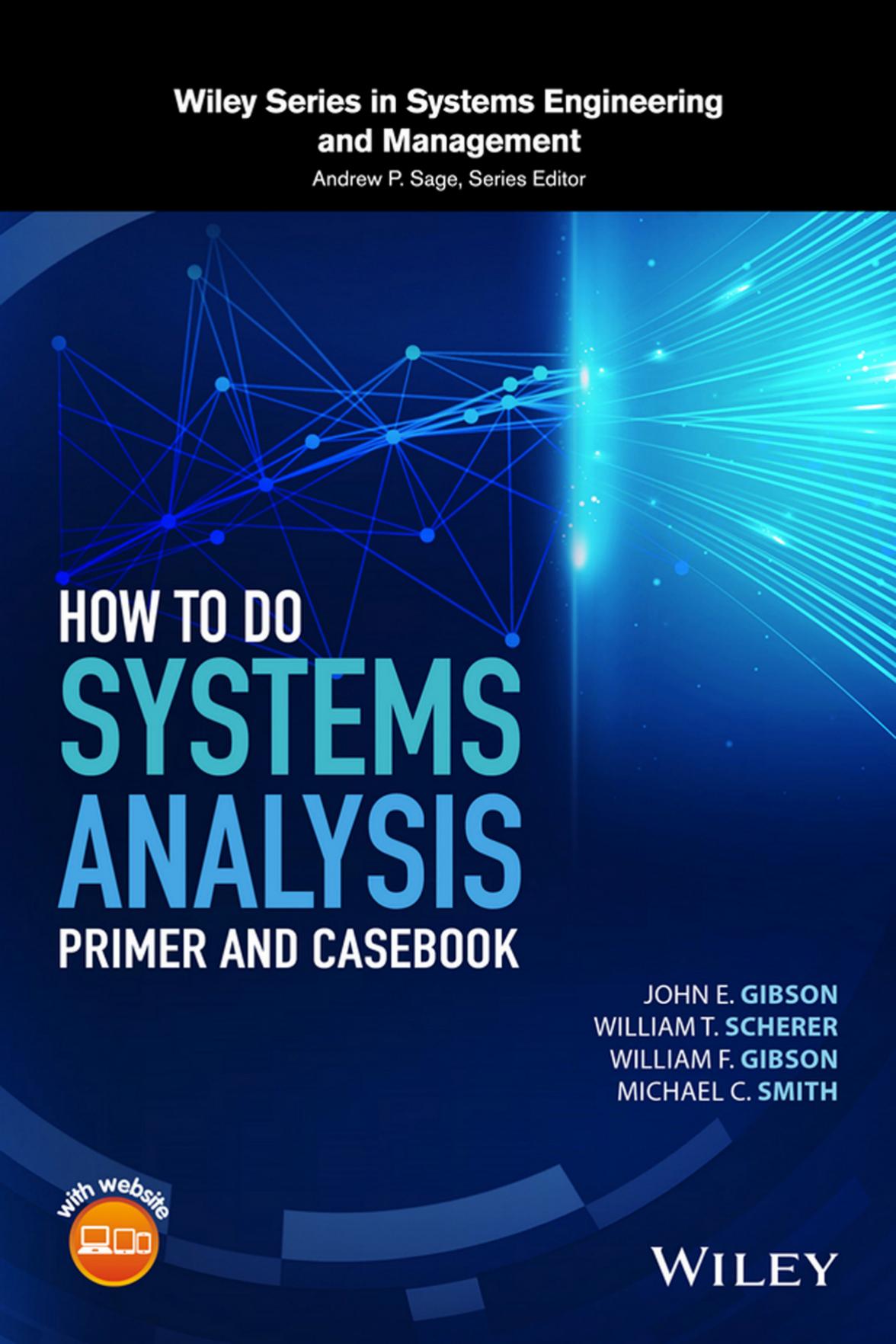


**Wiley Series in Systems Engineering
and Management**

Andrew P. Sage, Series Editor



**HOW TO DO
SYSTEMS
ANALYSIS**
PRIMER AND CASEBOOK

JOHN E. GIBSON
WILLIAM T. SCHERER
WILLIAM F. GIBSON
MICHAEL C. SMITH



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How to Do Systems Analysis

**WILEY SERIES IN SYSTEMS ENGINEERING
AND MANAGEMENT**

Andrew P. Sage, Founding Editor

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How to Do Systems Analysis Primer and Casebook

