PROJECT INTERFACE MANAGEMENT

Reducing Risk on Major Projects

Michael J. Bible and Susan S. Bivins

J.ROSS
PUBLISHING

ISBN-13: 978-1-60427-130-0

Printed and bound in the U.S.A. Printed on acid-free paper.

10 9 8 7 6 5 4 3 2 1

Library of Congress Cataloging-in-Publication Data

Names: Bible, Michael J., 1966- author. | Bivins, Susan S., 1941- author.
Title: Project interface management : reducing risk on major projects / by
Michael J. Bible and Susan S. Bivins.
Description: Plantation, FL : J. Ross Publishing, Inc., [2018] | Includes
index.
Identifiers: LCCN 2018025761| ISBN 9781604271300 (hardcover : alk. paper) |
ISBN 9781604278026 (e-book)
Subjects: LCSH: Portfolio management. | Risk management.
Classification: LCC HG4529.5 .B533 2018 | DDC 658.4/04—dc23 LC record
available at https://lccn.loc.gov/2018025761

Direct all inquiries to J. Ross Publishing, Inc., 300 S. Pine Island Rd., Suite 305, Plantation, FL 33324.

Phone: (954) 727-9333
Fax: (561) 892-0700
Web: www.jrosspub.com

Contents

Preface

BACKGROUND

As an interesting and dynamic supersystem, the modern world continues to evolve and change to meet the demands, needs, and desires of its people while dealing with the ever-increasing challenges of sustaining our planet and minimizing our impact on the global environment. Technological advancements are permeating all facets of modern life, feeding an insatiable appetite for better, faster, cheaper. Safe and comfortable automobiles are no longer adequate. Rather, we need automobiles that are safe, comfortable, and drive themselves. Safe and fast air travel is no longer the standard. Rather, it is our ability to stay *connected* continuously while traveling. Coupled with increasing demands from an ever-growing and changing population, it is natural to expect this complexity to seep into projects.

Projects exist to create a result. Often, this *result* takes the form of a *system* to be used directly or indirectly to meet the needs, demands, or wants of the population. Whether the system is a new phone, automobile, airplane, space capsule, or online service, the projects undertaken to deliver these systems are becoming increasingly complex. The reasons are simple. First, systems created by these projects are becoming more complex as a result of technology and materials used to develop them; people want products that are lighter, more durable, and last longer. Often this requires the use of specialized equipment to develop the product. Second, requirements for what the system or product should deliver to the user are becoming more complicated. For example, we don't just want a phone, but a phone that takes photos and video, can connect to the internet anywhere in the world, function as a recording device, and even one that creates a virtual reality environment; in essence, a simple phone is no longer the standard; rather it must function more like a small personal computer with many times the power and capacity of yesteryear's supercomputers, yet with miniaturization unimaginable just a few decades ago. Such demands result in more complicated system architectures and project development approaches that require collaboration by myriad specialized entities; all of these factors contribute to geometrically increasing complexity in the project environment.

Many of the projects undertaken today are large-scale undertakings, and many are megaprojects, commonly defined as complex projects that cost $1 billion (U.S.) or more, take years to design and build, and involve multiple public and private stakeholders. They are deployed in the areas of infrastructure, oil and gas, mining, aerospace, defense, major events such as the Olympic Games, or massive information technology projects. It is not uncommon to hear the term *gigaproject* or even beyond, *the teraproject*, as we begin to comprehend giant projects costing $1 trillion (U.S.). According to Bent Flyvbjerg, a professor at the University of Oxford's Saïd Business School, megaprojects have grown explosively and now constitute eight percent of the global gross domestic product, and most are poorly executed. The "iron law of megaprojects," he wrote in a 2014 paper in the *Project Management Journal*, is that they are "over budget, over time, over and over again," (Flyvbjerg, 2014). Nine out of ten megaprojects experience cost overruns, and most take much longer to build than expected. What results, Flyvbjerg says, is the "survival of the un-fittest": the least deserving projects get built precisely because their cost-benefit estimates are so misleadingly optimistic (Flyvbjerg, 2014).

Edward Merrow states that in 2010, 65% of projects with budgets over one billion in U.S. dollars do not meet their business objectives, and most are unprofitable (Merrow, 2011).

Whether they are megaprojects or simply large-scale complex projects, their long planning horizons defy the common project management concepts of deterministic schedules, costs, risks, and assumptions. Cost overruns are large and benefit shortfalls are common. Virtually all major capital projects involve complex interfaces among diverse stakeholders and various contractors. The multiple stakeholders often have conflicting objectives; system interfaces are often complex and fall between or among stakeholder organizations without sufficient definition or management. In addition, many of these stakeholders have no direct contractual relationships, yet they share critical system interfaces that may mean the difference between great success and exceptional failure.

Interface management is an emerging discipline that aligns critical interactions among project management, systems engineering, and the organization's operations management to reduce risk and enhance the chances of successful system design and development, completion, and transition to the operation of major capital projects. As projects increase in scale and become more technically and contractually complex, there is a growing need to systematically identify, document, and manage technical, project, organizational, and industry interfaces to ensure effective system integration and adherence to project constraints (e.g., cost; schedule; scope; quality; and health, safety, environment, and security (HSES) requirements; etc.) while meeting stakeholder expectations and industry regulations.

The successful completion of complex projects requires synergy between technical and management personnel to complete the project scope of work and deliver a system that meets the need of the project sponsor. The multiple stakeholders often have conflicting objectives—system interfaces are often complex and fall between or among stakeholder organizations without sufficient definition or management. According to Merrow, the task of managing large complex projects "is a task centered around the effective management of the interfaces. The interfaces are opportunities for conflicts and misunderstandings to occur. They are the places where things tend to 'fall between the cracks,'" (Merrow, 2011).

Interface management performs a critical function by providing a systematic process for facilitating and managing information flow across shared boundaries by independent project and organizational entities without a contractual or functional relationship. Interface management is the mechanism by which these entities reach agreements associated with system interfaces and establish a common understanding along shared boundaries—preventing unexpected system integration problems late in project development.

ABOUT THIS BOOK

The purpose of this book is to assist organizations that are undertaking complex projects by helping project personnel and interface management professionals understand, implement, and effectively manage interfaces for large complex capital projects. It provides a holistic view of interface management that includes people, processes, tools, and techniques that work together to allow teams from multiple organizations to reduce project risk that is endemic to such large complex capital projects; much of this risk arises from the need to effectively manage and deliver numerous interfaces between and among multiple entities that may or may not have contractual obligations to one another. The book is offered as a practical reference guide to be used to:

- Familiarize project and organizational personnel with the scope of interface management to ensure a consistent and shared understanding of roles and responsibilities,

- Provide practical guidance for the implementation of a project interface management program that incorporates proven practices in a variety of domains, and
- Describe ways to effectively and efficiently manage interfaces during project execution that minimize the risk of rework during integration.

CONTENT AND ORGANIZATION

The book contains nine chapters and is structured sequentially with each chapter designed to build upon the previous one. Chapters 1 and 2 establish the foundation for understanding organizational strategy, the need for projects, and how complexity impacts project development. Chapters 3, 4, 5, and 6 describe the basics of interface management and the concepts underlying the interface management function. Chapters 7, 8, and 9 focus on the practical application of interface management during the project life cycle with an emphasis on sharing best practices.

Chapter 1 provides an introduction to organizational strategy and establishes the basis for why organizations undertake projects. Chapter 1 also prepares the context for interface management by providing a brief review of human history. This brief examination helps us to fully appreciate the incredible rate of change over recent history. The chapter also briefly describes portfolio management, project management, and systems engineering, including an overview of types of project development approaches. These project approaches often set the stage for the necessary interfaces because of the acquisition and contracting strategies employed. Understanding how projects are structured plays an important role in understanding how to apply interface management in a project environment. Chapter 2 presents a discussion of complexity and how complexity affects project development. Understanding the factors contributing to complexity can help in comprehending the need for interface management as an important means of reducing risk and enhancing the probability of project success.

Chapters 3 and 4 introduce interface management and the processes used to manage interfaces. Chapter 3 provides an introduction to interface management and describes key terms, definitions, and concepts. As expected in an emerging field, there are many alternative definitions, terminology, and meanings that sometimes conflict with one another. This chapter establishes a basis of common understanding of the concepts used throughout the book. Chapter 4 describes the interface management process and the interface life cycle. This description is not peculiar to a specific project environment, but rather is a generic process that can be tailored to any project environment.

Chapters 5 through 9 collectively address how to plan, implement, manage (execute), and close out interface management and the interfaces themselves. Chapter 5 discusses the interface analysis process and describes how to begin to decompose the necessary interfaces, forming the basis for interface planning. In Chapter 6, the authors discuss the interface planning process and describe how to develop a project interface management system (i.e., plans, procedures, personnel structure, tools, training, etc.). In essence, this chapter describes how to establish an interface management system appropriate to the project's interface complexity.

Chapter 7 builds upon Chapter 6 and focuses on how to implement the interface management system as actual project execution, or construction, commences. Implementing any management system in a large-scale complex project can be a challenge. Chapter 7 offers guidance and best practices suggested to implement interface management effectively and efficiently and to ensure a *fast start*.

Chapter 8 describes how to manage interfaces during project execution and discusses interface activity as project execution work gets under way and proceeds. This chapter takes a pragmatic approach to typical situations that might occur during project execution and describes how to address these situations. Finally, Chapter 9 describes how interface management supports technical compliance and interface integrity, including the interface verification process and interface close-out. This chapter completes the interface management cycle and illustrates how the intense interface activity during project execution concludes as various parts of the system are integrated and verified, and helps to ensure that the project result is delivered to expectations.

AUDIENCE

This book is not intended to replace existing project management processes or international systems engineering practices. Rather, it is aligned with and supports both the Project Management Institute (PMI) Project Management Body of Knowledge (PMBOK) and the International Council on Systems Engineering (INCOSE) Systems Engineering Handbook while focusing on the processes, roles and responsibilities, and activities associated with effective management of system interfaces during project development. More important, this book demonstrates how interface management not only simplifies system interface complexity between independent parties, but also aligns project management and systems engineering domains to break down barriers that might otherwise create delays, excessive cost overruns, and unnecessary integration risk.

This book provides a road map to effectively design, develop, implement, and manage a tailored project interface management process in a relatively short period of time. In addition to decomposing the process into easily understandable and logical steps, the book also identifies specific tools, techniques, and resources needed to support the process, together with examples throughout. With the guidance, engagement, and support of upper management, and reasonably effective project and program management infrastructure, any organization can implement its own interface management process, make better decisions, and increase its chances of achieving effective development and integration of complex interfaces. People whose organizations are already using interface management might think about how to use the concepts in this book to supplement or improve existing processes.

The book is also intended for use as a textbook in an interface management course within graduate and upper level undergraduate business and engineering degree programs. It provides a road map for students to understand interface management through the application of tools and techniques, using a defined process. By structuring the text to coincide with the logical progression of the interface management process and illustrating tools and techniques to use along the way, students will obtain a clear understanding of the emerging discipline of interface management.

