"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."

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"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.

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Project Management for Engineering, Business and Technology

SIXTH EDITION

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Loyola University Chicago

Herman Steyn
University of Pretoria

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

To Karen and Janine
H.S.

Brief Contents

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.

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John M. Nicholas
Herman Steyn

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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.

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.

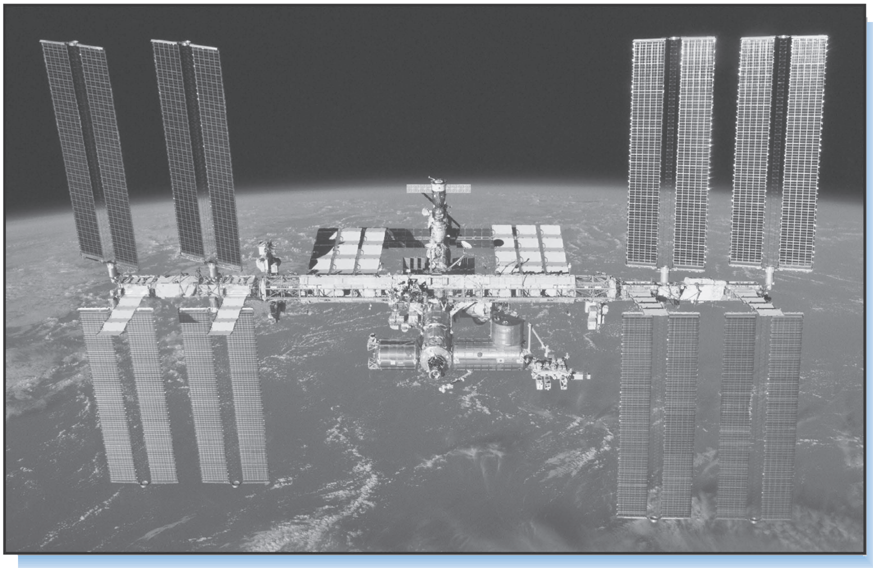

Figure I.2
The International Space Station, a modern large-scale project.
Source: Photo courtesy of NASA.

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.

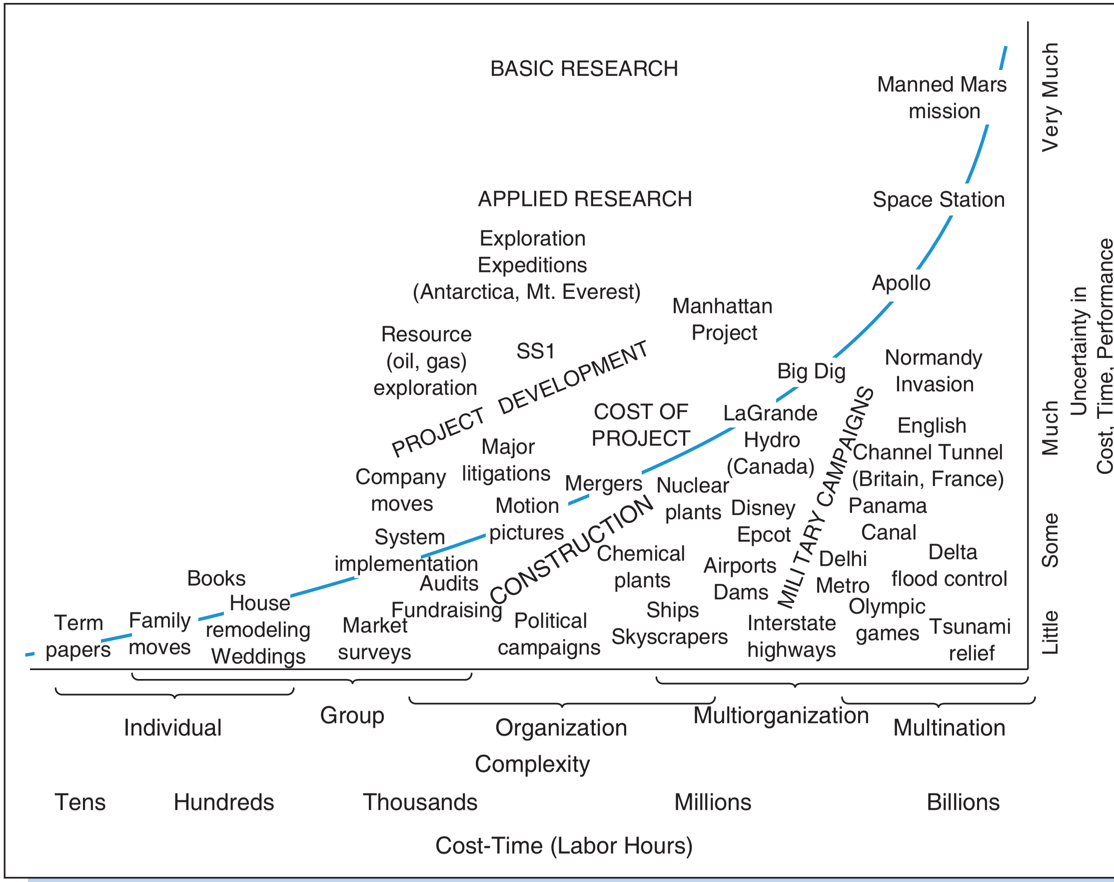

Figure I.3
A typology of projects.