**John E. Gibson
William T. Scherer
William F. Gibson
Michael C. Smith**

WILEY

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Preface

The *systems approach*, *systems analysis*, *systems engineering*, or *systems thinking*, whatever one calls the concept, is more likely to be caught than taught. Asking the right questions is often more important than knowing the right answers. The collective experience of the authors in teaching and practicing systems engineering in academia and in the public and private sectors exceeds a combined 100 years. This experience leads us to conclude that the best way for students and practitioners to master the systems concepts is to face realistic, often unstructured, and typically ambiguous problems that require much more than reciting answers or applying methods from the text. Moreover, we have observed that students discover that what they learn from the material presented in Part One of this text becomes integrated into the way they think, as they gain more experience applying the principles and methods through cases such as those provided in Part Two. These cases, developed by instructors based on their professional experience, are situations that students and practitioners face in their own lives, from finding places to live while in school, evaluating employment opportunities, reading about current events and issues, or making other major life decisions.

The unique approach in this book is to motivate systems thinking, or as we like to say: “See the world with new eyes—that of a systems thinker.” Throughout the book are examples from the past and from today’s pressing issues, which illustrate these concepts, along with case studies in Part Two to give the reader exposure to the practice of systems analysis and systems engineering. The resulting book is appropriate for numerous fields and professionals that need the perspective and tools of systems analysis, including anyone working in the analysis of complex systems, such as in business consulting, financial services, healthcare, telecommunications, and so on.

The goal of the book is to assist in creating the active learning experience such that both students and practitioners internalize systems thinking and the systems approach as they become more effective systems engineering practitioners, including greater proficiency in both technical and professional competencies. We measure the success of this approach by observing the extent to which students demonstrate good systems thinking in the way they approach cases, conduct analysis, communicate findings and recommendations to clients and other stakeholders, and demonstrate professionalism in their ability to both collaborate with others and conduct themselves within ethical standards of practice.

We believe that present books in the area of systems analysis and engineering are excellent; however, many fail to emphasize the art of systems problem-solving

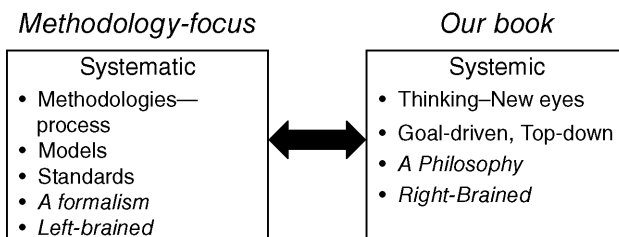
(systems analysis) by focusing instead on operations research methods (mathematical models, such as linear programming) or on the formal systems engineering processes (as stressed by INCOSE: The International Council on Systems Engineering). This book focuses on systems analysis, broadly defined also to include problem formulation and interpretation of proposed alternatives in terms of the value systems of stakeholders. Therefore, this book is a *complement*, not a substitute, to the other “traditional” books when teaching systems engineering and systems analysis. However, the nature of problem-solving discussed in this book is appropriate to a wide range of systems analyses—thus, it can be used as a stand-alone book for teaching the analysis of systems.

Numerous other books describe the processes of systems engineering, including systems engineering handbooks developed by NASA, DOD, Boeing, and so on.

Currently, there is also considerable discussion on the concept of system-of-systems—that is, systems that are of significant complexity and order that they require methodologies beyond the classic systems methodologies that are all basically derivatives of MIL-499B, a classic systems engineering military standard. The emphasis of this book, however, is not on the formal process of systems engineering eloquently described in the referenced books, but on the systems analysis component and the associated thought processes.

The design of this book is such that it can be used at different educational levels. Undergraduates, for example, focus on the basic problem-solving ideas, and the expected depth in their analyses and cases would be significantly less than expected from graduate students. How the book is used, that is, as a primary text or supplemental/complementary text, also depends on the student level. Experience at both levels has shown that experienced students (such as our Accelerated Master’s Degrees students—working professionals in an executive degree format program) clearly understand (from their experiences) the issues addressed in the book and can relate the material directly to their work experiences, especially from what we call the systemic perspective; thus, for them the book is a required and a primary source. Undergraduates, typically without the benefit of significant work experience, see the value in a general problem-solving method that applies to many situations, with more focus on the systematic aspects of the material. For them, we use the book as supplemental.

Fundamentally, we see two worlds typical in systems engineering (both are necessary!):



By systemic, we mean affecting the entire system or holistic.¹ By systematic, we mean a formal step-by-step process (in the most direct form, computer code is an example). This book makes a unique contribution by addressing the right-hand side, the systemic side. An analogy could be made to the left-brain (logical; often engineers) and right-brain (artistic) thinkers. The book focuses on problem definition, which is in our opinion a very difficult part of the systems process and an often neglected (or failed) part in practice (and books).