SOFTWARE TOOLS

It is not the intent of the authors to endorse one software product over others. However, we do make it clear that effectively managing project interfaces is difficult or impossible without the right tools. On large-scale complex projects, the sheer volume of interface items and the depth and breadth of inter-entity relationships indicate the need for a specialized software solution for both management and reporting of progress on interfaces. In relevant chapters throughout the book, we use illustrations from Kongsberg's Seaflex Web Interface Register (WIR) (km.kongsberg.com) to illustrate the concepts presented. In Appendix B, we use Coreworx Interface Management (CIM) (coreworx.com) software to illustrate similar concepts. A number of other software products are available on the open market, including, but not limited to, Omega Pims Interface Management (omega.no) and Aconex Interface Management for Construction (aconex.com). Readers are encouraged to explore these and other relevant products to assess their capabilities with respect to specific interface management needs.

To enhance learning and provide you with hands-on experience in the processes described in the book, we feel that instructors and readers should be able to use a tool to practice the concepts provided in the book. As a result, the authors have entered into an agreement with Kongsberg to allow instructors who are using the book as a textbook along with their students who are also using the book, six-month temporary limited access to Kongsberg Seaflex WIR. In addition, the agreement allows individual readers who purchase new copies of this book from authorized distributors limited access to predefined projects.

Instructors and individual book purchasers may contact Kongsberg to sign up by navigating to https://www.interfaceregister.com/imbook.aspx. The terms of use are described and you will be asked to provide contact and login information and to verify that you are eligible to use the software. After registering, instructors will work with Kongsberg to arrange access for their students in accordance with the Instructor Guide that is provided as part of the WAV™ material of this book (found at www.jrosspub.com/wav).

Please note that the authors and the publisher have no other commercial arrangement with Kongsberg or any other software offer with respect to this book, do not receive payment for the use of, and provide no express or implied warranty for these software tools. Rather, this agreement was made solely for the purpose of allowing instructors and students the opportunity to use an interface management software tool and individual readers to access predefined projects in order to maximize the learning experience and reinforce the concepts presented in this book.

REFERENCES

Flyvbjerg, B. (2014). What You Should Know About Megaprojects and Why: An Overview. Project Management Journal, Vol. 45: pp. 6–19. doi:10.1002/pmj.21409, John Wiley & Sons, Ltd. Retrieved from http://dx.doi.org/10.1002/pmj.21409.

Merrow, E. W. (2011). *Industrial Megaprojects–Concepts, Strategies, and Practices for Success*. John Wiley & Sons, Hoboken, NJ, USA.

Acknowledgments

We wish to thank Kongsberg for allowing us to use the Seaflex Web Interface Register software tool to illustrate concepts in this book. The use of this tool enhances our ability to reinforce key principles and concepts. The authors would also like to thank Coreworx Inc. for providing illustrations and descriptions from the Coreworx Interface Management module in Appendix B of the book. These illustrations help to show the reader alternate ways of structuring and managing the interface register.

We also wish to express our sincere appreciation to Thomas Rivrud of Kongsberg and Kelly Maloney of Coreworx for reviewing early chapter drafts and providing feedback based on their experiences in numerous real-world projects representing multiple industries. Both Thomas and Kelly have extensive experience in supporting large-scale complex projects, and their input certainly enhanced the content of this book.

We are especially grateful to our families; Susan's husband, Jim Bivins, and Michael's wife and son, Hege and Ethan Bible. Throughout this project they provided unfaltering support for our efforts and made sacrifices to allow us time to focus on this project. Thank you, Jim, Hege, and Ethan! We could not have accomplished this without all of you.

About the Authors

Michael J. Bible, PMP, CSEP, MSPM, IPMA-A, ESEP, MSSE, has over 30 years of professional and leadership experience supporting major programs and projects in the United States Department of Defense and the Norwegian Oil and Gas industry. Mike is a project management and systems engineering professional with a successful history of applying project portfolio, project management, and systems engineering in large-scale complex project environments.

During his career, Mike has worked with several large corporations including URS (AECOM Corporation) and Scientific Application International Corporation (SAIC) on several large defense programs and projects including the Army's Mine Resistant Ambush Protected (MRAP) program and several Marine Corp Engineering Systems programs and projects. In addition, Mike served as a senior advisor to multiple, large-scale offshore oil and gas projects in the Norwegian Continental Shelf (NCS). Mike is a long-time member of the Project Management Institute (PMI) and the International Council on Systems Engineering (INCOSE) and has been honored to be a guest speaker at numerous PMI events including the Global Congress North America.

A retired United States Marine Corp officer, Mike earned a Master of Science in Project Management (MSPM) from George Washington University and a Master of Science in Systems Engineering (MSSE) from Johns Hopkins University. Mike currently lives with his wife and son in Trondheim, Norway, and can be reached at mb1775@gwu.edu.

Susan S. Bivins, PMP, MSPM, has more than thirty years of management and leadership experience dedicated to delivering successful information technology, organizational change management, and professional consulting services projects for major global corporations. She specializes in project and portfolio management; international, multicultural, and multi-company initiatives; and business strategy integration in the private and public sectors.

During her career with IBM, Sue managed multiple organizations and complex projects, including operations and support for the Olympics, and a strategic transformational change program. Since retiring from IBM, she has led multi-company joint initiatives with Hitachi, Microsoft, and Sun Microsystems (Oracle), and has served as Director of Project Management at Habitat for Humanity International.

She earned her MSPM from the Graduate School of Business at George Washington University, where she received the Dean's Award for Excellence and was admitted to the Beta Gamma Sigma business honorarium. A member of the Project Management Institute, she served on PMI standards teams, has authored several journal articles, and is a frequent webinar and conference speaker, including multiple presentations for the PMI Global Congress North America. Sue currently lives with her husband in St. Louis, Missouri, USA, and can be reached via e-mail at sbivins@gwu.edu.

This book has free material available for download from the Web Added Value™ resource center at *www.jrosspub.com*

At J. Ross Publishing we are committed to providing today's professional with practical, hands-on tools that enhance the learning experience and give readers an opportunity to apply what they have learned. That is why we offer free ancillary materials available for download on this book and all participating Web Added Value™ publications. These online resources may include interactive versions of material that appears in the book or supplemental templates, worksheets, models, plans, case studies, proposals, spreadsheets and assessment tools, among other things. Whenever you see the WAV™ symbol in any of our publications, it means bonus materials accompany the book and are available from the Web Added Value Download Resource Center at www.jrosspub.com.

Downloads for *Project Interface Management: Reducing Risk on Major Projects* consist of:

MATERIALS FOR ALL READERS

Figures and Tables

All figures and tables from each chapter are provided to be used in presentations or instructor teaching material with appropriate attribution.

Excel Workbook for Set-Up in Interface Management Software

This Excel workbook contains set-up sheets for the sample project that can be used to establish the sample Project Diamond interface management projects in the interface management tool for which temporary access has been granted to readers.

Project Document Templates

These documents established for the sample company ABC Corporation and sample Project Diamond can be used as templates for project and interface documents on real projects and include:

- ABC Management of Project Development
- Project Diamond Mandate
- Project Diamond Execution Plan
- Project Diamond Interface Control Document

INSTRUCTOR MATERIALS

In addition to the materials available for all readers, the following instructor-only materials are available.

PowerPoint Slide Deck for Each Chapter

A generic PowerPoint slide deck is provided covering the material in each chapter, including overview, content, and summary slides. The slides can be downloaded and tailored by the instructor or included with other lecture materials.

Instructor Guide

An Instructor Guide for a one-semester graduate course is provided. It contains example course objectives, course description, suggested subject/topic and student deliverables for each session, sample mid-term exam questions, sample final exam questions, suggested weekly discussion topics, description of class project, and information about contacting Kongsberg to obtain access to Seaflex WIR interface register tool for instructors and students. Of course, instructors may tailor the outline to reflect different course durations and add additional required or recommended readings, grading policies, meeting times, instructor information, logos, etc.

Other Benefits and Materials

As time permits, the authors and other interface management professionals are available to respond to occasional questions or discussion points from instructors using the book for their classes, for brief guest presentations, and for introductory interface management briefings.

From time to time, additional or updated materials may be provided for instructors, readers, or both. Updates will be identified in descriptions of the WAV materials, the Instructor Guide, and on the publisher's website. At present, we are considering developing a series of short videos to complement the textbook material with the authors' and other interface management professionals' real-world experiences. We anticipate making them available starting in late 2019.

1

Accelerating Change and the Context for Projects

"Life is really simple, but we insist on making it complicated."
—Confucius

"Project management is the science of project planning combined with the art of reacting to surprises during execution."
—Edward W. Merrow

While this book is about interface management, a short detour is taken to provide a historical perspective on the rise of human society, the accelerating pace of change, and the increasing magnitude of people-driven endeavors that will help us understand why the need for interface management in modern projects has evolved and why it will continue to occupy a place of importance in future projects. Modern life has changed rapidly during the information age mainly through technological breakthroughs, leading to advancement in virtually all facets of human life. Project interface management is driven by three main factors: complexity, communication, and people. These factors represent happenings in society. It is natural, then, to realize that projects and how they are developed, will change as society changes. Recognizing accelerating change and its inevitable impact on complexity helps explain the emerging need for new project management disciplines, such as interface management, to increase the likelihood of completing projects successfully.

An important aspect of understanding what interface management is and how to apply it on large complex capital projects is that of understanding the context for why and how these projects are undertaken in the first place—meaning we need to know why the project was selected and how it contributes to creating value for the entity undertaking or sponsoring such projects. So, in addition to the historical perspective, this chapter also provides a synopsis of the portfolio management, project management, and systems engineering (SE) milieu in which these projects are conceived and carried out. This chapter also provides an overview of why these projects are undertaken by organizations and the context in which they are performed, describes distinguishing factors of large-scale capital projects, discusses how the contract strategy influences project complexity (and certainly interface management), and provides insight into strategic decisions that will eventually mold the management system that will be used to manage the project.

It is often stated that "it is hard to see the forest when you're standing among the trees." This book is as much about the future of managing large-scale projects as it is about the present—but we need some historical background. How did we get here? To understand this basic question, we need to step away from the trees and take a brief look into our (mankind's) past. So, briefly, we go back to the beginning—a simpler time in human life—and reflect upon how we humans got to the point of requiring such systems and management processes. This brief look into human history provides a perspective on how slowly things changed in earlier times and how rapidly modern society is changing now, thus forming the basis for complexity in modern projects.

1.1 BRIEF HISTORY OF SOCIETAL EVOLUTION

While anthropologists are divided on when the genus *Homo* emerged, it is estimated that the first members of the human family (hominids) lived in Africa between six and seven million years ago, and spread to Europe and Asia about two million years ago. Early *modern* humans of the genus *Homo* species *sapiens* (*Homo sapiens*, or us) evolved in East Africa approximately and arguably 200,000 years ago, based on evidence from fossils found in Kenya and Ethiopia. Life for our early ancestors was nomadic, undoubtedly difficult, and focused on foraging, hunting, and surviving threats. Other earlier species of hominids such as Neanderthals (*Homo neanderthalensis*) lived alongside *Homo sapiens*, developing crude tools and harnessing fire, until becoming extinct. Of the six known species of humans (Harari, 2015), we *sapiens* are the only survivors.

