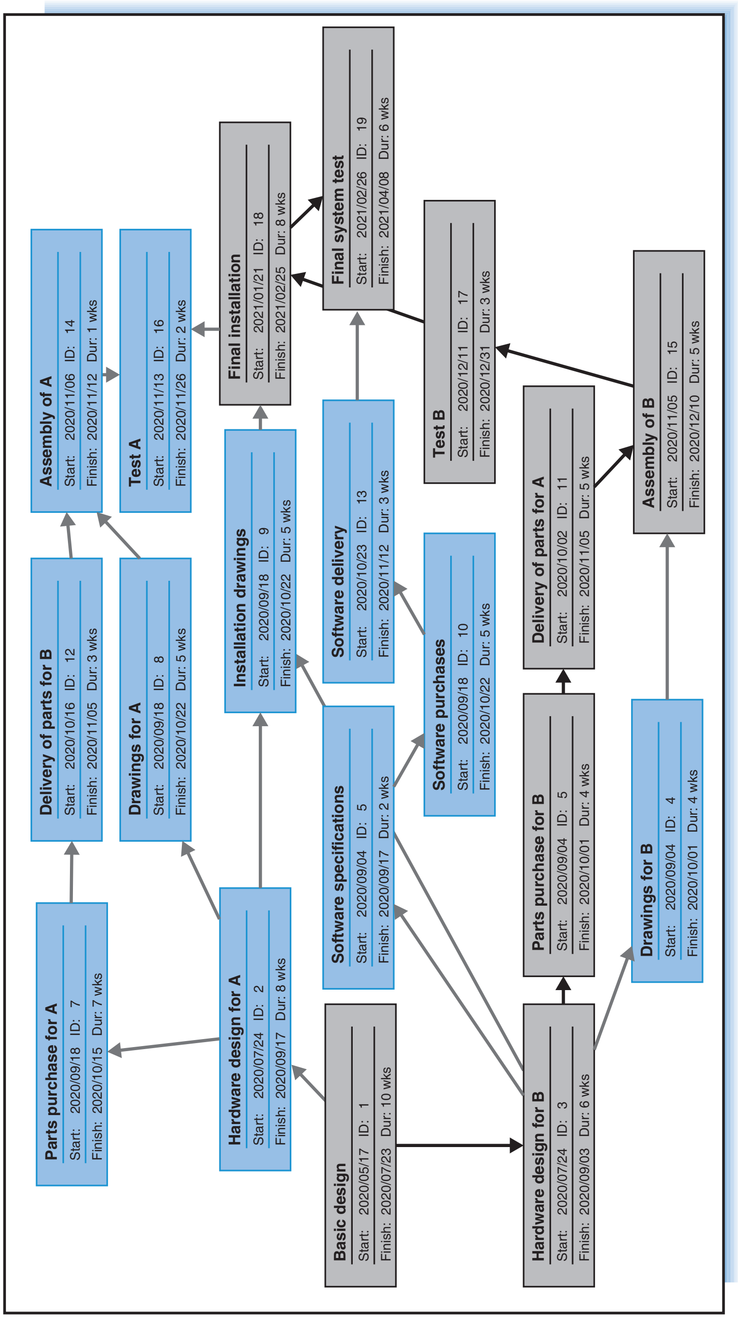
IV Technical section

IV.1 Statement of work and scope

The major tasks to be performed are the design, fabrication, installation, and checkout of the LOGON system for the Chicago distribution center of MPD Co. The work will be executed in accordance with the conditions set forth in the specifications in IBC's proposal and confirmed in the agreement.

Subtasks required to perform the major tasks are shown in Item 6 (letters refer to task designations on Item 6):

1. Perform basic design of overall system (H).
2. Prepare detailed design specifications for robotic drone transporter, storage rack systems, and shipping and parcel containers to be sent to CRC, SEI, and UPC (J, I, M, N).



Item 6
Principle project tasks.

3. Prepare specifications for the software and DEM-LAN and CRC 4000 system interface (L).
4. Prepare detailed assembly drawings for robotic drone transporter units and storage rack system (O, K).
5. Prepare drawings and a master plan for system installation and test (P).
6. Fabricate seven robotic drone transporter units and rack support subassemblies at IBC facility (U, V).
7. Perform functionality tests on all transporter units at IBC facility (X).
8. Perform structural and functional tests on rack systems at IBC facility (W).
9. Perform installation of all subsystems at MPD Chicago facility site (Y).
10. Perform subsystems checkout and overall system final checkout at MPD site (Z).

