

Chapter 1

Introduction

sys-tem (sɪs'tɛm) *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.

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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: 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 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.

Simon Ramo, *Cure for Chaos*, 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 777 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.

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

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importance to a client. It may be complex 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). 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 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]

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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). 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 horse players’ 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 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 of the

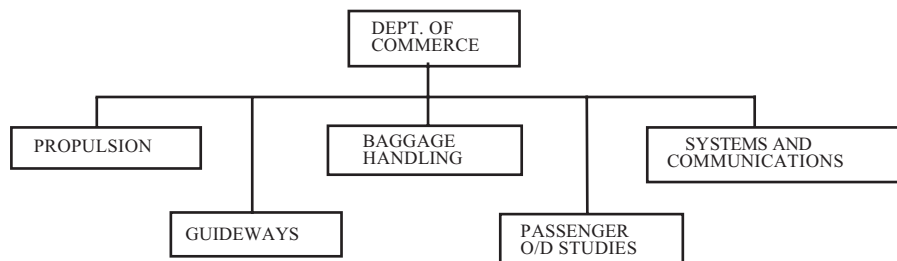


FIGURE 1.1 The original HSGT study concept. The Department of Commerce wished to assemble a study team to establish the concept of high-speed ground transportation (HSGT) on a conceptually correct basis. Originally, it felt that the study should have the five units shown above. However, when the team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

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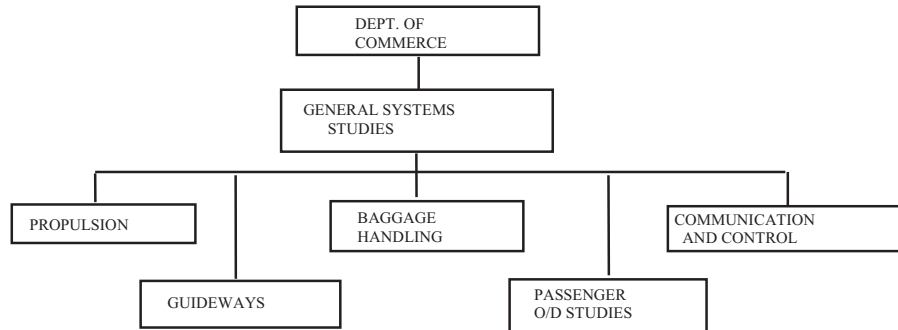


FIGURE 1.2 The final HSGT report formulation. Here we see the general systems aspect of the problem broken out and placed in the overall coordinating position. Now the term “communication and control system” is less ambiguous.

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.

Later in the chapter, we indicate that *Operations Research* (OR) may be considered an immediate precursor of systems analysis. Thus one may fairly inquire as to exactly the difference between the two. In Section 1.8, we will see that Smith 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 “system 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

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term systems analysis (SA). Thus for us in this text

$$SE = SA$$

Numerous books describe the process of systems engineering,² 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 (S.O.S.)—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.³ 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 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.

TABLE 1.1. Some Typical Definitions of Operations Research

“OR is simply the application of scientific method (i.e., quantitative, analytic thinking with empiric checking) to the problems of an executive authority.”

—Waddington

“OR is the application of scientific ideas and methods to improve the efficiency of an industrial process, an organization or, in the most general of senses, the working of any part of society.”

—Frend, et al.

“OR is a scientific method of providing executive departments with a quantitative basis for decisions regarding operations under their control.”

—Goodover

“OR in world government emphasizes the study of complex structures. It is the stress on model building which distinguishes OR from other management services.”

—Ward

“OR is the application of mathematical techniques to problems of organization with the objective of optimizing the performance of the system.”

—Wardle

“OR is by definition the scientific study of the process and methods of work in the field, office, or on the bench, to the extent that it does succeed in discovering ways of improvement.”

—Singh

“OR is an experimental and applied science devoted to observing, understanding, and predicting the behavior of purposeful non-machine systems.”

Op. Res., Vol. 19–3, No. 71, p. 1135

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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 in order 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.

1.4 ATTRIBUTES OF LARGE-SCALE SYSTEMS

In this text we will concentrate on a particular aspect of the field called large-scale systems. How does a large-scale system differ from a non-large-scale system? Almost certainly there is a policy component to the issue under consideration. Generally, a large-scale problem is not merely one containing many components, although that can occur. The usage has become common to differentiate between (a) the low-order, well-defined physical system to which almost all of the mathematical theory of operations research is directed and (b) larger, more complex issues with a policy component. By “policy component,” we generally mean that the goals of the system and the index of performance are subject to the personal standards and judgment of the client. The typical large-scale system will have many of the following attributes:

Policy Component. In addition to the physical infrastructure, or the so-called “engineering component,” a large-scale system often contains a social or “policy” component whose effectiveness must be evaluated by its accord with general social, governmental, or other high-order judgments, rather than by simple economic efficiency.

High Order. A large-scale system (LSS), or “General System,” will usually have a large number of discernible subsystems or parts. These parts can be quite different from one another and may be interconnected in complex ways. Some of the elements of the large-scale system may include living elements as linkages. In addition, social, economic, political, environmental, and technological considerations will often be involved.

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Complex to Describe. Because of the large number and variety of its elements, the LSS is often difficult to describe analytically or to model precisely via dynamic computer simulation.

Lengthy Installation. Because of the cost and effort needed for its installation, the LSS may take a number of years to construct and install. Thus special care is needed with respect to graceful phasing-in of the new system and phasing-out of the old system that it replaces.