So, we have *How to Do Systems Analysis: Primer and Casebook*. This book is not intended to be an instructional guide to systems engineering (such as practiced in industry or government), but a book that engages one in beginning or enhancing their journey toward becoming a systems thinker—a requisite skill for systems engineers and all problem solvers. *Trends come and go, but quality Systems Analysis thinking abides*. Throughout the book are pointers and references to excellent books and articles that provide detailed techniques, research, and think pieces on the disparate aspects of systems analysis. We have deliberately left much of Jack Gibson’s original material alone. We feel strongly that there is considerable wisdom in these words and that this wisdom is timeless. Unfortunately, systems thinking and good systems engineering remain elusive, as evidenced by the fairly recent (Summer 2006) experiences with the Big Dig in Boston and the current U.S. healthcare system debates. Many of Jack’s examples and experiences, some dating back to the 1950s, add considerable insight to the realm of systems thinking. We have used draft parts of this book in graduate and undergraduate courses that introduced systems engineering concepts since the early 1990s; then the first book of this nature was based largely on Jack Gibson’s contribution, *How to Do Systems Analysis*, published in 2007. The material uniformly received excellent reviews from students for its unique perspective on problem-solving in all types of domains. It is particularly relevant for students with some professional experience who appreciate its practical and accessible concepts.

How would we read this book? Top-down of course. One might start with reading in Part One, beginning by reading Chapter 6 completely, followed by Chapter 1, then reading the first several pages of Chapters 2–5, using the cases in Part Two to reinforce and practice the concepts presented in Part One. For undergraduate students, Chapters 2–4 form the core concepts of a general systems analysis

¹ A wide-reaching term designating views in which the individual elements of a system are determined by their relations to all other elements of that system. Being highly relational, holistic theories do not see the sum of the parts as adding up to the whole. In addition to the individual parts of a system, there are “emergent,” or “arising,” properties that add to or transform the individual parts. As such, holistic theories claim that no element of a system can exist apart from the system in which it is a part. Holistic theories can be found in philosophical, religious, social, or scientific doctrines. (Source: Public Broadcasting Systems.)

methodology. Chapter 6 is, in effect, an executive summary of systems analysis and can basically stand on its own.

We encourage you to engage in and enjoy the material.

WILLIAM T. SCHERER

WILLIAM F. GIBSON

MICHAEL C. SMITH

Charlottesville, Virginia

January 2016

Original Preface from Jack Gibson

There appear to be three generic points of view one may take in writing a textbook. These are . . . the *problem-centered* viewpoint, the *technique-centered* viewpoint, and the *reader-centered* viewpoint. Of course, it is also possible to write a book with no consistent point of view at all, one probably need not add. The problem-centered view is not common in general texts but is an acceptable approach for advanced texts on focused, narrow topics. My text, *Designing the New City*, Wiley, 1977, was written from this perspective. However, if the author has an introductory, general purpose in mind, this approach leads to difficulties. In such a situation, problem-centering usually leads to a book of recipes. That is, the author is led to saying for a series of instances, “given this problem, here is how to handle it.” One becomes bogged down in specifics, and it is difficult to achieve a general perspective of the topic. This is a severe limitation in itself, and, furthermore, it is unappealing to the academic mind. The technique-centered approach is more common in basic introductory texts.

Generally speaking, technique-centered texts typically provide a chapter or two of introduction and then launch into a survey of the main topics and techniques in the field. It is assumed that the reader will be able to select the appropriate tools to solve his or her specific problem. If one is faced with a problem similar to the type of problems used to illustrate the technique under discussion in the text, this is a good approach. But what it gains in general perspective and an overall viewpoint, it may lose in usefulness in applicability. The technique-centered approach seems to be popular with academics, since we generally have a mind bent that seeks general understanding and we are less interested in problem-solving and specifics. I have written several texts with this perspective, among them being *Introduction to Engineering Design*, Holt, Rinehart & Winston, 1968, and *Nonlinear Automatic Control*, McGraw-Hill, 1963.

The reader-centered point of view has initial appeal as a guide to the perplexed, but in practice it sometimes descends to pontification and anecdotal generalities—that is, retelling of old and possibly irrelevant personal “war stories.” This approach assumes a common starting point for its readers, and, as in the present text, this starting point is usually an assumption of a reader’s unfamiliarity with the topic. *Scientific American* magazine practices this approach in a masterly way. The first paragraph or two of each of its articles is couched at a simple, obvious level and then acceleration is smooth and gradual.

