Preface

What we call *Engineering Systems* are the systems that fulfill important functions in society: transporting people and cargo, transmitting messages, providing energy, improving our health, and so forth. They are characterized by high levels of interwoven technological and social complexity.

Why This Book?

This book is about these systems, but it is also about an emerging way to think about how to model, analyze, and design these systems. Thus, the term engineering systems describes both these systems and new ways of analyzing and designing them. Core to this way of thinking is including the social sciences as an integral part of the considerations that engineers must use in their work.

As we will show, the importance of engineering systems to engineers, to the modern world, and to our future cannot be overstated. But how did we get here?

At the dawn of mankind, many millennia ago, humans developed the skills to meet their basic needs and they did so by relying mainly on what nature would provide. By the 1600s, but especially during the 1800s, accumulating changes began to shape life on our planet. Profound mathematical, philosophical, political, and scientific advances led to inventions and more inventions. At first, these innovations were accessible *only* to a small elite. Further advances and industrial mass production made them accessible to millions of people. Meanwhile, breakthroughs in medicine and agricultural productivity substantially decreased infant mortality and raised life expectancy. In the first half of the twentieth century, these inventions gave rise to large-scale infrastructures, and as each reached millions of consumers—at least in the “developed” nations—they helped satisfy our basic needs for shelter, food, and communication in ways unimaginable only a century earlier.

As technological capabilities continued to improve and the world’s population continued to grow, and, along with it, the great systems that had been engineered, some unexpected side effects began to come to the fore. Rapid industrial growth and the resulting pressure on the natural environment, increased globalization of trade and commerce, and a perception of limited availability of resources became touchstones. It became clear that technology and technical systems must be harmonized by social processes and policies that would allow individual needs to be met while not harming society at large. Today, the boundaries between our large-scale technology-based systems are becoming increasingly blurry. This increasing degree of complexity and interconnectedness poses formidable challenges for the new generation of engineers, scientists, and managers in the twenty-first century.

All this is further complicated by the fact that technology increasingly influences our individual and collective social behaviors, which in turn influences the technology and systems we create. With increasing complexity and interconnectedness come higher levels of performance, but also unprecedented risks such as runaway climate change or the (real) possibility of cascading failures that jump from one system to another.

To put engineering systems in context requires repeating, in brief, some things that have been written elsewhere: a brief history of technology; the past and potential future evolution of the world’s human population; and so on. What emerges is the history of an engineered world that is becoming increasingly capable of meeting human needs just as it is becoming increasingly complex to understand and manage. One of our major premises is that codesign of regulations and policy with new technological systems must become the new way of designing these systems. A deep understanding of the technical possibilities in hand with deep appreciation of policy and regulation is necessary for such codesign, and such is possible through the increasing capability of a new kind of engineer, an engineer who not only provides technical expertise but assumes a leadership role in the overall design and development of these complex systems. Hence, the new field: engineering systems, and the challenges and opportunities of what some call sociotechnical engineering and others call “engineering in the large” or macro-engineering.

How Our Book Is Organized

In eight chapters, we seek to illuminate what we mean by engineering systems. Chapter 1 traces the history from major inventions to systems, focusing on the transportation, communications, and energy systems as examples that form three "spines" to which we return in later chapters, and which become increasingly connected as we go along. Chapter 2 discusses the properties and characteristics of engineering systems. They are large, spread out, complex, dynamic, open, and fulfill important functions in society for which we propose a simple organizational taxonomy. Chapter 3 provides a framework for thinking and rethinking about systems. We call this the (re)visioning perspective; it defines and uses the constructs: system scale and scope, functionality, structure and architecture, and temporality.

In our daily lives, we observe the cadence of engineering systems in seconds, minutes, or hours: trains arriving and departing at a busy station; lights and electrical appliances being turned on and off; e-mails from and to our computers, Blackberrys, and iPhones. These and other systems also exhibit important properties over much longer time scales of weeks, months, and years. The life-cycle properties of systems, collectively referred to as the "ilities" because so many end in "ility," are the subject of chapter 4. They include quality, safety, reliability, and—of more recent concern—flexibility, interoperability, and evolvability.