IV.2 Schedule and calendar

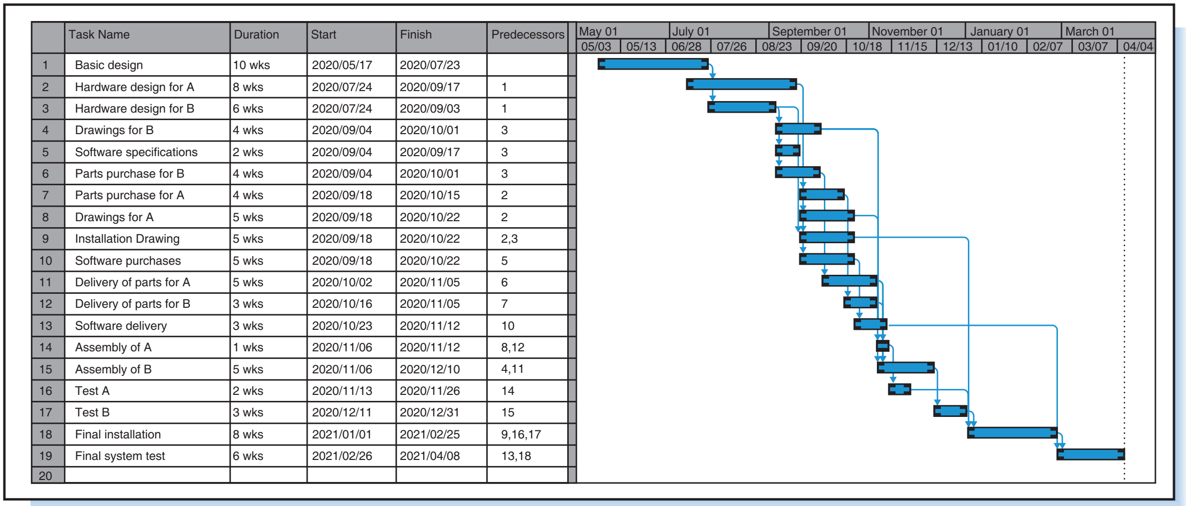
The project will commence with basic design on or before May 11, 2020; installation at the site will begin on or before January 10, 2021; and final system approval by MPD Co. will be on or before May 2, 2021. The schedule for significant aspects of the project is in Item 7. The indicated milestones are:

1. Commence basic design	May 11, 2024
2. Basic design review	July 26, 2024
3. Transporter and conveyor design review	September 6, 2024
4. Computer system specs review	September 20, 2024
5. Hardware group A and B review	November 29, 2024
6. Begin installation at site	January 10, 2025
7. Final user approval	May 2, 2025

Starting dates for activities dependent on the results of formal reviews will be adjusted to allow for significant changes in the length of predecessor activities, although no adjustments are anticipated.

Work package instructions and a detailed schedule for basic design have been distributed. Subsequent schedule and work package information will be distributed and discussed at review meetings.

The schedule of contract deliverables is given in Section IV.9.



	Task Name	Duration	Start	Finish	Predecessors
1	Basic design	10 wks	2020/05/17	2020/07/23	
2	Hardware design for A	8 wks	2020/07/24	2020/09/17	1
3	Hardware design for B	6 wks	2020/07/24	2020/09/03	1
4	Drawings for B	4 wks	2020/09/04	2020/10/01	3
5	Software specifications	2 wks	2020/09/04	2020/09/17	3
6	Parts purchase for B	4 wks	2020/09/04	2020/10/01	3
7	Parts purchase for A	4 wks	2020/09/18	2020/10/15	2
8	Drawings for A	5 wks	2020/09/18	2020/10/22	2
9	Installation Drawing	5 wks	2020/09/18	2020/10/22	2,3
10	Software purchases	5 wks	2020/09/18	2020/10/22	5
11	Delivery of parts for A	5 wks	2020/10/02	2020/11/05	6
12	Delivery of parts for B	3 wks	2020/10/16	2020/11/05	7
13	Software delivery	3 wks	2020/10/23	2020/11/12	10
14	Assembly of A	1 wks	2020/11/06	2020/11/12	8,12
15	Assembly of B	5 wks	2020/11/06	2020/12/10	4,11
16	Test A	2 wks	2020/11/13	2020/11/26	14
17	Test B	3 wks	2020/12/11	2020/12/31	15
18	Final installation	8 wks	2021/01/01	2021/02/25	9,16,17
19	Final system test	6 wks	2021/02/26	2021/04/08	13,18
20					

Item 7
Project schedule.

