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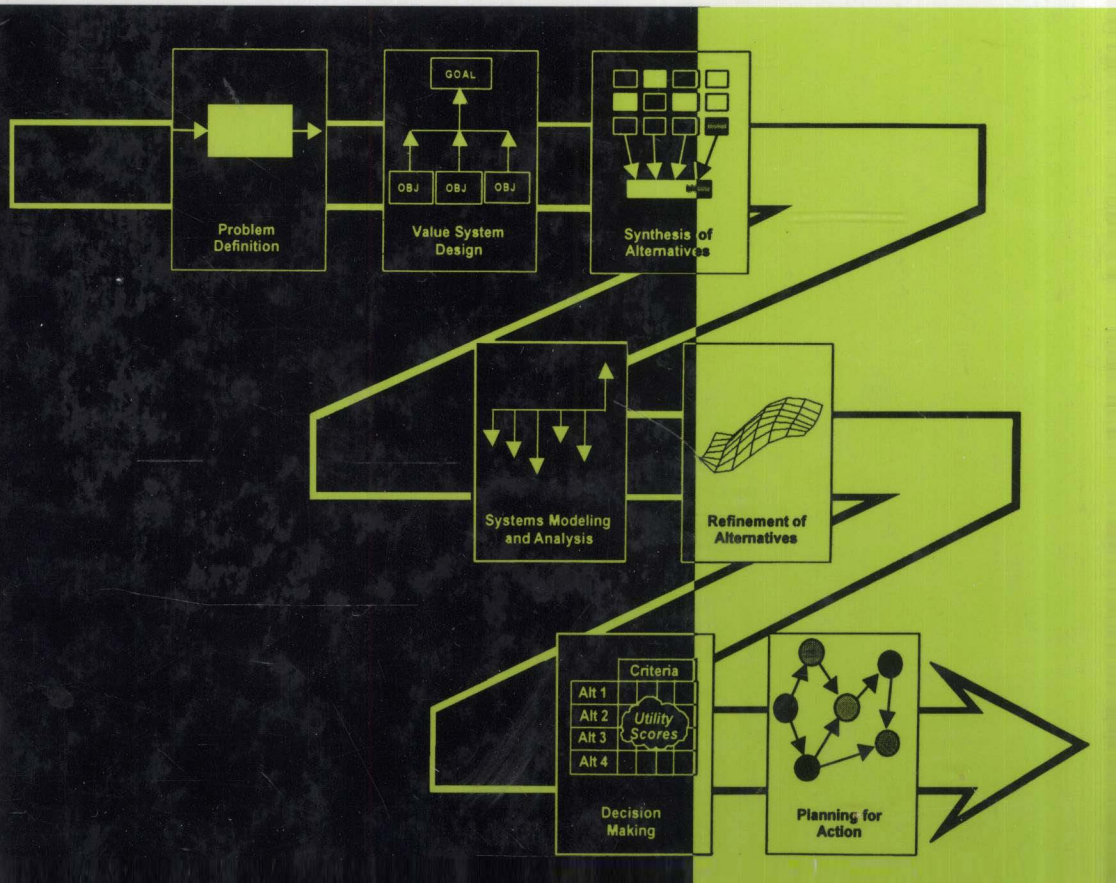
Introduction to Systems Engineering

Andrew P. Sage • James E. Armstrong Jr.



INTRODUCTION TO SYSTEMS ENGINEERING

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Introduction to Systems Engineering

INTRODUCTION TO SYSTEMS ENGINEERING

Preface

This book discusses some fundamental and introductory considerations associated with the engineering of large-scale systems, or systems engineering. We begin our effort by first discussing the need for *systems engineering* and then providing several definitions of systems engineering. We next present a structure describing the systems-engineering process. The result of this is a *life-cycle model* for systems engineering processes. This is used to motivate discussion of the functional levels, or considerations, involved in a systemic process:

- Systems methods and tools
- Systems methodology
- Systems management

While there will be a number of discussions throughout the book on systems engineering life-cycle processes and systems management—especially in the first, second, and last chapters—our major focus is on (a) methods for systems engineering and (b) problem solving using a systems engineering approach. Problems for student solution will be presented at the end of each chapter.

The major content in the book is that in Chapters 3, 4, and 5. In these chapters we present a number of methods appropriate for

- Issue *formulation*
- Issue *analysis*
- Issue *interpretation*

We will apply these to a variety of situations that should enable us to develop

an appreciation for the engineering of large systems, as well as for problem solving in general.

This text is written primarily for upper-division undergraduate students in systems engineering and in engineering management. It is also, we believe, useful as an introductory graduate-level textbook. It should also have value for other engineering areas that offer courses in systems engineering problem solving, systems engineering design, and systems engineering methods. Prerequisites for the text are moderate. It will generally be assumed that the reader has a fundamental background common to beginning upper-division undergraduates in engineering in the United States. This will include differential and integral calculus as well as differential equations. Some introductory knowledge of probability theory is also assumed as well as an understanding of some physical engineering systems.

The book should also be attractive to the many professionals in industry concerned with systems engineering and technical direction-related efforts. These include professionals in such diversified areas as project management, software engineering, information systems engineering, manufacturing, command and control, and defense systems acquisition and procurement.