Chapter 5 presents the very wide array of methods and tools for modeling and analyzing engineering systems. While there is no single method that can do it all, the set of tools offer a powerful instrumentarium for better understanding and, ultimately, designing systems. Indeed, design is the focus of chapter 6, where we explore the large teams that typically design engineering systems and their need to communicate effectively across disciplinary boundaries as well as the social norms and presence of legacy that are so influential in such systems. Since implementation and real-world improvement are often considered more important than theoretical visions, there is rarely an opportunity for a clean sheet or "Greenfield" design.

Given the challenges, where will the next generation of engineers, managers, and scientists come from to deal with such complexity? Chapter 7 discusses some aspects of the history of engineering education and the roots of engineering systems. We show the long evolution to our present time, when technology and social phenomena are considered simultaneously in the context of large-scale systems. We note the profound and positive effect of the integration of biological science into engineering in the late twentieth century. We believe that similar benefits can occur with the integration of the social sciences into the engineering science base.

In chapter 8, we take the liberty to speculate a bit about what the future may hold. We do not claim to have a crystal ball, but it appears that our civilization is headed toward what might be called a global system-of-systems—a complex web of collaborating systems for managing and providing water, food, energy, information, and more. How will this evolve? How can we meet human needs today and tomorrow without taking more from the Earth than she can give? How will we effectively design and manage these systems across national and continental boundaries? These are some of the challenges ahead of us. Many have been recognized and recently articulated by the National Academy of Engineering of the United States.

It is becoming increasingly clear that technology defined narrowly cannot solve our problems, but that what we need is a set of technological innovations, social policies, and carefully chosen system architectures codesigned to deal with both desired and undesirable effects. This way of thinking significantly expands the boundaries of what we have come to call "engineering." It is a challenge worth taking.

Our MIT Connection

All three authors have current appointments at the Massachusetts Institute of Technology, and MIT has played an important role in each of our lives. MIT has made significant contributions to many of the systems we discuss, including advances in transportation science, information theory, the development of the Internet, and other achievements recounted in this book.

We are acutely aware of our bias in discussing engineering systems as an emerging field of research and education. The founding of MIT's Engineering Systems Division (ESD) in 1998 was preceded by a series of committees and deliberations about how better to integrate big "E" engineering with management science, the social sciences, and the humanities. These discussions extended over several decades beginning in the 1960s. MIT was not alone in having such discussions, and similar trends at integration can be observed at other universities, often under different names. The trends, insights, and way of thinking described in this book are not unique to MIT or the United States. We take note of activities at Stanford University, Carnegie Mellon University, TU Delft, the University of Illinois, Georgia Tech, Keio University, Singapore University of Technology and Design, Masdar Institute of Science and Technology, École Polytechnique, and many others. Engineering systems as a discipline is, in fact, taking shape as a global phenomenon.

One of our hopes is that this book will help set the context for and serve as an introduction to a new MIT Press book series on engineering systems that will help advance understanding of macroscopic engineering. Two other books are also being launched at the same time as this book. *Engineering a Safer World* by Nancy Leveson is dedicated to developing a better understanding of system safety. Safety is one of the ilities we discuss in chapter 4. Leveson explains that traditional safety engineering approaches that are primarily based on the assumption of failed mechanical components are no longer sufficient in a world where machines and systems are increasingly controlled by software and blaming individual operators often misses the root cause of accidents. The other book, *Flexibility in Design* by Richard de Neufville and Stefan Scholtes, discusses a new approach to designing systems in a context of significant exogenous uncertainty. Inspired by the "real options" approach to systems design, the authors develop a sophisticated yet simple four-step framework for designing systems with embedded flexibility to adapt to uncertain futures, and in doing so significantly advance our understanding of flexibility as a system property. A fourth book in the series is scheduled for release in 2012: *Design Structure Matrix Methods and Applications* by Steven D. Eppinger and Tyson R. Browning.

It is our hope that additional books will follow in the MIT Press Engineering Systems series, and that over time both a theoretical basis as well as a practical set of approaches to sociotechnical engineering will emerge that enable the codesign of new technical systems and appropriate management and regulatory systems. At a minimum, we hope these books will stimulate interest and debate on a topic that confronts us every day in one form or another.

The inventions and systems of yesterday and today have delivered enormous benefits to mankind. They have also unleashed forces with potential for severe unintended impacts. We owe it to ourselves and to future generations to tackle the engineering challenges they pose, with all their complexity and interconnectedness, in a holistic way and with a healthy mix of confidence and humility.

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Olivier de Weck
Daniel Roos
Christopher Magee
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