IV.3 Budget and cost

The price of the contract is $14,520,000, fixed fee with limited escalation, based on a target final approval date of May 2, 2025. Expenses and fees will be billed and are payable monthly as incurred. The agreement provides for an escalation clause tied to inflation indices for material expenses for the steel rack support system. A penalty of $10,000 a day will be imposed on IBC for target completion overruns. Contingency arrangements in the agreement allow for reconsideration of the penalty in event of disruption of work for labor disputes.

Principal tasks, subtasks, man-hours, and dollars to perform them have been estimated. Total expenses, as tabulated in Item 8, for labor, overhead, materials, subcontracting, and general/administrative are $13,140,270.

Expenditures of direct labor are under immediate control of department heads in design, fabrication, procurement, and customer service departments because they assign personnel to the project.

The project manager is responsible for man-hour and direct expenses and will receive biweekly reports of time and money expenditures.

IV.4 Information requirements

Most of the information required by IBC to perform under the terms of the agreement has been supplied by MPD Co. A limited amount of site information will be obtained from additional surveys performed by IBC. MPD will assist in survey work to expedite the project.

IV.5 Documentation and maintenance

Functional managers will send biweekly expense and progress reports to the project manager. The project manager will send monthly project summary reports to functional managers and to other managers and supervisors listed in distribution.

Cost, performance, and progress documentation will be maintained and reported through the company project cost accounting system.

The project manager will prepare a final summary report for IBC and MPD company archives.

The project manager is responsible for maintenance of all project files. All copies of project documents sent outside IBC will leave only under his direction.

IV.6 Work review

Internal review of work produced in each of the design, fabrication, procurement, and customer service divisions is a responsibility of the division head for each of the functional disciplines.

IV.7 Applicable codes and standards

Storage racks and supporting structures, electrical harnesses, and radio transmitters are to be designed to the applicable standards of AATOP, ASMER, OSHA, the Illinois Building Requirements Board, and the City of Chicago.

IV.8 Variations, changes, contingencies

The agreement with MPD defines the conditions for considering a change in compensation or penalties due to a change in the scope of work or cost of steel-fabricated materials, or unanticipated stoppage of work for labor dispute. It describes the procedure whereby authorization for such a change may be obtained from MPD.

Item 8

LOGON project cost estimate.

Task	Labor time	Labor rate	Labor cost	O/H @ 0.25	Materials	S/C	G/A @ 0.1	Total
Project coordination	5,000	112	560,000	140,000				
	5,000	48	240,000	60,000				
		Total	800,000	200,000	20,000		102,000	1,122,000
Project development	1,000	112	112,0 0	28,000				
	1,000	80	80,000	20,000				
		Total	192,00	48,000	45,000		28,500	313,500
System design	125	112	14,000	3,500				
	375	96	36,000	9,000				
	375	48	18,000	4,500				
		Total	68,000	17,000	6,000	1,550,000	164,100	1,805,100
H Basic hardware	750	120	90,000	22,500				
	4,000	96	384,000	96,000				
	3,500	60	210,000	52,500				
		Total	684,000	171,000	54,100		90,910	1,000,010
I Hardware design A	450	104	46,800	11,700				
	2,750	96	264,000	66,000				
	2,250	60	135,000	33,750				
		Total	445,800	111,450	24,500		58,175	639,925
J Hardware design B	625	104	65,000	16,250				
	3,375	96	324,000	81,000				
	3,250	80	260,000	65,000				
		Total	649,000	162,250	61,500		87,275	960,025
K Drawings B	400	104	41,600	10,400				
	400	72	28,800	7,200				
		Total	70,400	17,600	57,400		14,540	159,940
L Software specs	400	112	44,800	11,200				
	600	96	57,600	14,400				
	600	80	48,000	12,000				
		Total	150,400	37,600	23,300	116,000	32,730	360,030
M Parts purchase B	5	112	560	140				
	40	96	3,840	960				
		Total	4,400	1,100	250	758,000	76,375	840,125
N Parts purchase A	10	112	1,120	280				
	50	96	4,800	1,200				
		Total	5,920	1,480	350	719,500	72,725	799,975

Item 8
(*CONTINUED*)