1.1.1 Prehistory

Prehistory (the time before human language was developed sufficiently to capture it) is classified today into three discrete periods based on the types of artifacts and materials used—the Stone Age, the Bronze Age, and the Iron Age (Thomsen, 1836).

From about 2.5 million years ago to 14,000 years ago, the Stone Age was in full swing, a prehistoric period in which hominids used stone to make tools. The Stone Age is divided by some sources into the Paleolithic and Neolithic periods (Kulper, 2015) with the Paleolithic period humans leading nomadic lives as hunters and gatherers, and with the later Neolithic period humans discovering agriculture and domestication of animals, which allowed them to settle in one place (DifferenceBetween.net, 2011).

The Bronze Age ushered in the use of metals in tools and implements and is thought to have begun first with the creation of small precious objects from copper, and subsequently, with the creation of copper tools and weapons. Later in the Bronze Age, the true bronze alloy of tin and copper was used. The Bronze Age also fostered increased specialization of human skills and the invention of both the wheel and the ox-drawn plow (Kulper, 2015). Along with specialization, these inventions contributed to greater urbanization and the creation of social order (Metropolitan Museum of Art, 2017).

The Iron Age came later, beginning about 3,000 years ago when humans learned to heat and forge iron, which made way for more permanent settlements (Encyclopedia Britannica, 2015). Weapons forged of iron also armed large battle forces and enabled the migration of peoples that changed Europe and Asia over the next 2,000 years (Encyclopedia Britannica, 2015).

1.1.2 Beginning of History—the Cognitive, Agricultural, and Scientific Revolutions

Approximately 70,000 years ago, while *Homo sapiens* spread from Africa throughout Europe and East Asia, fictive language emerged (Gale, 1971) and history began. Harari identifies three revolutions that have shaped history—the Cognitive Revolution, which began about 70,000 years ago; the Agricultural Revolution, which began about 12,000 years ago; and the Scientific Revolution, which began only about 500 years ago (Harari, 2015).

During the Cognitive Revolution period, humans invented boats, oil lamps, needles for sewing, and bows and arrows (Harari, 2015). The same period shows evidence of art, religion, and social orders thought to be driven by dramatically increased cognitive function. It took a few thousand more years to develop kingdoms, early polytheistic religions, and money.

During the Agricultural Revolution, humans domesticated plants and animals, enabling the formation of permanent communities (Harari, 2015). About 5,000 years ago, the two early civilizations of Mesopotamia and Egypt were established (Gascoigne, 2001). Mesopotamia, on the land between the Tigris and Euphrates rivers, had rudimentary civil services and laws to protect people from one another, while ancient Egypt in northeastern Africa stretched along the fertile soils of the Nile river valley. Both civilizations used early forms of writing—cuneiform in Mesopotamia and hieroglyphs in Egypt. The Agricultural Revolution saw the rise of the first kingdoms, money, and religions. Over 2,000 years ago, the Han Empire in China, the Roman Empire around the Mediterranean, and Christianity all rose and flourished. Some other monotheistic religions arose earlier (Judaism) and later (Islam).

In just the last 500 years, humans have driven the Scientific Revolution by admitting our ignorance and striving to not just maintain the social order and status quo, but to "discover new medications, invent new weapons, and stimulate economic growth" (Harari, 2015). It also led to the development of weapons "not only to change the course of history, but to end it" with respect to nuclear weapons. Harari points out the astounding growth in human power (not to mention complexity) by pointing out that a peasant who fell asleep in the year 1000 AD could awaken in the year 1500 without missing a beat, but one who fell into a similar sleep in the year 1500 would have a rude awakening by "the ringtone of a twenty-first century iPhone" (Harari, 2015) and would find a world beyond comprehension. This statement by Harari is important as it illustrates an increasing rate of change over these two time periods.

1.1.3 The Growth in Human Power During the Scientific Revolution

According to Harari's research, in the last 500 years the human population has increased 14-fold (from 500 million to about 7 billion), production has increased 240-fold (as measured by the total value of goods and services produced by humankind, which has grown from $250 billion to $60 trillion in today's U.S. dollars), and energy consumption has increased 115-fold (as measured by calories of energy per day, from 13 trillion per day to 1,500 trillion per day) (Harari, 2015). In his book, Harari cites several examples of the acceleration of the rate of change. One of those examples is that, "Prior to the sixteenth century, no human had circumnavigated the earth. This changed in 1522, when Magellan's expedition returned to Spain after a journey of 44,000 miles. It took three years and cost the lives of almost all the crew members, Magellan included. In 1873, Jules Verne could imagine that Phileas Fogg . . . might just be able to make it around the world in eighty days" (Harari, 2015). By contrast, he points out, at present an individual can safely and easily travel around the world in 48 hours or less.

Of course, rather than having his own ships or balloons, the present-day traveler relies on the infrastructure of airlines and terminals, the technology of aircraft and air traffic control, the educated and highly skilled people who staff them, and the governments, markets, and societies that regulate and support them. In other words, the rate of human growth and societal change is accelerating at an ever-increasing pace, as is the complexity of living with these changes. The simple fact is that humanity has come a long way in a relatively short time, beginning with tens of thousands of years at a relatively languid pace, and continuing with fierce acceleration in more recent times. Progress begets change and it also begets complexity. In many ways, modern humans are struggling to adapt to the rapid rate of change.

1.2 IMPLICATIONS OF ACCELERATING SOCIETAL CHANGE

Human civilization has experienced a rate of change unimaginable by ancient humans. This rate of change is driven by advances in technology and science, along with the drivers of modern civilization. As Harari points out, although some may believe that science and technology hold the answers to all of our problems, science and technology must be ". . . shaped by economic, political, and religious interests" (Harari, 2015). It is governments, businesses, and other entities that have funded the scientific breakthroughs and innovations that have extended our life expectancy and perhaps, too, our quality of life.

1.2.1 Creating a Complicated Modern Civilization

These governments, businesses, religious, and other organizations, guided by their ideologies, determine what to fund and even what the future will contain; they allocate funds among the conflicting objectives and priorities of communities of life on earth. While continuous invention and innovation have given us modern conveniences and longer lives, they have also yielded massive population growth, ever-shifting demographics, peril for many cohabitant species of our planet, and explosive rates of change. They have also created a complicated or even complex modern civilization.

While we humans have, in general, progressed, the complication in modern society is evident in all parts of our lives—from the food we grow, to the way we travel, to how we communicate, etc. As societies, some of us have many choices (and complications) arising from the vast options we have about how to live our lives, even where we choose to live. Others in less developed nations and parts of the world are not as fortunate. It is reasonable to suggest that the world will continue to become even more complex with increasing populations, the development of new products with the advancement of technology, and the desire by governments and organizations to improve the quality of life for its citizens. Undoubtedly, projects will continue to be a part of the evolution of humans, but we need to recognize the rapid change that has occurred in the recent history of humanity and how this change has affected projects—more important, how it will continue to affect projects going forward into the future.

Modern society grapples with issues associated with the pace of change, as is evident in global opportunities to increase the application of robotics and artificial intelligence, while at the same time dealing with the basic need to dramatically increase global food production to keep pace with population growth facing environmental phenomena that threaten to reduce the capacity to do so. Projects, which are a major means of achieving positive change, also struggle with the forces of change. They too must adjust to the rapidity of change and how to properly handle complexity resulting from it. As evidenced by the almost universally high rate of large-scale project delays, overruns, and failure to fully achieve the operational results for which they were undertaken, we as project professionals in various industries have not been fully able to adapt to the rate of change and growth of complexity; meaning that often, project organizations are ill-equipped to effectively manage complex projects—often because of things we don't know that we need to know.

1.2.2 Evolving Layers of Complexity in the Systems We Create

The rapid advances in technology, especially over the past 30 years, have afforded humans incredible opportunities to share information through countless media, affecting the way we conduct communication. Face-to-face conversations have often been replaced by social media, and classroom learning by online self-paced and sometimes non-communal education—thereby making us alone in a crowded place. The ability to conduct real-time dialogue and video with anyone, virtually anywhere, also gives us the wherewithal to conduct business in real time across geospatial and cultural boundaries. In terms of technology, modern society has an insatiable appetite for more—more functionality, more capability, more everything. This affects the products people buy and use in everyday life and how we live.

Individuals and organizations create a perpetually escalating demand for new and improved products and services. Often, these products and services interact with other products and services, creating layers of complexity related to integrating new systems with existing or even other new systems. The challenges will be compounded by continued population growth, political conflicts, and environmental impacts—requiring even more advanced solutions. Given that the rate of change and evolution of societies will likely continue to accelerate, organizations will need ever-better management systems to address them and thus remain relevant and competitive. Thoughts of stand-alone systems operating independently are becoming the modern unicorn in an increasingly connected world where one system operates as part of an interconnected supersystem.

1.3 DEVELOPING THE STRATEGY

The modern global marketplace will continue to evolve to meet the needs, demands, and desires of a growing global population in search of a higher living standard and longer and higher quality of life. Companies and organizations providing those products and services are also subject to change and complexity. As a result, these companies and organizations continually innovate to improve the effectiveness and efficiency of existing products and services in order to remain competitive, and they also invent new products and services in order to meet a growing global demand. This is evident in everyday life products, such as our mobile phones, for example, where a single device is used for numerous functions: telephone, camera, voice and video recorder, texting, etc. (even tracking the steps we take in a day), that only 20 years ago required several devices in order to perform the same functionality and tasks, or that we couldn't perform at all. In recent decades, especially since the 1980s, we have experienced an increase in the global marketplace where companies and organizations can reach across countries and continents to identify suppliers, vendors, and manufacturers to aid in developing new products and services, creating product and system development possibilities that were not available only a few short decades ago.

Every organization exists for a purpose, which typically includes providing services and products to support customers and clients. Whether government agencies or multinational corporations, organizations undertake strategies to identify a long-term plan that hopefully leads to the achievement of organizational success factors: hiring more people, capturing a greater proportion of a particular market share, higher share price or earnings per share, providing more efficient services, etc. While a strategy does not guarantee a road map to organizational success, developing (and revising) a strategy demonstrates deliberate and careful decisions about what the organization should do in the future to remain successful. The process of establishing an organizational strategy is important in the rapidly changing global marketplace; poor strategic decisions certainly can lead to the demise of the organization, particularly when those decisions are based on faulty assumptions or fail to anticipate future changes in a complicated marketplace. These decisions ultimately and ideally result in the types of projects sanctioned, among other organizational activities.

In the book *Mastering Project Portfolio Management*, Bible and Bivins (2011) provide an appropriate analogy to explain the importance of strategic direction. In Lewis Carroll's *Alice's Adventures in Wonderland*, Alice comes to a crossroads in the *Pigs and Pepper* scene and is uncertain as to which direction she should go. In a nearby tree, she notices the Cheshire cat and asks the cat which way she should go. The cat responds, "That depends a good deal on where you want to get to." Alice replied that it really didn't matter. The cat replied, "Then it doesn't matter which way you go."