For better or worse, the reader-centered approach is the one taken in this text. I will assume you are a systems analyst faced with a problem situation. We will go through a step-by-step approach to the application of the systems approach to the

situation, using techniques as the need arises. We will not focus on the details of the analytic techniques to be used; it is assumed that you will learn the details of these (mostly mathematical) techniques elsewhere. From the present text, I hope you will learn just what “systems analysis” (SA) is and what the “systems approach” means. You will see from examining the cases, which are based on actual practice, how the need for mathematical techniques develops, and how to apply them. Moreover, I hope that you will develop a sense of the pitfalls and difficulties in practicing SA. This is a tall order, especially for readers without professional work experience.

Unless you are able to provide a “reality check” from your own work experience, you may be tempted to accept the suggestions herein for analyzing problems as simple and obvious. In reality they are neither, but unlike advanced mathematics, which is obviously difficult going in, SA appears almost trivial on first observation. We will discuss this trap as we go on.

JACK GIBSON
Ivy, Virginia
January 1991

Acknowledgments

Many people have contributed to this book, but first and foremost is John “Jack” Egan Gibson, one of the most intelligent and insightful people I have met and a true systems thinker and cofounder of the modern systems approach. I’ve had the pleasure of working for 30 years in the premier systems engineering department in the world, a department cofounded by Jack and Andrew P. Sage. During those years, I’ve had the pleasure of working with giants in the field, including Gibson, Sage, Aleco Christakis, John Warfield, and Wil Thissen. I’d especially like to acknowledge my two mentors, Chip White and Doug White, for their wisdom and friendship.

I’d like to thank my coauthors, Will Gibson and Mike Smith, two outstanding colleagues and true disciples of the systems approach. Finally and most importantly, I’d like to acknowledge the considerable support and love from my wife, Amy, and my trio of daughters, Kendall, Merritt, and Linden, the lights of my life.

W.T.S.

This book is the culmination of the work of many individuals. The primary is John Egan Gibson. Over the years, I pleasantly continue to be surprised by the comments I receive from his students, colleagues, clients, and friends. His seminal ideas and insights continue to provide the framework by which individuals and groups analyze problems. And, I continually see the practical application of these ideas in the non-academic environment. Many of Jack’s former graduate students and faculty members provided valuable comments and perspectives on this work.

Additionally, over many years working on the predecessor text and this one, I have enjoyed collaborating with Bill Scherer; we continually chide each other about how Jack’s systems approach continues to prevail. And, an additional evangelist of this discipline is Mike Smith, from whom I continue to learn. Over the many years, I could not have completed this work without the help of two very important people. This book would not have been in your hands without the love, tolerance, and support of my wife, Hilary, and our son, Ted.

W.F.G.

“Systems thinking” is something that is observed, learned, and earned over the course of many years, through academic preparation, professional practice, and life experiences. As I look back over the past 30+ years of learning and practice, I see the thumbprints of many individuals – colleagues, clients, students, friends, and family – whose influence and encouragement gave me insights into “How to do systems analysis.” I am grateful to my coauthors, Bill Scherer and Will Gibson, who invited me to participate and have embraced my contributions as helpful in

advancing systems thinking among young minds and older practitioners. I am also grateful for the experiences afforded to me throughout my professional career by clients who trusted my colleagues and me to provide thoughtful analysis based largely on the principles presented in this book. And, of course, my greatest appreciation goes to my family, especially my wife, Amanda, whose steadfast love and support exceeds what I deserve or ever expected; and our four children, Martha, Laura, David, and Elizabeth, whose ideas and perspectives always challenge me to think more systemically and recognize the importance of approaching problems with humility and grace.

M.C.S.

About the Companion Website

This book is accompanied by a companion website:
www.wiley.com/go/Gibson/HowtoDoSystemsAnalysis

The Student's website includes:

- Excel data sets associated with specific cases
- Other materials may be added to this website that complement the materials in the textbook and enhance the learning experience.

Part I

Primer

Chapter 1

Introduction

Sys-tem (sĭs' təm) *n.*

1. A group of interacting, interrelated, or interdependent elements forming a complex whole.
2. A functionally related group of elements, especially:
 - a. The human body regarded as a functional physiological unit.
 - b. An organism as a whole, especially with regard to its vital processes or functions.
 - c. A group of physiologically or anatomically complementary organs or parts: *the nervous system; the skeletal system.*
 - d. A group of interacting mechanical or electrical components.
 - e. A network of structures and channels, as for communication, travel, or distribution.
 - f. A network of related computer software, hardware, and data transmission devices.
3. An organized set of interrelated ideas or principles.
4. A social, economic, or political organizational form.
5. A naturally occurring group of objects or phenomena: the solar system.
6. A set of objects or phenomena grouped together for classification or analysis.
7. A condition of harmonious, orderly interaction.
8. An organized and coordinated method; a procedure.
9. The prevailing social order; the establishment. Used with: *You can't beat the system.*

[Late Latin *systema*, *systemat-*, from Greek *sustēma*, from *sunistanai*, to combine: *sun-*, *syn-* + *histanai*, set up, establish.]