Task	Labor time	Labor rate	Labor cost	O/H @ 0.25	Materials	S/C	G/A @ 0.1	Total
O Drawings A	1,625	104	169,000	42,250				
	1,750	72	126,000	31,500				
		Total	295,000	73,750	85,800		45,455	500,005
P Installation drawings	1,125	112	126,000	31,500				
	1,500	104	156,000	39,000				
	1,750	72	126,000	31,500				
		Total	408,000	102,000	35,400		54,540	599,940
Q Software purchase	20	112	2,240	560				
	40	96	3,840	960				
		Total	6,080	1,520	1,600	717,500	72,670	799,370
U Assembly A	25	112	2,800	700				
	250	96	24,000	6,000				
	300	80	24,000	6,000				
		Total	50,800	12,700	64,000		12,750	140,250
V Assembly B	250	112	28,000	7,000				
	2,750	96	264,000	66,000				
	2,750	80	220,000	55,000				
		Total	512,000	128,000	87,000		72,700	799,700
W Test A	50	104	5,200	1,300				
	750	96	72,000	18,000				
	750	80	60,000	15,000				
		Total	137,200	34,300	47,000		21,850	240,350
X Test B	75	104	7,800	1,950				
	1,125	96	108,000	27,000				
	1,125	80	90,000	22,500				
		Total	205,800	51,450	70,000		32,725	359,975
Y Final installation	800	112	89,600	22,400				
	3,000	96	288,000	72,000				
	2,250	88	198,000	49,500				
		Total	575,600	143,900	121,000	105,000	94,550	1,040,050
Z Final test	500	112	56,000	14,000				
	2,500	96	240,000	60,000				
	1,500	84	126,000	31,500				
		Total	422,000	105,500	12,500	60,000	60,000	660,000
Totals			5,682,400	1,420,600	816,700	4,026,000	1,194,570	13,140,270

The agreement, Paragraph 9.2, under prime compensation, states:

Whenever there is a major change in the scope, character, or complexity of the work, if extra work is required, or if there is an increase in the expense to the CONTRACTOR for steel-fabricated materials as negotiated in the agreement with the responsible SUBCONTRACTORS, or if there is a stoppage of work resulting from a labor dispute with management, the CONTRACTOR shall, upon request of the CLIENT, submit a cost estimate of CONSULTANT services and expenses for the change, whether it shall involve an increase or a decrease in the Lump Sum. The CLIENT shall request such an estimate using the form provided herein (Attachment F). Changes for reasons of labor dispute with management will be reviewed and determined according to the conditions specified (Attachment G).

During system installation and tests, MPD has made arrangements to reroute 70 percent of its Chicago parcel business to other centers. The remainder will be stored at an alternative facility near Chicago. In the event of a schedule overrun, the reroute plan will remain in effect. MPD requires 30 days' notice of anticipated schedule overrun to extend the agreement with the alternate Chicago storage facility.

IV.9 Contract deliverables

All items are to be assembled, installed, and in operation at the site in accordance with technical specifications in the agreement.

Subcontractors will transport components and parts to the IBC plant per dates:

Item	Date
Parts and components for robot transporters from CRI	November 1, 2024
Parts and components for storage rack systems from SEI	November 4, 2024
One shipping container and one each of three sizes of parcel buckets from UPC	November 10, 2024
Robotic drone transporter system control software from CRC	October 25, 2024

Following are the items identified in the agreement as deliverable to MPD:

Item	Date
Hardware (group A)	
Seven storage racks, 7′ × 15′ × 85′ (D × H × L)	November 15, 2024
Installed at site	
Final structural, functional checkout	November 29, 2024
Delivered 400 shipping containers installed at site	December 6, 2024
Delivered 1,000 size D43A parcel buckets	December 13, 2024
Delivered 600 size D25B parcel buckets	December 13, 2024
Delivered 600 size D12C parcel buckets	December 13, 2024
Hardware (Group B)	
Seven robot transporter units (each 80 pounds maximum load capacity compatible with three sizes of parcel buckets)	
Installed at site	November 8, 2024

Item	Date
Seven-unit functional checkout	November 10, 2024
Integration checkout, groups A and B	January 3, 2025
Software Group	
Submission of software specifications to CRC	September 19, 2024
(Installation of DEM-LAN network, four CRC 2950 workstation terminals, and CRC 4000 server, performed by CRC)	February 7, 2025
Software-integration checkout, performed by CRC	March 7, 2025
Final checkout	
Two copies, system operation/maintenance manuals	March 7, 2025
Robotic drone transporter/CRC 4000 integration	April 4, 2025
Benchmark systems test, with parcels	April 8, 2025
User training	April 11–12, 2025
Final system checkout, user	Latest, May 2, 2025

Index

Note: Numbers in *italics* indicate figures and in **bold** indicate tables on the corresponding pages.