"Unlike Alice in Wonderland, an organization must have a destination in mind that leads to success and a proper road map to get there. In today's competitive environment, an organization must take the best road that leads to continued relevance, prosperity, and success. No easy task given the rapid rate of societal change. This is the purpose of strategic planning" (Bible and Bivins, 2011). An organization's strategy is driven by its mission, values, goals, and objectives. Its mission answers the questions "why are we here?" and "what is our purpose?" or "what do we do?" The vision is a fast-forward to some stated future time frame of how the world (or at least the portion of it affected by the organization's mission) will be if they succeed in the execution of the mission. An organization's values are shared beliefs that drive its people's behaviors; that is, they describe how employees or other stakeholders are to conduct themselves with respect to each other and other stakeholders. Values are often accompanied by a set of behaviors that describe each of the values. Goals and objectives state what is to be accomplished. When they are decomposed, they become more specific and time bound. The objectives are to be achieved within the mission, to be delivered in keeping with the organization's values, and to move the organization toward achieving its vision. With amazing rates of change all around us, of course, strategy must not remain static—it must be as agile as the environment in which it is developed.

A strategic plan allows an organization to (1) identify its aspirations and how it will attain them in order to stay relevant in the marketplace; (2) communicate, clarify, and align its commitments around the long- and short-term goals, and (3) provide consistent guidance for decision making, resource allocation, budget planning, and training (Urbanick, 2008). The essence of the strategic plan is to attain an organizational state in which everyone shares a common vision of what the organization wants to achieve in the future, understands what is required to achieve that vision, and is motivated to contribute to the organization's success.

In many large organizations, strategic planning is conducted at the corporate level and based on the corporate plan each group or division in the organization's hierarchy may perform its own strategic planning process, albeit at a more tactical level appropriate for the subset of corporate goals it supports. Ideally, these plans will roll up to form an integrated whole, and roll down so that the goals and objectives at the lower level and the initiatives undertaken all support the corporate strategy.

The organization's objectives are accomplished (or should be) by selecting and managing the optimal combination of projects that drive the organization's achievement of its strategy—that is the meaning of project portfolio management (PPM). We included this brief description of strategic planning to reinforce the importance of strategy to the PPM process and ultimately to the reasons why we perform projects. Projects, and more specifically, portfolios of projects and programs, are central to the achievement of organizational goals and objectives. The goals and objectives are the strategy, which, in turn, is key to the continued relevance and success of the organization.

1.4 INTRODUCTION TO PROJECT PORTFOLIO MANAGEMENT

PPM is an iterative process linking the strategic objectives of the organization to selecting and managing the right project portfolios. The less a project contributes to accomplishing an organization's goals and objectives, the less value it creates and the more resources are wasted or at least inefficiently utilized. To better utilize resources and achieve desired outcomes, organizations are becoming more concerned about which projects to undertake in the first place, which has led to a more formal process called PPM. Harvey Levine (2005) defines PPM as ". . . a set of business practices that brings the world of projects into tight integration with other business operations. It brings projects into harmony with the strategies, resources, and executive oversight of the enterprise and provides the structure and processes for project portfolio governance." The Project Management Institute (PMI) more broadly defines PPM as ". . . the coordinated management of portfolio components to achieve specific organizational objectives" (PMI, 2008). Bible and Bivins (2011) also suggest that PPM is a flexible, responsive, and iterative process to select and execute the right projects that maximize achievement of the organization's strategic goals and objectives subject to physical, political, financial, and other resource constraints.

The PPM process can be thought of as the actionable management process necessary to achieve the organization's strategic objectives through project portfolio selection, implementation, monitoring and control, and evaluation. PPM is not the same as enterprise project management or management of multiple related projects as the name might imply. A project portfolio is a group of projects selected and executed specifically because together they best help an organization to achieve its objectives. The objectives are the lowest level output of the strategic planning process, which produces the organization's mission, vision, goals, and the objectives that support each goal.

The fundamental task of PPM is selecting a portfolio of projects that maximizes the achievement of those objectives while achieving balance among, and coverage of, the objectives. Although effective PPM contributes to the achievement of organizational objectives, it is not the only source of achievement. The organization's ongoing business operations also contribute to the achievement of objectives as we will discuss later in this section. Every organization is resource constrained. An effective PPM process provides the structure to make reasoned trade-offs about how the resources should be allocated to maximize potential benefits. Thus, sound decision making through a disciplined and methodical process is a crucial attribute of an effective PPM process. Through such a process, the organization can make rational decisions as to how best to employ constrained resources across objectives to maximize the benefits of its project portfolios.

The foundation of the organization's PPM process is laid during the development of the strategic plan, which identifies the organization's destination and a road map to achieve desired future outcomes. The result of the PPM process is the selection and implementation of a group of projects, which are intended to achieve specific strategic objectives. Modern projects require management systems and processes to increase the likelihood of success; resulting in the rapid rise of project management and the adoption of formal project management tools, techniques, processes, and systems.

1.5 INTRODUCTION TO PROJECT MANAGEMENT

Project management is at least as old as the Great Pyramids so it predates the Scientific Revolution that began only 500 years ago. While the roots of project management extend to ancient times, only within the last half century has formal project management gained wide acceptance and traction in many organizations. Business and government agencies have become more aware of the need to manage projects using formal practices and processes to ensure greater project success, i.e., "doing the work right" (PMI, 2008). Meredith and Mantel provide three primary reasons to explain the emergence of project management ". . . (1) the exponential growth of human knowledge, (2) the growing demand for a broad range of complex, sophisticated, customized goods and services, and (3) the evolution of worldwide competitive markets for the production and consumption of goods and services" (Meredith and Mantel, 2006).

These reasons have not gone unnoticed. In 2016, U.S. President Barack Obama signed the Program Management Improvement and Accountability Act aimed at enhancing accountability and best practices in project and program management across the U.S. federal government. Throughout the United States' Department of Defense (DoD), there is an ever-growing emphasis on program and project management as acquisition personnel design, develop, and procure hundreds of billions of dollars of advanced military equipment. The DoD's Defense Acquisition University (DAU) is dedicated to formally training and educating personnel in defense acquisition program and project management and establishing standards for program management career field certification (DAU, 2010). Expanding beyond the DoD, the U.S. National Aeronautics and Space Administration established the Academy for Program/Project and Engineering Leadership and many leading corporations have established project management training programs and project, program, or portfolio management offices (PMOs) to develop project, program, and portfolio management methodologies tailored to organizational needs. Similar advances have occurred in other parts of the world, in, for example, the United Kingdom's Cabinet Office, which supports the British Prime Minister and Cabinet. The ever-growing emphasis on project management can also be illustrated through the expansion of project management professional certification from PMI.

Founded in 1969, PMI has grown to several hundred thousand members internationally with a "primary goal to advance the practice, science, and profession of project management throughout the world in a conscientious and proactive manner so that organizations everywhere will embrace, value, and utilize project management and then attribute their successes to it" (PMI, 2010). APMG International also provides certification training and examinations and accredits professionals in multiple disciplines, including project, program, and portfolio management. Not only do organizations want to complete projects successfully by *doing the work right*, they also want to successfully complete the *right* projects. Completing projects on time and within budget has little to no value if projects fail to contribute to the successful achievement of the organization's strategic objectives.

1.5.1 Defining Project Management

As defined by Harold Kerzner, "Successful project management can then be defined as achieving a continuous stream of project objectives within time, within cost, at the desired performance/technology level, while utilizing the assigned resources effectively and efficiently, and having the results accepted by the customer and/or stakeholders" (Kerzner, 2017). In essence, a project is a temporary endeavor to create a unique product, service, or result (a *system* for example) (PMI, 2008). The temporary nature of projects indicates that a project has a beginning and an end. Although considered *temporary*, project durations may equate to several years in some large-scale complex project developments, such as military weapon systems, enterprise information systems, offshore oil and gas processing facilities, etc.

The part that occurs between the beginning and the end of a project, in this book, is called the project development process. The project development process is defined by various project development *phases* such as: conceptual design, detailed engineering, procurement, fabrication and construction, transportation, installation, mechanical completion, and commissioning. In some organizations, procurement, fabrication, construction, transportation, installation, etc., may be grouped together and called execution. Different organizations and industries may call them by slightly different names, and different sets of contractors and ultimate end users may sometimes cause the names of the phases to be different, but the example should suffice to present the concept of development phases. As the project progresses through each development phase, various project management processes are used to initiate, plan, execute, monitor, and control, and close the related project work. Every industry, organization, and project is different, and the method used to develop the project will vary accordingly. Regardless, each project will follow a general development approach consisting of some form of engineering, procurement, and construction (EPC). In essence, we need engineering to design thoroughly the *result* of the project (engineering design), build or commercially procure (order and receive) material and equipment (procurement), and finally, assemble those items into the final system (construction). It is normal for this cycle to repeat itself through several project phases, or stages, until the final system is completed.

1.5.2 Balancing the Project Constraints

Managing projects requires constant focus on the scope of work and completing the work on time (i.e., as scheduled) and within budget while meeting quality and safety expectations. Ideally, the scope of a project is precisely defined early. By knowing the scope of work, the effort required (resources multiplied by time) can be accurately estimated, leading to an approximate cost to complete the project. In addition, knowing the scope of work allows for planners to optimize the work so that the activities are defined and resources are applied to complete the activities in the most efficient sequence, resulting in the schedule to perform the work. The foundation (but, of course, not the only factor) for an effective schedule is the amount of confidence in the scope of work—the greater the confidence in the scope of work, the better. Precise knowledge of the scope of work and what is required generally translates to less risk than a situation in which the scope of work is not well understood or defined. (Of course, in getting from concept through detailed design, such schedule and cost estimates become more definitive and less variable, or less stochastic and more deterministic. However, large-scale complex projects often overrun even those estimates. Reducing those costly overruns and under-delivery experiences are a major purpose of interface management.) This basic principle of scope certainty affects many aspects of managing projects and the system used to monitor and control project work. Ultimately, the goal of project management is to complete all defined project work with high quality according to the schedule, without overspending or getting anyone hurt (i.e., safety). The impact of risk and the ability to manage risk certainly affect the outcome of this goal.

This book is not intended to provide the reader a detailed examination of project management—there are many books on that subject. Here, we simply want to state that a central challenge in project management is to have a high degree of certainty about the scope as early as possible in the project. Knowing exactly what the project is to produce increases the chances of delivering the project successfully, assuming good management and safety practices during the project development process. Unfortunately, it is rare to have such certainty early in the project. In fact, *changes* (expected and unexpected) are common in all types of projects, large and small, which result in more work, extra cost, and increased time. The main point is that a *dependent relationship* exists among cost, schedule, and scope (also quality and safety). As scope increases, cost will increase and more time will be added to the schedule; requiring more quality and safety management. The simple question then is, why can't we always be certain about the work that needs to be completed by the project?

Several factors affect a project's success and management's ability to control scope, schedule, cost, quality, and safety. Naturally, as project complexity increases, the difficulty in managing the project increases. In Chapter 2, we will discuss the topic of complexity in more detail since complexity has a direct impact on project interface management. However, a project to build a single-family home is not the same in terms of complexity as a project to build a 150-story skyscraper. Building a single-family home, while still a project, is more like a *process* than a *project*, especially when using preconfigured blueprints—millions of homes have been built over the last decades and the technology has remained relatively stable. Comparatively, not many 150-story skyscraper buildings are being built. Such buildings incorporate technology and safety control systems exceedingly more advanced than those in single-family homes, and each one is unique. Thus, a 150-story skyscraper construction project is larger in scale and size, more unique, and more technologically complex than a project to build a traditional single-family home, making a skyscraper much more difficult to manage than a single-family home project. Add to that the fact that the forces of weather and other phenomena have an impact not only on construction schedule, but on the design as well. The uniqueness, scale, size, and complexity of such a project impacts the project team's ability to manage and control scope, cost, schedule, quality, and safety.