The following are among the most important objectives for systems engineering, expressed in terms of systems engineering processes:

1. Systems engineering processes should encompass all phases of the system life cycle, or life cycles as the case may be, including transitioning between phases.
2. Systems engineering processes should support problem understanding, as well as communication among all interested parties at all phases in the process.
3. Systems engineering processes should enable capture of design and implementation needs for the systems engineering product early in the life cycle, generally as part of the requirements specifications and conceptual design phases.
4. Systems engineering processes and associated methods should support both bottom-up and top-down approaches to systems design and development.
5. Systems engineering processes should enable an appropriate mix of design, development, and systems management approaches.
6. Systems engineering processes should support quality assurance of both the product and the process that leads to the product.
7. Systems engineering processes should support system product evolution over time.
8. Systems engineering processes should be supportive of appropriate standards and management approaches that result in trustworthy systems.

9. Systems engineering processes should support the use of automated aids for the engineering of systems, such as to result in production of high-quality trustworthy systems.
10. Systems engineering processes should be based upon methodologies that are teachable and transferable and that make the process visible and controllable at all life-cycle phases.
11. Systems engineering processes should be associated with appropriate procedures to enable definition and documentation of all relevant factors at each phase in the system life cycle.
12. Systems engineering processes should be associated with appropriate metrics and management controls.
13. Systems engineering processes should support operational product functionality, revisability, and transitioning, both at the initial time of operational implementation and later at the time that a system is phased out of service or retired, or reengineered for continued productivity and use.
14. Systems engineering processes must support both system product development and system user organizations; they must also be compatible with the environments associated with systems development and operation.
15. Systems engineering processes should support quality, total quality management, system design for human interaction, and other attributes associated with trustworthiness and integrity.

When all of these are accomplished, it will be possible to produce operational systems that are economical, reliable, verifiable, interoperable, integratable, portable, adaptable, evolvable, comprehensible, maintainable, manageable, and cost-effective and that lead to a very high degree of user satisfaction. These would seem to represent attributes for metrics, or to be translatable into attributes for metrics, that can measure the quality of an operational systems engineering product. They can be translated into standards with which to measure system performance and systems engineering process effectiveness. Together with cost information, this will allow us to obtain cost and operational effectiveness of systems engineering products.

Needless to say, we believe that systems engineering is one of the fundamental engineering subject areas. Its role in engineering, as well as in engineering education, is stressed in Chapter 1. Chapter 2 describes systems engineering processes. While the focus in this text is upon systems engineering methods, selection of appropriate methods is necessarily contingent upon the process or product line used to engineer the product. Chapters 3, 4, and 5 each focus on one of the major steps in systems engineering:

- Issue *formulation*
- Issue *analysis*
- Issue *interpretation*

They each describe a plethora of methods for these steps. Technical direction and systems management guide the choice of an appropriate process and methods to be used within this process. The concluding chapter of this text describes some facets of systems management. This is not, however, a principal objective of this text. The major objective, as noted, is an exposition of systems engineering methods.

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CHAPTER 1

Introduction to Systems Engineering

This chapter and Chapter 6 (the last chapter of this text), each attempt to provide a perspective on all of systems engineering. This is a major challenge. We believe that some introductory comments, followed by another look at the big picture after we have discussed some of the methods based details in our intervening chapters, is an appropriate way to meet this challenge.

1.1 INTRODUCTION

Here, as throughout the book, we discuss some fundamental and introductory considerations associated with the engineering of large-scale systems, or *systems engineering*. We begin our effort by first discussing the need for systems engineering and then providing several definitions of systems engineering. We next present a discussion of systems engineering processes or systems engineering life cycles. A life cycle is the product line, or process, that is used to create a product or service, or perhaps even another process. We will also discuss the three functional levels, or considerations, that are associated with systems engineering:

- Systems methods and tools
- Systems engineering life-cycle processes, or methodology
- Systems management

While there will be some discussions throughout this chapter, as well as in the next and final chapters, on systems engineering methodology and systems

management, our major focus in most of the book is on methods for systems engineering and on methods for problem solving through use of a systems engineering approach. Here we wish to provide an overview of where we wish to go. We will also attempt to indicate what it is that systems engineers do in professional practice. We will provide a brief indication of the history of systems engineering and will also discuss some of the challenges and pitfalls associated with systems engineering efforts.

In the next chapter, we will discuss a framework, or methodology for systems engineering. We will indicate that this framework is generally comprised of three fundamental steps:

- Issue *formulation*, such as to identify the needs to be fulfilled and the requirements associated with these in terms of objectives to be satisfied; constraints and alterables that affect issue resolution and generation of potential alternative courses of action
- Issue *analysis*, such as to enable us to determine the impacts of alternative courses of action including possible refinement of these alternatives
- Issue *interpretation*, such as to enable us to rank order the alternatives in terms of need satisfaction and to select one for implementation or additional study

We will present a number of methods appropriate for these three steps in Chapters 3, 4, and 5. This comprises the majority of the content of this effort, which is basically concerned with systems engineering methods for the formulation, analysis, and interpretation of issues. To put these methods-based discussions in perspective, we illustrate how they fit into the overall systems engineering picture. These are the objectives of Chapter 2, which is devoted to systems engineering life-cycle processes, and Chapter 6, which is devoted to systems management.

We will apply these systems engineering steps — Formulation, Analysis, and Interpretation — to a variety of situations that should enable us to develop an appreciation for systems engineering and problem-solving efforts. The primary purpose of the text is to describe a variety of systems methods and illustrate their use in formulation, analysis, and interpretation situations that are associated with problem solution and systems definition, development, and deployment. The text concludes in Chapter 6 with a brief discussion of the role of each of these functional levels in the engineering and management of large-scale systems.

1.2 SYSTEMS ENGINEERS

What do systems engineers do? The answer to this question is ostensibly straightforward. They *define*, *develop*, and *deploy* systems. The systems (products or services) they engineer usually involve many considerations associated