Source: [Answers.com](https://www.answers.com): American Heritage

In the systems approach, concentration is on the analysis and design of the whole, as distinct from . . . the components or parts . . . The systems approach relates the

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John E. Gibson, William T. Scherer, William F. Gibson, and Michael C. Smith.

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Companion website: www.wiley.com/go/Gibson/HowtoDoSystemsAnalysis

technology to the need, the social to the technological aspects; it starts by insisting on a clear understanding of exactly what the problem is and the goal that should dominate the solution and lead to the criteria for evaluating alternative avenues . . . The systems approach is the application of logic and common sense on a sophisticated technological basis . . . It provides for simulation and modeling so as to make possible predicting the performance before the entire system is brought into being. And it makes feasible the selection of the best approach from the many alternatives.

(Ramo, 1969, pp. 11–12)

1.1 WHAT IS A SYSTEM?

A system is a set of elements so interconnected as to aid in driving toward a defined goal. There are three operative parts to this short definition. First is the existence of a set of elements—that is, a group of objects with some characteristics in common. All the passengers who have flown in a Boeing 787 or all the books written on systems engineering form a set, but mere membership in a definable set is not sufficient to form a system according to our definition. Second, the objects must be interconnected or influence one another. The members of a football team then would qualify as a system because each individual’s performance influences the other members. See Ackoff (1971) for an interesting taxonomy of systems concepts (also see Whitehead *et al.*, 2014).

Finally, the interconnected elements must have been formed to achieve some defined goal or objective. A random collection of people or things, even if they are in close proximity and thus influence each other in some sense, would not for this reason form a meaningful system. A football team meets this third condition of purposefulness, because it seeks a common goal. While these three components of our working definition fit within American Heritage’s definitions, we should note that we are restricting our attention to “goal-directed” or purposeful systems, and thus our use of the term is narrower than a layman’s intuition might indicate.¹

It must be possible to estimate how well a system is doing in its drive toward the goal, or how closely one design option or another approaches the ideal—that is, more or less closely achieves the goal. We call this measure of progress or achievement the *Index of Performance (IP)* (alternatively, *Measures of Effectiveness [MOE]*, *Performance Measures [PM]*, *etc.*). Proper choice of an Index of Performance is crucial in successful system design. A measurable and meaningful measure of performance is simple enough in concept, although one sometimes has difficulty in conveying its importance to a client. It is typically complex and challenging in practice, however, to establish an index that is both measurable and meaningful. The temptation is to count what can be counted if what really matters seems indefinable. Much justifiable criticism has been directed at system analysts in this regard (Hoos, 1972; Syme *et al.*, 2011). The Index of Performance concept is discussed in detail in Section 2.3.

Our definition of a system permits components, or the entire system in fact, to be of living form. The complexity of biological systems and social systems is such that complete mathematical descriptions are difficult, or impossible, with our present state of knowledge. We must content ourselves in such a situation with statistical or qualitative descriptions of the influence of elements one on another, rather than complete analytic and explicit functional relationships. This presents obvious objective obstacles, as well as more subtle subjective difficulties. It requires maturity by the system team members to work across disciplinary boundaries toward a common goal when their disciplinary methodologies are different not only in detail but in kind.

From these efforts at definition, we are forced to conclude that the words “system,” “subsystem,” and “parameter” do not have an objective meaning, independent of context. The electric utility of a region, for example, could be a system, or a subsystem, or could establish the value of a parameter depending on the observer’s point of view of the situation. An engineer for the Detroit Edison Company (DTE Energy) could think of his electric utility as a system. Yet, he would readily admit that it is a subsystem in the Michigan Electric Coordinated System (MECS), which in turn is connected to the power pool covering the northeastern portion of the United States and eastern Canada. On the other hand, the city planner can ignore the system aspect of Detroit Edison and think of it merely supplying energy at a certain dollar cost. This is so if it is reasonable for him to assume that electricity can be provided in any reasonable amount to any point within the region. In this sense, the cost of electricity is a regional parameter. The massive Northeast U.S. power failure in 2003, along with the resulting repercussions directly affecting over 50 million people, clearly illustrates the regional nature of these systems.

That the function of an object and its relationship to neighboring objects depends on the observer’s viewpoint must not be considered unusual. Koestler, for example, argues persuasively that this is true for all organisms as well as social organizations. For these units, which we have called “systems,” he coins the term “holon.”