1.5.3 Rapid Change in Projects

While project management is a relatively new management discipline, it is greatly affected by the rapid rate of societal and global change. Here, project management is affected in two ways: (1) by the increasingly complicated project development approaches offered by a relatively new global marketplace and (2) by the complex systems resulting in rapidly changing technologies that projects must produce. The world has become a much more connected (technologically and physically) global society, allowing for greater flexibility for project developments and increased capability and functionality of the systems produced by projects.

The opening of the global marketplace through numerous trade agreements has resulted in opportunities for all participants, but while these new markets provide greater access, they have also resulted in complicated project development approaches. Organizations and companies are now able to select vendors, suppliers, fabricators, constructors, engineers, etc., from a global versus local marketplace, creating more opportunities for project sponsors to leverage global technologies, capabilities, and competencies. Essentially, the world is the global supermarket where the best products and services can be acquired for the cheapest price (albeit not always the most safe, the best quality, or morally acceptable). As expected, organizations that are sponsoring projects, especially large-scale projects, have the opportunity to subdivide a project's scope of work into several *parcels* and contract to global companies (vendors, suppliers, etc.), reaping the economic and business benefits of such a strategy.

In addition, the systems being created by the project continue to increase in complexity as a result of continued rapid technological advances, enabling constant opportunities to improve existing products and services and create new products and services with greater capabilities and functionality. The never-ending consumer requirement for *faster, better, cheaper* creates a competitive cycle to *one-up* business competitors in hopes of retaining or expanding market share in a particular market; this means organizations constantly search for a balance between the lowest price and the most product functionality and performance. Later in this chapter, we discuss this topic further; the main point here is to recognize that projects are changing rapidly as the world around us changes.

More precisely, projects are becoming more complicated because the systems developed by projects are increasingly more complex and so is the way we develop projects. In this book on project interface management, we provide a systems approach mentality to illustrate strategies for simplifying complexities and complication, such that it can be managed effectively. First, we focus on large-scale capital projects as they tend to fall in categories of higher complication and complexity. With this focus, we are not suggesting that interface management is only applicable to large-scale projects; on the contrary, interface management is applicable to any projects that have explicit or implicit interfaces. However, these large-scale capital projects do provide very good examples to illustrate the concepts in this book to those who may not be familiar with interface management. Clearly, these concepts can also be translated to less complicated and complex projects characterized with a high number of system interfaces and/or a complicated development approach.

1.5.4 Just a Few Words on Benefits Management

We mention benefits management here because, although it has always been necessary, it has only been recognized and practiced widely and explicitly during the past decade or two. Managing strategic benefit starts with opportunity identification and then the establishment of the business case. It is managed throughout the project life cycle and beyond. Surprisingly, many organizations stop measuring at just the time that real benefits begin to accrue. The actual benefits accrue to the sponsor or the end user, but the practice of benefits management has often been relegated to the project management level, where it can't possibly be managed. The likelihood that a project under development continues to promise the strategic benefit for which it was selected is a strategic issue and should be managed at that level. Once the project begins to deliver those actual benefits, assessing and tracking them against strategic expectations belongs to the sponsor or strategic portfolio or program management office, which will own and manage benefits long after the project ends.

Like interface management, benefits management is an emerging discipline. Steve Jenner in *Managing Benefits* defines a benefit as "The *measurable* improvement from change, which is perceived as positive by one or more stakeholders, and which contributes to organizational (including strategic) objectives." He defines benefits management as "the identification, quantification, analysis, planning, tracking, realization, and optimization of benefits" (Jenner, 2014). PMI defines a benefit as "an outcome of actions, behaviors, products, or services that provide utility to the sponsoring organization as well as to the program's intended beneficiaries (PMI, 2013). Levatec says that ". . . benefits are provided to a sponsoring organization *and* to intended beneficiaries; both are worthy of mention" (Levatec, 2014). For the first time, the PMI Pulse of the Profession survey in 2017 looked at levels of *benefits realization maturity* as one of the measures of project success, and stated that "the traditional measures of cost, scope, and time are no longer sufficient" and that it is time for projects to deliver the benefits for which they were selected (PMI, 2017).

As large complex projects sometimes overpromise and under deliver, it is worth noting that we need to be wary of obstacles we face in forecasting, particularly cognitive biases. Lovallo and Kahneman in *Harvard Business Review* argued that forecasters suffer from "delusional optimism: we overemphasize projects' potential and underestimate likely costs, spinning success scenarios while ignoring the possibility of success." Stephen Jenner wrote an excellent article on this subject in the *PM World Journal* (Jenner, 2012). In addition to cognitive bias, it may be wise to be wary of deliberate overstatement of benefits in order to achieve funding for major projects.

1.6 INTRODUCTION TO LARGE-SCALE CAPITAL PROJECTS

The term large-scale capital projects can be quite misleading and open to interpretation. In this book, the term *large-scale capital project* is characterized to mean a project requiring several hundred million, or billions, of U.S. dollars, requiring multiple years for project development and characterized by several organizations or entities contributing to project development. The authors' intention is not to precisely define *exactly* what does or does not constitute *large-scale*, but rather to provide a visual context and allow subjectivity to help categorization. Essentially, these projects tend to cost a considerable amount of money, require a small army of people and organizations to help with development (i.e., several hundred or thousands), and extend in duration over a long period of time (i.e., several years). Large-scale projects are highlighted because they tend to perform poorly as factors contributing to complexity are not well understood and/or not managed effectively.

Merrow identifies special challenges for megaproject teams that include geographic dispersion, integrating joint venture partners that "beg for no one to be in charge," and interface management (Merrow, 2011). In more than thirty years of studying megaprojects, Merrow says, "Most of the big mistakes that companies make in developing and executing these projects stem from a basic lack of being able to pursue a common goal with clarity and good behavior" (Merrow, 2011). Some of these mistakes come from greed, failure to understand who has the risk, failure to shape the opportunity and specify the governing principles of the contract or deal, and inappropriate actions to reduce cost—these projects fail at an "alarming and unsustainable rate." We would add failure to manage interfaces to Merrow's list. Virginia Greiman, who served on Boston's *Big Dig* project as deputy chief counsel and head of risk management, has identified 25 characteristics of megaprojects that go beyond simply long duration and scale, including projects that have a long, complex, and critical front end; complicated financing schemes; dynamic governance structures; and are subject to public scrutiny and/or policymaking, among other factors (Greiman, 2013).

On a brighter note, as reported by the PMI Pulse of the Profession (2017), project performance has improved, but much work remains. The PMI 9th Global Project Management Survey stated, "For the first time in five years, more projects are meeting original goals and business intent and being completed within budget. There has also been a significant decline in dollars lost. Organizations are wasting an average of $97 million for every $1 billion invested due to poor project performance—that's a 20% decline from one year ago" (PMI, 2017). Of the industries included in the study, healthcare reported the highest average waste on project spending. A more detailed breakout of several key industries included in the study, ranked from highest to lowest, demonstrates the range of project waste:

- Healthcare $112 million per $1 billion
- Telecom $106 million per $1 billion
- Energy $101 million per $1 billion
- Manufacturing $98 million per $1 billion
- Government $97 million per $1 billion
- Financial Services $97 million per $1 billion
- Construction $94 million per $1 billion
- IT $78 million per $1 billion

Of the geographic regions covered in the study, PMI noted specific markets stood out. India reported the lowest average monetary waste on projects ($73 million per $1 billion), followed by both China and the Middle East ($82 million per $1 billion). Conversely, Europe reported the highest average waste on project spending at $131 million per $1 billion (PMI, 2017). Many infrastructure projects fall into the *large-scale* project category so we provide some discussion of these in the next section.

1.7 INFRASTRUCTURE EXAMPLES OF LARGE-SCALE COMPLEX PROJECTS

Infrastructure development is an ongoing concern for cities, states, and nations around the world. From wastewater treatment facilities, transportation systems, and major road systems to national electricity grids and telecommunication systems, infrastructure supports and enables all of the comforts and capabilities of the modern lifestyle. Improving and adding to productive infrastructure represents an investment in the future—supporting economic growth and helping to raise living standards over time. Some examples of modern large-scale infrastructure projects are described in the following paragraphs.

1.7.1 California High-Speed Rail

There are numerous ongoing major (large-scale) projects underway around the world. In the United States, the state of California broke ground on the *California High-Speed Rail* (CHSR) project in 2015 with an expected first stage development cost of $68 billion, which covers 520 miles between San Francisco and Los Angeles. Ultimately, the CHSR project will extend from Sacramento in the north to San Diego in the south. The system is designed for speeds up to 220 mph and a travel time of three hours from San Francisco to Los Angeles, which is less than half the driving time.

1.7.2 China-Pakistan Economic Corridor Project

The China-Pakistan Economic Corridor is a transportation and energy infrastructure project designed to link Kashgar in western China with Gwadar, a port city in Pakistan. Project plans include the construction of new roads and railways and the upgrade of existing transportation infrastructure. A substantial improvement of the Karakoram Highway, which travels over a 15,000-foot pass at the China-Pakistan border, is underway as of 2016, as are dozens of other transportation projects. China announced $46 billion in foreign direct investment and low-cost loans to bring the corridor to completion since it would provide faster access to markets in South Asia, the Middle East, and Africa.

1.7.3 Riyadh Metro (Rail & Bus) Project

The Riyadh Metro is an urban rail and bus transportation system under construction in Riyadh, Saudi Arabia. Construction began in 2013 and is expected to conclude by the end of 2018. Plans call for six rail lines traveling a combined 109 miles, in addition to a bus line network covering 715 miles. The project is designed to combat rising traffic congestion in a city expected to grow from 5.7 million people in 2014 to 8.2 million by 2030. The system will handle up to 3 million passengers per day. Construction includes 85 air-conditioned stations, 11 bridges, 16 miles of tunnels, and 21 park-and-ride facilities. Three international consortiums are handling the $22.5 billion project's design and construction. Major international firms participating in the project include the German engineering conglomerate, Siemens; the French rail transportation company, Alstom; and the Canadian transportation company, Bombardier. This does not include the complex network of sub-suppliers, vendors, and subcontractors.

1.7.4 Panama Canal Expansion Project

The Panama Canal, one of the most impressive modern infrastructure projects, is a shipping route connecting the Pacific Ocean with the Atlantic Ocean across the Isthmus of Panama. It utilizes a system of locks to raise ships about 85 feet above sea level to the shores of Gatun Lake in the middle of the isthmus. The Panama Canal Authority initiated construction on a $5.25 billion canal expansion project in 2007. The Panama Canal expansion project adds a third traffic lane to the canal and expands some existing canal channels. The new traffic lane and its locks will accommodate larger container ships equipped to carry nearly three times as many containers as the smaller ships, effectively doubling the canal's shipping capacity. The new traffic lane opened for business in 2017.