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.

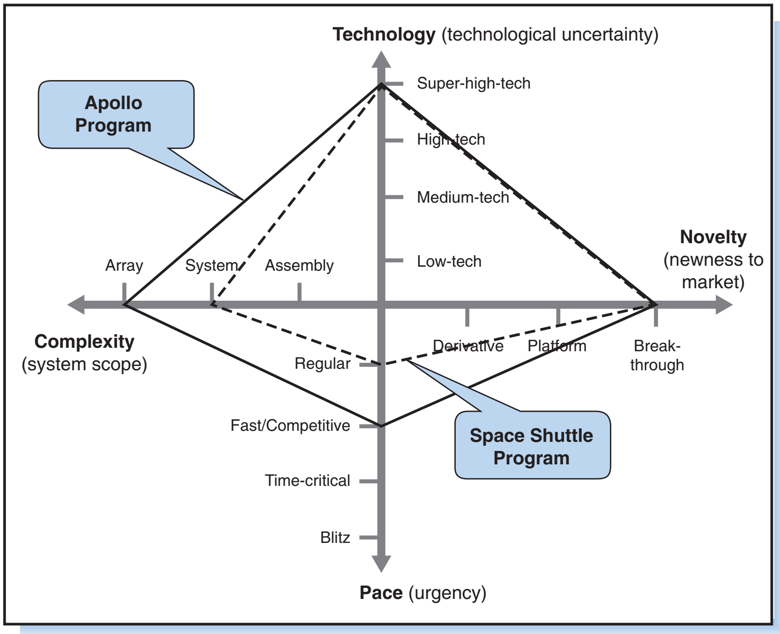

Figure I.4
Shenhar and Dvir's NTCP diamond model contrasting the Apollo and space shuttle programs.
Source: Shenhar A. and Dvir D. *Reinventing Project Management: The Diamond Approach to Successful Growth and Innovation*. Cambridge, MA: Harvard Business School Press; 2007.

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.

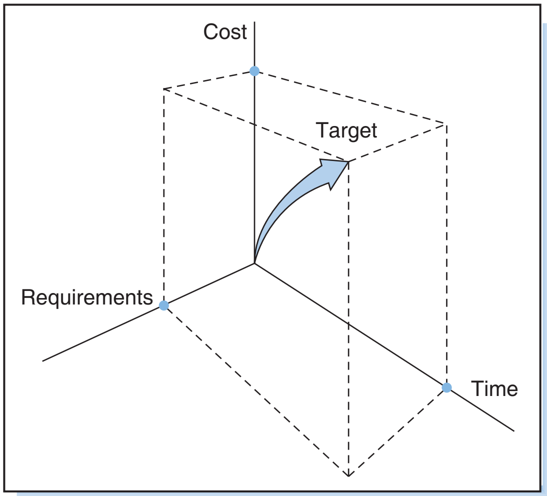

Figure I.5
Three-dimensional project goal.
Source: Adapted from Rosenau M. *Successful Project Management*. Belmont, CA: Lifetime Learning Publications; 1981, p. 16.

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.

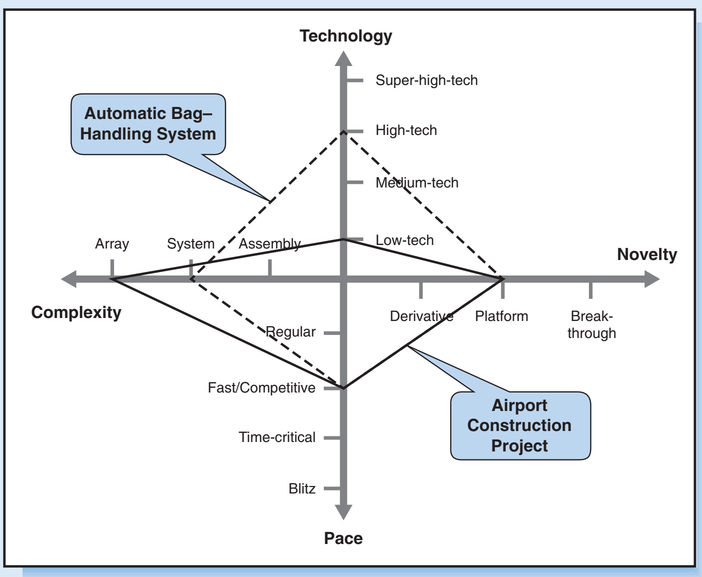

Figure I.6
"Diamond" profiles for the Denver Airport and for the baggage-handling system.
Source: Shenhar A. and Dvir D. *Reinventing Project Management: The Diamond Approach to Successful Growth and Innovation*. Cambridge, MA: Harvard Business School Press; 2007.

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

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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.

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 Apollo*, Chapters 2–5.
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.
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.
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.
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.
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.

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.

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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.
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.
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