But “wholes” and “parts” in this absolute sense just do not exist anywhere, either in the domain of living organisms or of social organizations. What we find are intermediate structures or a series of levels in an ascending order of complexity: sub-wholes which display, according to the way you look at them, some of the characteristics commonly attributed to wholes and some of the characteristics commonly attributed to parts. . . . The members of a hierarchy, like the Roman god Janus, all have two faces looking in opposite directions: the face turned toward the subordinate levels is that of a self-contained whole; the face turned upward toward the apex, that of a dependent part. One is the face of the master, the other the face of the servant. This “Janus effect” is a fundamental characteristic of sub-wholes in all types of hierarchies.

(Koestler, 1971)

This issue is further confused by the recent extensive use of the term “system-of-systems” or SoS, which refers to systems whose level of complexity creates emergent behavior and where the level of decision making and stakeholder values becomes difficult to determine.

Some uses of the term SoS apply to extremely *complicated* systems with many independently functioning but highly integrated subsystems such as might be found in a modern commercial or military aircraft or in an advanced manufacturing system with all of its associated logistics. While the system is, indeed, *complicated* and much care must be taken to understand, model, design, optimize, and test all of the many interfaces and scenarios under which the system must perform, the system is still very much the product of careful design around well thought-out functional requirements and operational objectives.

Other uses of the term SoS apply to systems that exhibit great *complexity* in which the emergent interactions and outcomes are difficult to model or anticipate and may not reflect any particular design intent, for better or worse. In this case, use of the word “system” may be applied without ever acknowledging or agreeing on the major objectives of the “system”—as in health care system, education system, economic system, and environmental system—and the best we can do is attempt to describe and understand the emergent behavior, regardless of whether or not we can influence or control the outcome.

The more formal use of SoS has been led by the U.S. Department of Defense and associated organizations (see Nielsen (2015), for an overview of SoS). Whether such SoS requires different methodologies is up for debate; however, the discussion has been evolving for over 60 years, with efforts in the 1980s and earlier on “meta-systems” methodology and S2 (*e.g.*, Sage (1981), Eisner *et al.* (1991), Jackson and Keys (1984)).

1.2 TERMINOLOGY CONFUSION

Because one is often introduced to system analysis in a specific context, it may be confusing subsequently to find the method used in an entirely different context. Engineering students, for example, may follow a “systems” curriculum that specializes in automatic control, communications theory, computer science, information retrieval, and so on, and which entirely excludes general system planning and policy-oriented questions (Brown and Scherer, 2000; Pyster *et al.*, 2012). Students of management may think of fiscal control or ERP (Enterprise Resource Planning) “systems” when they use the phrase “system analysis.” We have sewage systems, social systems, and fantasy football team selection systems. Perhaps Koestler was wise to avoid the word “system” entirely, but then again, he only renamed the problem. Here is an example of a dual use of the word “system” that resulted in initial confusion by members of a government advisory panel.

A panel of engineers was requested by the federal government to establish the future research and development needs in the field of high-speed ground transportation (HSGT) (U.S. Department of Commerce, 1967; Herbert, 1968). The panel originally conceived the study in the categories shown in Figure 1.1. It soon became apparent, however, to the “system” subpanel that a number of the tasks, which they had been asked to consider, fell into the category we will call “general system planning.” Such items as subsystem interaction, reliability, and system management are

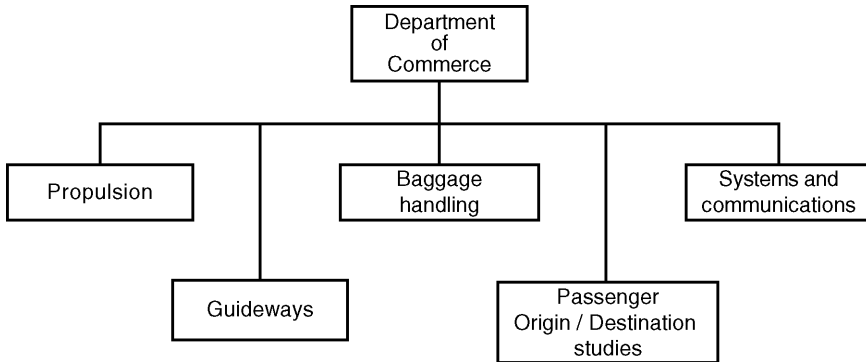


Figure 1.1 The original HSGT study concept. The Department of Commerce wished to assemble a study team to establish the concept of high-speed ground transportation (HSGT) on a conceptually correct basis. Originally, it felt that the study should have the five units shown above. However, when the team of experts assembled, they discovered that there existed considerable confusion as to the meaning of the “systems and communications” unit.

included in this category. Yet what about communications and control, the question of a single, overall centralized control computer system versus many individual machines, or the reporting of the position and velocity of individual vehicles? Just as surely, these are more specific “systems.” Thus, the final report of the HSGT panel was organized as shown in Figure 1.2. This is a more functional arrangement, and it helped the panel to produce a less confusing and thus more useful report.