1.7.5 London *Crossrail* Project

The London *Crossrail* project is a capacity enhancement rail project centered on London. It involves the laying of a new 118 km rail track from Maidenhead and Heathrow in the west to Shenfield and Abbey Wood in the east. The project will allow an additional 1.5 million people to travel between London's key business districts in just 45 minutes. The world's first underground continues to grow, adding 26 miles of tunnel connecting 40 stations for quicker and more direct travel opportunities for travelers. The estimated cost of construction is $23 billion. The project is scheduled for completion in phases, with the first new track going into service in 2018 and all remaining tracks in service by 2020.

1.7.6 Large-Scale (Major) Infrastructure Project Summary

The aforementioned projects are only a small sampling of large-scale or major projects underway across the planet. Infrastructure projects are an example of how complexity affects large-scale projects in general. It's not just the sheer volume of equipment, people, materials, tools, regulations, and such, but the way these elements must interact over a long timeline to ensure various work activities are finished correctly and completely (and, of course, safely). The *Big Dig* project in Boston, formally named the Central Artery Tunnel project that rerouted a formerly elevated interstate highway through a 3.5-mile tunnel, built a bridge over the Charles River, and created a greenway in the space that was left by the former elevated highway, was one of the largest urban infrastructure projects ever undertaken in the United States. It also cost several contractors restitution fees. By its own reckoning, the *Big Dig* was "originally projected to cost $2.5 billion and was to be completed by 1998. Instead, the project cost $14.8 billion and was not completed until 2006" (Greiman, 2013). Nevertheless, it is not only a technical marvel, it has relieved transportation problems for millions in the Boston area, provided a series of parks and public spaces, and made Boston Logan International Airport much more accessible.

Modern railway and other infrastructure projects now incorporate highly advanced safety automation and control systems to ensure safety of operations—such as systems to signal, monitor, and control train operations as well as systems to provide comfort and safety to those using the rail system. These systems include everything from redundant emergency braking systems to efficient air (heat and cooling) systems.

Imagine life as a passenger on a train over 100 years ago that was rife with dangers—from the billowing smoke entering train cars from coal burning engines to trains that broke down constantly or failed to show up on time (or at all). Comfort was an option not afforded on early twentieth century trains, but is something taken for granted on modern rail systems. Modern train travel by comparison allows for a relatively inexpensive, safe, and comfortable method of modern travel. As seen from the infrastructure projects previously mentioned, transport projects continue to improve service, safety, and functionality for future passengers, but this example is recurring in all industries from defense to energy to telecommunications.

1.8 OVERVIEW OF PROJECT DEVELOPMENT STAGE-GATE PROCESS

Large-scale project developments are commonly guided by a deliberate decision-making process that examines the feasibility and progress of the project at specified points through a life cycle from idea to operation and ultimately through disposal. As mentioned, each project moves through a number of phases. For example, a feasibility phase, concept selection phase, evaluation/improve phase, execution phase, operation phase, and decommission and disposal phase. The aim of project development phases is to provide a structured road map to guide the project along its development. At the conclusion of each phase, a decision acts as the mechanism to enter the follow-on (or next) phase. In this way, the organization or project sponsor can evaluate progress, maturity, and continued relevance of a project. Project development processes, characterized by phases and decision points, provide a valuable mechanism to increase the likelihood of success and/or terminate project developments at the earliest point. Projects, especially large-scale developments, require extensive capital investments. Project development processes act as protection for capital investments by ensuring a process to make good decisions at predefined points in the project's development.

Early phases may focus on the feasibility of a particular project idea. During this phase, several concepts may be evaluated to ascertain if undertaking the project would result in value creation for the project sponsor. At the conclusion of the phase, a decision meeting is conducted to determine if the project should progress to the next phase. If successful, the project advances to the next phase, such as the concept selection phase where at the conclusion another decision meeting is performed. This process repeats itself until the project life cycle reaches an end, which may include termination during development or disposal after operation, for example. There are many different project development approaches, but all follow a similar process to the *stage-gate* process for new product development.

Dr. Scott J. Edgett and Dr. Robert G. Cooper developed the Stage-Gate® model to serve as a road map for effectively managing the process of new product development. The Stage-Gate® model is widely used to manage the idea-to-launch process (Cooper, 2011). Although originally devised for new product development, it has been adapted to project management and systems engineering projects across multiple industries, and is, in some circles, considered *de rigueure* for major capital projects. Figure 1.1 shows the Stage-Gate® model with sample phases and decision gates.

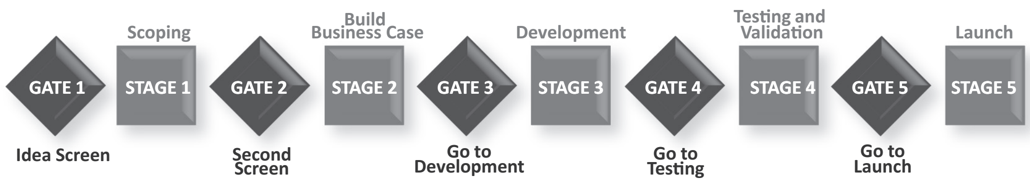

Figure 1.1 Stage-Gate Process. Stage-Gate® is a registered trademark of Stage-Gate Inc. (Used with permission from www.stage-gate.com.)

In the Stage-Gate® model, Dr. Edgett and Dr. Cooper describe a number of stages including: discovery (Stage 0), which is not shown; scoping (Stage 1); building the business case (Stage 2); development (Stage 3); test and validation (Stage 4); and launch (Stage 5). Between the stages, management decision points (gates) are established. Stages are where the action occurs and deliverables are developed. These deliverables then act as input to the decision-making process—at the decision gates—where the deliverables are measured against criteria; resulting in a decision output (i.e., go/no-go, hold, recycle, etc.).

The types of project development processes can vary between industries and between organizations within a specific industry. The choice of project development approach and the underlying project development process will affect a project's development in a good or not-so-good manner. Some development models may impose strict and expansive requirements that need to be met for each gate. Others may view such requirements as overly bureaucratic. Some project development processes may not provide sufficient structure, allowing for excessive free-form activity that could create problems with delayed manifestation later in the development process.

1.8.1 U.S. Department of Defense Project Development Example

Arguably, one of the most complex project development processes exists within the U.S. Department of Defense (DoD) to guide the department's system acquisition process. An overview of the process is illustrated in Figure 1.2, but a more comprehensive view of the process can be found at the DAU website (https://www.dau.mil/tools/t/Department-of-Defense-Acquisition-Life-Cycle-Chart). Granted, the DoD highly encourages tailoring the process for the specific nature of the project, but with such an expansive development framework, even the process of tailoring can be difficult. The

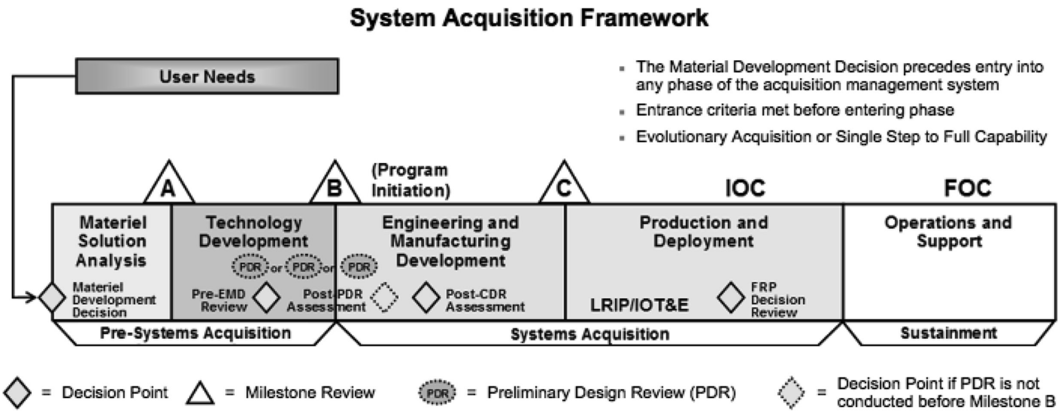

Figure 1.2 U.S. DoD *System Acquisition Framework*

DoD's *System Acquisition Framework* divides the acquisition process into *Pre-System Acquisition*, consisting of two phases (Material Solution Analysis and Technology Development), then System Acquisition (consisting of Engineering and Manufacture Development and Production System Deployment) and on to Sustainment (consisting of Operations and Support phases). *Milestones A, B, and C* act as *gates* between early phases with specific *decision points* embedded within the phases.

A deeper examination of the *System Acquisition Framework* reveals a network of stringent guidance requirements within each phase, including mandatory technical activities, major deliverables/products, inputs and outputs, etc. Many of the systems acquired by the DoD must integrate into an existing mission-oriented architecture, creating a maze of system interfaces between the system being acquired and the existing architecture with which the system is to be integrated.

1.8.2 Oil and Gas Industry Project Development Example

In comparison to the U.S. DoD System Acquisition Framework, a typical oil and gas project development process shown in Figure 1.3 seems quite basic and follows a less complicated project development approach. As is the case with the DoD's acquisition framework model, the oil and gas industry's project development process follows a prescribed path while providing management decision points before the start of each phase.

In a typical oil and gas project development, the *appraise* phase begins with a hydrocarbon discovery. This phase screens identified options for technical and commercial viability and establishes

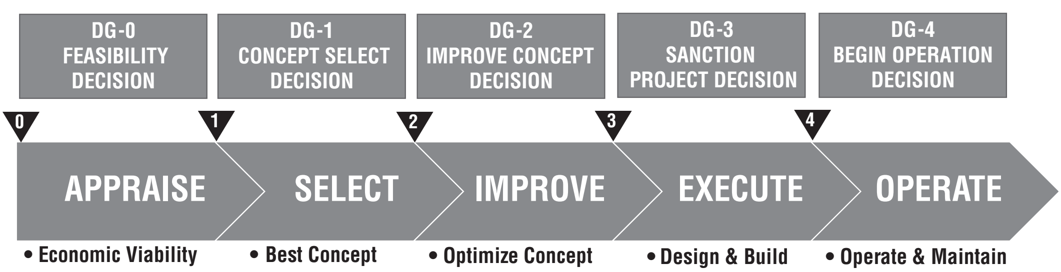

Figure 1.3 Oil and gas project development approach example

a short list of options to be advanced to the next stage. As the project continues to advance through the development process, the system concept matures. At decision gate DG3, the decision can be made to sanction the project and begin development. This phase can be the most time consuming and expensive, as it entails engineering, procurement, construction, transportation and installation, mechanical completion offshore, and commissioning (i.e., system verification and validation) in preparation for decision gate DG4 to put the system into production.

We show these project development phases and frameworks to indicate how the project progresses from an idea toward a stage at which it matures sufficiently that a decision can be made to develop the project (or, in the U.S. DoD's case, a program). When a project or program is sanctioned at DG3 for oil and gas (Milestone B for the U.S. DoD), this represents the stage at which the project as an *idea* begins the process of translating into an actual project result or *system*. After this decision gate, project execution or project development begins. Embedded within the project development process, systems engineering (SE) plays a vital role in structuring how the work will progress throughout the development process.

Also throughout the development process, projects require a systematic approach that focuses on how the work is being performed. The SE process is a key resource supporting project management and ensuring that modern systems are designed and developed correctly. By *correctly*, the authors mean in compliance with the governing regulations, codes, and standards while ensuring technical integrity of the system throughout development and integration of the system into the existing infrastructure, thus delivering a system that is safe to operate while meeting the needs of those who use it.

1.9 INTRODUCTION TO SYSTEMS ENGINEERING

Whereas project management is about *what* work needs to be completed, SE focuses on *how* to accomplish the technical work while maintaining a holistic perspective. SE is a key component of the work and activities that occur between the stage gates. As stated by the International Council on Systems Engineering (INCOSE): "Systems engineering is a discipline that concentrates on the design and application of the whole (system) as distinct from the parts. It involves looking at a problem in its entirety, taking into account all the facets and all the variables and relating the social to the technical aspect. Systems engineering is an iterative process of top-down synthesis, development, and operations of a real-world system that satisfies, in a near optimal manner, the full range of requirements... Systems engineering is an interdisciplinary approach and means to enable the realization of successful systems. It focuses on defining customer needs and required functionality early in the development cycle, documenting requirements, and then proceeding with design synthesis and system validation while considering the complete problem: operations, cost and schedule, performance, training and support, test, manufacturing, and disposal... Systems engineering considers both the business and the technical needs of all customers with the goal of providing a quality product that meets the user needs... Certain keywords emerge from this definition description including: interdisciplinary, iterative, socio-technical, and wholeness" (INCOSE, 2015). INCOSE describes SE as a process and a perspective as well as a profession.

The SE perspective is based on *systems thinking*, which "occurs through discovery, learning, and dialog; leading to sensing, modeling, and talking about the real-world in order to understand, define, and work with systems" (INCOSE, 2015). *Systems thinking* is a perspective and an awareness of the *whole system* and how parts within that system interrelate and the interrelationships between elements within the system as well as between the system and external systems. The SE process has an iterative nature that supports learning and continuous improvement. As the processes unfold, systems engineers uncover the real requirements and "the emergent properties of the system" (INCOSE, 2015). Complexity can lead to unexpected and unpredictable behavior of systems; hence, one of the objectives is to minimize undesirable consequences. This is accomplished by including and seeking contributions from experts across relevant disciplines coordinated by the systems engineer. Since SE has a horizontal orientation, the discipline (profession) includes both technical and management processes. Both processes depend upon good decision making. Decisions made early in the life cycle of a system, whose consequences are not clearly understood, can have enormous implications later in the life of a system. It is the task of the systems engineer to explore these issues and work to resolve these uncertainties as early as possible in project development.

1.9.1 Use of Systems Engineering

The SE discipline, working in unison with project management, has emerged as an effective way to manage project complexity and change. As both complexity and change continue to escalate in our products, services, and society, reducing the risk associated with new systems or modifications to complex systems continues to be a primary goal of SE. Every system life cycle consists of the business aspect (business case), the budget aspect (funding), and the technical aspect (product). SE creates technical solutions that are consistent with the business case and the funding constraints. Yet, system integrity requires that these three aspects be in balance and given equal emphasis at all decision gate reviews.

Whenever someone, whether an individual or an organization, desires to achieve a result, they must perform a series of actions and operations—not just randomly; these actions and operations must be performed in a mandatory order (considering their dependencies), who will be performing them, and what tools and techniques will be used. Because they want a specific result, individuals and organizations follow processes, whether predefined or ad hoc. Just as each project is unique from every other project to some degree, so too will the processes that are used to develop the project's *result*. Because these process components (activities, tools, sequence, etc.) and their interactions (information flow, artifact flow, communication, timing, and such) can vary, processes will differ even if being performed by organizations with the same goal.

In large-scale projects, mistakes made early in project development can ripple through later project phases (e.g., from engineering to procurement and construction) if not detected and corrected. SE, in unison with project management, provides the foundation for understanding what needs to be accomplished in order to deliver the project result and also how it should be accomplished to ensure minimal errors of commission and omission throughout the project development process. In SE, the technical processes enable systems engineers to coordinate the interactions between engineering specialists, project management functions, system stakeholders, operations, and other interested parties. These processes also address conformance with expectations and regulatory requirements of industries, governments, and others. Ultimately, SE technical processes lead to the creation of a full set of requirements (user and regulatory) that address the desired capabilities and functions for a specific system within the bounds of design constraints, performance, external interfaces, and the environment.

1.9.2 Project Management and Systems Engineering Combined

The combination of project management and SE provides powerful mechanisms to understand and effectively manage large-scale project developments. Even so, project development results in a web of highly complicated interactions among the parties who are contributing to the project result. As we've seen, modern projects rely on many geographically dispersed organizations with specialized knowledge, experience, competencies, technologies, and materials to contribute to highly complex system developments. These organizations are expected to contribute their respective deliveries at the right time to be integrated with other deliveries and assembled in a predefined sequence. Along the process, thousands or millions of details are coordinated through a variety of interactions across multiple communication channels, from formal to informal. The laws of probability suggest that something will go wrong, resulting in more work, extra time, and more cost than planned. However, project management and SE provide the foundation of structure and organization; they are emplaced together to lead, manage, control, and of course, produce the complex systems that are the purpose of major project development.

1.10 DESIGNING AND DEVELOPING COMPLEX SYSTEMS

Every project is undertaken to produce a result. The infrastructure projects presented earlier are examples of systems produced by large-scale projects. However, each of these systems created by the infrastructure projects consists of several different subsystems, components, logics (signals), etc. In essence, each of these systems has a hierarchy within the system. It is normal to think of a project as a stand-alone entity with no connection to the outside world. As evidenced by the previous infrastructure project examples, modern projects are typically integrated as part of an existing system architecture, or part of an urban landscape, or part of a transport network.

For example, a new offshore oil and gas processing facility off the coast of Norway will be integrated into existing subsea transportation lines or connected to surface transportation systems to move hydrocarbons from the point of recovery to global markets. Large wind farms need to be connected to existing power infrastructure architectures in order to deliver the power they create. New airplane development projects need to be integrated into existing air transportation networks and hubs. These *supersystems* also undergo routine upgrades and modifications, resulting in a trickle-down effect on the systems with which they interact or connect. Project development durations of several years increase the challenges of designing a system and integrating it with an existing architecture, especially one that may have undergone updates and changes during the development of the new project.

It is common in some industries to undertake multiple concurrent projects which are to be integrated with one another and need to finish at or near the same time. Parallel projects may or may not have the same sponsor; if they do not, the span of control over integration of the various project systems is more complicated. In the oil and gas industry, it is quite normal for one offshore field development project to integrate into the field development of another company. Naturally, the benefit is the reuse of the existing offshore subsea infrastructure to transport newly discovered hydrocarbons along an existing pipeline network. However, this requires the project team of one project to coordinate closely with the team of the other project to ensure smooth integration, thus increasing project management and SE complexity. Emerging problems within one project can quickly become the problem of the other project; potentially resulting in commercial and legal consequences. In an ever-connected and technologically advanced society with rapidly evolving conveniences, modern project design and development are difficult to manage (and are arguably impossible to control).

What then is the fate of future projects given the accelerating pace of change observed over the last fifty years? No one can predict the future, although some suggest otherwise, but it is possible to make reasonable inferences about the future based on trends over the last few decades. If the recent past is any indication, it is reasonable to suggest that, technologically, we will continue to advance in an effort to address existing and expected future challenges for a burgeoning global population. Growing and shifting populations will require more food, energy, infrastructure, health services, and protection. People are likely to further explore opportunities for efficiency, economy, capacity, and capabilities; the projects they spawn will continue the trend to capitalize on open markets and availability of global suppliers and vendors. Technology will continue to be a large part of increasing product capability and functionality; the need for sustainability will hopefully minimize the impact on natural resources and the environment. In essence, projects will continue the trend of producing increasingly complex systems through more complicated project developments. Project sponsors will continue to make selecting the most economical development approach a primary consideration. In essence, the intensity of change is likely to persist; continuing to make the delivery of systems created by projects more difficult. Our management processes must keep pace with—and harness—what is technologically possible.

1.11 COMMERCIAL CONTRACTING DECISIONS AND FACTORS INFLUENCING PROJECTS

At the heart of every sanctioned project are the capital investment costs (CAPEX) that are required in order to develop a project. Obviously, every project sponsor desires to minimize the CAPEX while achieving maximum return on investment (i.e., maximum value creation). Regardless of industry, this results in many creative commercial arrangements and strategies. When sanctioning a major capital project, the project sponsor (owner) must select a basic contracting strategy for developing the project. This strategy has two key components: (1) types of contracts and (2) how the project scope will be delivered.

Rarely does a single organization have sufficient resources to undertake a major project and deliver the entire scope itself. Various approaches exist—and for good reason: the choice of contracting approach can and will affect the outcome of the project. The commercial strategy must be selected with careful consideration not only for the potential upside of the approach (i.e., opportunities), but with consideration of the risk and appreciation of the demands that each strategy places on the owner's organization. Any contracting strategy, of course, can result in undesirable consequences if it is selected without the necessary resources in place and if the assumptions about the strategy are invalid. The appropriate approach to produce optimal results will be different depending on the structure and culture of the owner organization and the specific circumstances of a given project. The approach that produces favorable results for one owner could be problematic for another.

1.11.1 Types of Contracts

The type of contracts to be used for developing the project is largely dependent upon the degree of certainty of the scope of work; that is, how well the scope of work is understood, complete, and clear. When the client is certain of the scope of work, the client may shift more risk to the contractor, who may be willing to accept the risk because much of the scope uncertainty is removed. When the scope of work to be performed is more uncertain, the project sponsor is usually more willing to assume risk and the contractor will likely seek protection from that uncertainty. Obviously, this affects the type of contract the project sponsor can reasonably use.

1.11.1.1 Fixed Price Contract

A fixed price contract is used when the scope of work is well understood and clearly defined. In essence, prospective contractors submit bids as an all-inclusive *fixed* price to deliver the scope of work. By requesting and submitting a fixed price, both the client and contractor have high confidence in the work that needs to be completed and the scope is not expected to change. When a scope of work is clearly defined and well-understood, the risk to the contractor is (relatively) low. By submitting a fixed-price bid, the contractor is expressing its relative certainty of ability to deliver the scope of work on time and to quality expectations. Changes can be made to the scope of work, but this results in increased costs. However, in large-scale projects, precisely defining every aspect of the project scope can be a daunting task and other types of contracts may be used. Although we continue to derive deterministic schedule and cost estimates for large-scale complex projects, in reality, we'd be better served to use stochastic cost and schedule (ranges with probabilities) as many new product organizations do. An unusually naïve client may believe that he is shifting risk to the contractor by using a fixed price, but its use in the wrong circumstance has come back to bite many a client.