Thus far we have discussed the difference between the general or “comprehensive” system viewpoint we take in this text, *i.e.*, the specific problem at issue, plus all

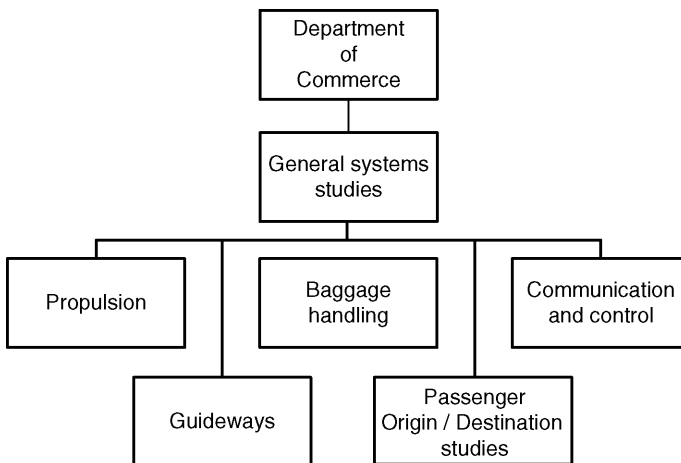


Figure 1.2 The final HSGT report formulation. Here we see the general systems aspect of the problem broken out and placed in the overall coordinating position. Now the term “communication and control system” is less ambiguous.

of the interactions and impacts of the specific issue with its setting, including policy issues and a more localized, exclusively technological “control system” point of view. There are at least three additional semantic difficulties to be discussed.

In the early twenty-first century, as the U.S. populace was tiring of the prolonged war in Iraq and Afghanistan, the military sought an option that would allow it to capitalize on its technological superiority and reduce its reliance on soldiers in harm’s way (and concomitant casualty rates). There was an insatiable demand to meet insurgencies in locales such as Syria, Libya, and Somalia, in addition to Iraq, Afghanistan, and Yemen. To meet this demand, unmanned drones seemed to be a cost-effective option.

So, for more than 10 years, to varying levels of success, pilots flew their television monitors, rather than strapping into their F-16s; Maverick and Ice Man were still graduating from Top Gun in Miramar only to sit at a Game Boy™ machine and shoot images on a screen.

However, as always, the Law of Unintended Consequences reared its ugly head—in 2015, as demand increased for drone operations in Yemen and Syria, the daily mission rates dropped from 65 to 60, as an increasing number of the 1,200 fighter pilots in the Air Force were completing their tours of duty and opting not to re-enlist.

The reason for this dilemma faced by the military was that pilots were facing new types of stresses—rather than flying from aircraft carriers in the Gulf Sea or from airbases in Bahrain, they were flying Reaper and Predator drones via satellite links in the United States. The perceived benefit was that the pilots were living safely, away from SAMs (surface to air missiles). However, while they were with their families, the constant shift back and forth between war and family activities created, in effect, a feeling of perpetual deployment.

Col. James Cluff, the commander of the Air Force’s 432nd Wing, stated, “Having our folks make that mental shift every day, driving into the gate and thinking, ‘All right, I’ve got my war face on, and I’m going to the fight,’ and then driving out of the gate and stopping at Walmart [*sic*] to pick up a carton of milk or going to the soccer game on the way home—and the fact that you can’t talk about most of what you do at home—all those stressors together are what is putting pressure on the family, putting pressure on the airman.”²

The Government Accountability Office (GAO) conducted a study and released its findings in April 2014.³ It found that while high-performing organizations, such as the Air Force, manage human capital to identify and target the optimum number of individuals to fill its drone group personnel needs, it fails to account for all tasks these units complete. Air Force officials stated that, as a result, the crew ratio for drone efforts was too low, but the Air Force did not update it. It recognized that low crew ratios diminished combat capability and cause flight safety to suffer, that high work demands on drone pilots limited the time they have available for training and development, and it negatively affected their work–life balance, but the Air Force failed to utilize direct feedback from drone pilots to develop its approach to managing challenges related to recruiting, retention, training, and development of drone pilots.

The failure of the Air Force to examine and implement this issue from a holistic systems approach meant that, while it might have some short-term successes, it would ultimately have a failed initiative on its hands because it failed to analyze the challenge faced by pilots to balance their war-fighting roles with their personal lives. It needed to change its methods and metrics rapidly, applying an approach like the one we describe in this text.