1.11.1.2 Cost Reimbursable

Cost reimbursable contracts are used when the scope of work is less understood or less precisely defined. In large-scale projects that require significant engineering activity, a cost reimbursable contract is often used. The engineering process by nature is an *iterative* process. That is, work is performed and checked, which results in input to improve the design. This then results in another engineering iteration until the design matures such that it is compliant with regulatory and user requirements. As expected, this is usually not a preferred contract method for the project sponsor since the sponsor assumes the cost risk. The lack of scope definition can easily result in a never-ending cycle of work, resulting in cost overruns, or at least larger costs than the sponsor had anticipated. In some situations this cannot be avoided, but in nearly all cases it is better to have a fully defined and well understood scope. From a practical matter, reimbursable contracts are more difficult to plan than fixed price contracts.

1.11.1.3 Cost Plus Incentive Fee

Since the scope of work may not be well-defined and understood, how can an organization plan and schedule activities when they are not certain what the end result is to be, what the activities will be, or how much effort they will require? Of course, the answer is that they cannot schedule with any certainty. In these cases, the result is often a dynamic schedule that changes routinely. It is normal for project sponsors to add financial *incentives* to these types of contracts to lessen this risk. These incentives are intended as motivation for the contractor to finish the work as quickly as possible. In principle, the contractor receives a financial incentive payment for completing certain amounts of work. In some cases, without a trusting relationship, the contractor may be more motivated to continue the reimbursable work than to collect the incentive and it is for this reason these types of contracts can be quite costly for the project sponsor if not managed carefully.

As we will discuss in upcoming sections, these contracts can also have a ripple effect on other contracts when the project sponsor elects to use a multiple contractor approach to deliver the project scope of work. This is the second aspect of the contract strategy, deciding how the scope of work will be delivered.

1.11.2 Multiple Contractors versus *Turnkey*

Combined with the types of contracts, the project sponsor also needs to decide whether the entire scope will be awarded to a single organization or if the scope will be subdivided and contracted to several parties. A multiple contract approach may divide the scope (i.e., *parcels*) into a few or many contracts. A client may choose this option when: (1) at least some parts of the project scope are well defined, (2) the client wants to take advantage of specialized capabilities, competencies, and skills, or (3) the client wants to obtain economic benefits afforded by the availability of many vendors and suppliers, or in other words, is looking for the lowest price among many qualified offerers.

As mentioned, the opening of the global marketplace has increased the availability of vendors, suppliers, and manufacturers, creating a virtual global supermarket for project sponsors. More contracts increase the owner's opportunity to save cost but also increases the owner's risk with respect to project integration. The multiple contractor approach allows the owner to leverage specialty firms with rare or critical competencies. It also allows the client to segment out the project scope so that it provides the least risk and best economic opportunities. However, segmenting the scope to many parties creates *interdependencies* between the scopes that need to be managed proactively to prevent late-stage development problems, which seem to be ever present in modern projects. When segmenting the scope to multiple contractors, the only contractual relationship is with the owner, and not between the contractors in most cases. That means that any implied interfaces usually are not explicitly specified in the scope of work for the contractors. Of course, how to manage that will be discussed in detail later in the book.

With a *turnkey* approach, the entire scope is provided by a single contractor on a *turnkey* basis and is seemingly straightforward. After award, the contractor develops a complete facility that requires the owner only to metaphorically *turn the key* and operate it. The contractor's scope is some form of EPC. In a turnkey approach, the project sponsor limits its options to the capabilities and competencies resident within the turnkey firm and any subcontractors it may obtain. A turnkey approach using a reimbursable contract, where the scope is not well defined, may be less beneficial as subdividing the scope into parcels and contracting some of the better-defined scope as fixed price; limiting the reimbursable to only those areas with uncertain scope. These are the types of trade-off the project sponsor will make in determining the optimal contract strategy.

1.11.3 Multiple Contractors, Multiple Contract Types

Regardless of approach, the contract strategy is an important element to project interface management. Certainly, the architecture of the system to be developed by the project is an important consideration (and will be discussed in more depth later in the book), but the parties responsible for the scope and the types of contracts are equally relevant. Arguably, one of the more popular contract strategies is to use multiple contractors and multiple contract types. From a client perspective, this can provide the optimal strategy in terms of minimizing capital investments and risk. As mentioned earlier, it is normal for parts of the project scope to be well understood and defined. It is natural to select a fixed price contract for this scope and advertise to the global marketplace. Typically, this results in a lower price for those segments of the work. For those parts of the scope that are less understood or for which the scope cannot be precisely defined, the client can use a reimbursable contract, but still has the option of opening the competition to global vendors and suppliers. In such cases, the client reaps the economic and risk benefits of both types of contracts.

Unfortunately, there is a key aspect of this strategy that is usually not well addressed. When undertaking an approach that uses multiple contractors with both fixed and reimbursable contracts, it is quite normal for the interdependencies among the different contractors to become challenging. On the one hand, the contractors with fixed price contracts understand their work quite well. This leads to a stable schedule and fixed price. On the other hand, the contractors with reimbursable contracts are less certain of the work they need to complete, which leads to a dynamic schedule that tends to change rapidly and to costs that are less well-known. As the work commences, if there are high levels of interdependency between fixed and reimbursable contracts, then it is challenging to align delivery of the interdependencies, resulting in problems for both parties. Even though the contractor with the fixed price understands the work that must be performed, this contractor can be dependent upon inputs from other parties, including those with reimbursable contracts. The contractor with the reimbursable contract may not be able to provide the material or information to other parties when needed. In fact, this contractor may not even be able to say when it can provide the material or information.

These types of situations are often, even typically, not considered as part of the contract strategy as the cost associated with the individual contracts tends to be the selection driver. But these challenges may be suboptimizing and will likely add to the complexity of the project and delivery of the scope of work necessary to complete the system or project result. From an interface management perspective, knowledge of the organization's strategy, its project development process, and the system to be developed by the project are key inputs to devising not only a contract strategy, but a project interface management system.

1.12 CONCLUSION

The accelerating pace of societal change has driven demand for increasingly complex products and services, which, in turn, have driven the rise of project-oriented organizations. Over the last 500 years (half a millennium!), mankind has experienced an explosion of change. Growing populations, technological advances, and opening of markets are only a few of the factors contributing to significant and rapid change that is affecting all parts of society. Regardless of individual views for or against the changes experienced in modern society, it has occurred, and there are no indications that this trend will subside. In fact, it is reasonable to expect the rate of change to continue to increase if the past 500 years or even the past 50 years are any indication.

Projects are becoming increasingly more difficult as development approaches become more complicated by the availability of globally dispersed vendors and suppliers and ever-increasing regulatory demands. In addition, systems created by projects are characterized by increasing complexity resulting from advancing technology to improve system efficiency, capabilities, and functionality. Whereas society is struggling with the rate of change, project environments are becoming increasingly complex and project professionals are struggling to adapt to how this change is affecting the systems developed by projects. As technology becomes geometrically more capable, we need to address how our management systems can keep pace. One of those critical emerging management systems to address complexity is interface management.

In Chapter 2, we set the stage for stakeholder and interface management by defining complexity and discussing how it affects project and technical management. This is one of the most important factors when considering project interface management. Since most large-scale projects involve multiple entities within and beyond the project scope early in project planning, the next chapter also addresses managing stakeholder complexity and using stakeholder analysis as a means of aligning the actors who are associated either directly or indirectly with the project, along with their needs and requirements. The result of this analysis will directly feed the interface management processes addressed in later chapters.

1.13 REFERENCES

Bible, M. J. and S. S. Bivins. (2011). *Mastering Project Portfolio Management*. J. Ross Publishing, Inc., Fort Lauderdale, FL.

Cooper, R. G. (2011). *Winning at New Products: Creating Value through Innovation,* Fourth Edition. Basic Books of Perseus Books Group, Philadelphia, PA.

Cooper, R. G., S. J. Edgett, and E. J. Kleinschmidt (2001). *Portfolio Management for New Products,* Second Edition. Basic Books of Perseus Books Group, Philadelphia, PA.

Defense Acquisition University (DAU) website. Retrieved 01/23/2010 from http://www.dau.mil/default.aspx.

DifferenceBetween.net. (2011). "Difference between Paleolithic and Neolithic." Retrieved from http://www.diffen.com/difference/Neolithic_vs_Paleolithic.

Editors of Encyclopedia Britannica. "Iron Age." *Encyclopedia Britannica*. (2015). Retrieved from https://www.britannica.com/event/Iron-Age.

Gale, R. M. (1971). 'The Fictive Use of Language.' *Philosophy*, 46(178), pp. 324–340. doi: 10.1017/S003181910001696X.

Gascoigne, Bamber. History World. From 2001, ongoing. http://www.historyworld.net.

Greiman, V. A. (2013). *Megaproject Management—Lessons on Risk and Project Management from the Big Dig*. John Wiley & Sons, Inc., Hoboken, NJ.

Harari, N. H. (2015). Sapiens, U.S. Edition. Harper Collins, New York, NY.

INCOSE. 2015. *Systems Engineering Handbook: A Guide for System Life Cycle Processes and Activities*, version 4.0. John Wiley & Sons, Inc., Hoboken, NJ.

Jenner, S. (2014). *Managing Benefits,* Second Edition. APMG International, High Wycombe, UK.

Jenner, S. (2012). "Benefits realization—building on (un)safe foundations or planning for success?" *PM World Journal*, Vol. 1, Issue 1, July, 2012.

Kerzner, H. (2017). *Project Management: A Systems Approach to Planning, Scheduling and Controlling,* Twelfth Edition. John Wiley & Sons, Inc., Hoboken, NJ.

Kulper, Kathleen. "Bronze Age." *Encyclopedia Britannica*. (2015). Retrieved from https://www.britannica.com/event/Bronze-Age.

Levatec, C. J. (2014). *Strategic Benefits Realization*. J. Ross Publishing, Inc., Plantation, FL.

Levine, Harvey A. (2005). *Project Portfolio Management: A Practical Guide to Selecting Projects, Managing Portfolios, and Maximizing Benefits*. Jossey-Bass Business and Management Series, San Francisco, CA.

Lovallo, D. and D. Kahneman. (2003). "Delusions of Success: How Optimism Undermines Executives' Decisions," *Harvard Business Review*, July, 2003.

Meredith, J. R. and S. J. Mantel. (2006). *Project Management—A Managerial Approach*, Sixth Edition. John Wiley & Sons, Inc., Hoboken, NJ.

Merrow, E. W. (2011). *Industrial Megaprojects—Concepts, Strategies, and Practices for Success*. John Wiley & Sons, Inc., Hoboken, NJ.

Metropolitan Museum of Art. (2017). Heilbrunn Timeline of Art History, New York, NY. Retrieved from http://www.metmuseum.org/toah/hd/shzh/hd_shzh.htm.

Project Management Institute (PMI). (2008). *The Standard for Portfolio Management,* Second Edition, ANSI / PMI 08-003-2008.

Project Management Institute (PMI). (2013). *The Standard for Program Management,* Third Edition, PMI, Inc., Newtown Square, PA.

Project Management Institute (PMI). (2017). Success Rates Rise. Transforming the High Cost of Low Performance. Pulse of the Profession. 9th Global Project Management Survey.

Thomsen, C. J. (1836). *Ledetraad til Nordisk Oldkundskab* (Guide to Northern Antiquity), published in English in 1848.

Urbanick, Janice. (2008). "Strategic Planning Essentials for Construction and Design Firms." Retrieved from http://www.nawic.org/images/nawic/stratplanningess.pdf.