Later in the chapter, we indicate that *operations research* (OR) may be considered an immediate precursor of systems analysis (SA). Thus, one may fairly inquire as to exactly the difference between the two. In Section 1.10, we will see that B. L. R. Smith (RAND, 1966) argues that when RAND added an explicit policy component to OR studies, a new synthesis was achieved. Thus for us, system analysis equals an analytic OR study, plus a policy analysis.

Symbolically, then, Smith might say

$$SA = OR + PA$$

In other words, in modern usage, SA is a more general design philosophy than is OR, and it exhibits marks that are readily observable to an outside inquirer. See Section 1.3 for further discussion on this matter.

Finally, one may ask if SA differs from “system design” and/or “systems engineering.” In a precise technical sense, “analysis” is defined as taking apart into constituent elements, while “design” generally means “synthesis” or combining elements into a functional new whole. Unfortunately for all of us interested in precise terminology, the common use of “system analysis” in the literature almost always includes not merely an “analytic” phase, but also the development or recommendations for the solution or amelioration of the problem at hand—that is, “design” or synthesis. Following this usage, we include in the term “SA” that wider sense of synthesis.

What of the term “systems engineering?” In the older and narrower usage, “engineering” includes analysis and synthesis, but it is restricted to the design and operation of physical devices, that is, hardware design. However, in the broader and more modern sense, systems engineering (SE) includes all of the matters we include within the term systems analysis. Systems engineering, in fact, has its roots in classical control theory where the “system” was described in terms of an initial system state, controls (*e.g.*, designed to achieve the “desired” state of the system), transfer functions (that modeled the conversion from the initial state into the desired state), exogenous factors (that influenced the transfer function’s performance), a new system state, and feedback to the control function. All of this is characterized by latency, accuracy, response, and other measures of system performance. This approach to analyzing physical systems has expanded to large dynamic systems where the “stocks and flows” (see Senge (2006) or Meadows and Wright (2008)) include social systems, environmental systems, economic systems, and other large-scale complex systems involving technology, policy, legal and regulatory issues, and social and cultural considerations. This concept of systems engineering is broader than a view based primarily on the life cycle of physical systems and focuses

extensively on the *analysis* that leads to effective design of systems. Thus for us in this text:

$$SE = SA$$

Numerous books describe the process of systems engineering,⁴ including systems engineering handbooks developed by NASA, DOD, Boeing, and so on. Currently, there is also considerable discussion on the concept of SoS—that is, systems that are of significant complexity and order that they require methodologies beyond the classic systems methodologies that are all basically derivatives of MIL-499B.⁵ The emphasis of this book, however, is not on the formal process of systems engineering eloquently described in the footnoted books (and the synonym of the word system: “Method”), but on the systems analysis component as described above and the associated thought processes.

1.3 SYSTEMS ANALYSIS EQUALS OPERATIONS RESEARCH PLUS POLICY ANALYSIS

We will see in a later section of this chapter (see Section 1.10) that the RAND approach to systems analysis began with operations research and added a policy analysis component. We subscribe to that approach in this text. Of course, defining a term using two other ill-defined terms doesn’t help very much. So we should feel obliged to define OR and PA. Fortunately a number of students of the field have defined OR and Table 1.1 gives a collection of these definitions.

We notice the frequent occurrence of terms such as “scientific” and “mathematical” in these definitions; also there is the use of “optimization” and the emphasis on the concept of a “client.” The term “client” itself does not appear, but synonyms such as “executive authority,” “organization,” “society,” and so on, do. Thus, while the details differ among these definitions, a common basis emerges. We could go on with this definitional exercise to discover the typical analytic techniques of OR, such as linear programming, queuing theory, optimization techniques, simulation methods, and so on.

“Policy analysis” is a little more difficult to limit. But, if we note how RAND came to include the policy analysis aspect, matters become clearer. RAND knew from working with the military mind that it is hierarchal, a primary attribute of a Tayloristic value set. Taylorism, as we shall see, includes a rigid separation of “thinking” by managers from “doing” by workers. Thus, the U.S. Air Force, RAND’s original sole sponsor, tended to come to it with orders to do a certain analysis. When RAND analysts asked “why,” they were rebuffed. But as we will see, the Tayloristic mind-set is not suitable for creative analysis of new issues. The system analyst must know the goals of the issue and the underlying values from which the goals are formed to conduct an analysis properly. In the Air Force’s view, this took RAND out of the realm of OR into management’s territory, Policy Analysis. So RAND simply included policy analysis in its definition of what it did and that helped matters somewhat.