Unique. Often the LSS will be unique in its overall concept. Thus special care must be given to careful preliminary design and complete analysis. The designer will not be able to correct design errors in early models later in the production run, if only one is to be built.

Prior Complete Testing Impractical. Because of the size and cost of the LSS, it may be impractical to construct a test prototype prior to installation of the operating system, or even to assemble the complete system off-site for preliminary testing. We are thinking here of complete subway systems, and so on.

One could cite an almost endless list of LSS, of which the following are a few examples:

- The “Big Dig” transportation project in Boston
- The information technology infrastructure for the Department of Homeland Security
- President Reagan’s “Star Wars” initiative in the 1980s
- The Manned Mars Mission (considered in a later chapter)
- The complete water supply for a large city (or any infrastructure component)
- The integrated Highway/Rail/Air/River transportation system for a developing nation such as Colombia, funded by the World Bank in the 1960s
- The long-range business plan for a complex international corporation such as Royal Dutch Shell in the months before the 1970s OPEC oil crisis
- The New Orleans flood containment system (levees, pumps, drainage, staff, policies, etc., or the flood evacuation process)
- The U.S. Social Security System

1.5 INTELLIGENT TRANSPORTATION SYSTEMS (ITS): AN EXAMPLE OF A LARGE-SCALE SYSTEM

ITS systems involve the use of disparate technology to improve, typically without capacity increases, the performance of a transportation system. The preliminary analysis, design, and installation of an ITS is complex and lengthy. The system is of high order. It may involve numerous subsystems, from transit rail to freeways to arterial signal systems. Some of the elements may be analyzed in exact detail—for example, individual intersection signals and the associated control computers. Other elements

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may submit to statistical analysis; passenger origin/demand studies are an example. Design data are typically necessary from disparate sources, such as U.S. Census origin/destination data and local traffic management centers. Financial estimates of system operation will be less precise, but still well within the bounds of approximate analysis. But other elements upon which the success of the system rests seem to be beyond analytic description.

For example, *the demographics* of the urban region may change dramatically in 30 years. A recent study shows that, within a period of five years, one-half of the families in a typical American community have changed their place of residence (He and Schachter, 2003). Housing prices, which dramatically affect traffic congestion and have major ITS implications, have been soaring in the 2000s and also doubling in a five-year timeframe; however, a bubble burst is predicted by many (Anonymous, 2005a). Thus, if the return on investment of several ITS technologies is calculated on the basis of a 30-year operating life, one must extrapolate over six half-lives of the demographic base that the system is designed to serve—a rather risky process.

Political questions are even more difficult with which to grapple than demographic. For example, the so-called U.S. “Highway Trust Fund” is a special-purpose federal gasoline tax with a limited set of permissible uses. Currently, funds can be returned to the states to reimburse approved state highway construction and reconstruction based on a complicated allocation formula. Will the trust fund allocation process be broadened to include ITS type of improvements? This is a political question, but one that will have a greater impact on the benefit–cost studies than almost any technological factor. Another example is photo-red, where camera systems can be installed to detect and issue tickets to vehicles that run red lights (Anonymous, 2005b). Systems can be operated by local or state governments, or they can be operated by local entities via a profit sharing formula. Evaluation of such systems has proved their capability in terms of technology, accident reductions, and economic viability; however, considerable political opposition has limited their deployment in the United States, where the opposition is based on claims of invasion of privacy. Regions have been turning off effective and proven photo-red cameras, against the wishes of police agencies, for political reasons (Stockwell, 2005).

Sociological factors are most difficult of all to predict. What will be an acceptable level of urban pollution produced by a transportation system? What is an acceptable level of delay on the highways? What will be the performance requirements placed by federal dictate on the next generation of individual vehicles and transit vehicles? What safety needs, real and perceived, must be met by ITS technology in the future? What about questions of “ambience” and “user-friendliness?”

All of the above factors also contribute to the complexity of description of the system as well. For example, it is not easy to define “the city” or region for which one is analyzing the transportation needs. Should the Metropolitan Planning Organization (MPO) definition or the Standard Metropolitan Statistical Area (SMSA) definition be used? There are over 30 definitions of the word “city” in current use (Gibson, 1977), and federal regulations require that, to qualify for federal matching funds, a regional approach must be taken in the analysis rather than a parochial one limited to political boundaries.

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The typical urban transportation system takes a long time to install. The Bay Area Rapid Transit (BART) system in San Francisco–Oakland took over a decade to design and construct, while the District of Columbia Metro subway has been in planning and construction even longer. Detroit has discussed and planned its subway for over 35 years, and as yet not a spade of earth has been moved. Some of the links of the interstate highway system initiated under Eisenhower are as yet untouched after 50 years. In the meantime, the existing transport networks must continue to function, and indeed many of the elements of the existing transport system must continue to function even after the new system is installed. Recently opened after 18 years of planning and construction and almost \$15 billion in costs, the Big Dig is the largest civil works project in history.

Each ITS system is unique. Certainly, many of the individual components are identical to those used in other systems, and indeed commonality with other systems is highly to be desired. Doubtless also, much of the design and construction experience obtained from earlier work should be transferable. But the particular combination of elements and the interconnections among subsystems will be unlike those faced elsewhere.

Some engineers are uninterested in issues of public policy, and they may choose their careers to be able to focus on the design of physical objects and to avoid “people problems.” One might imagine such focused individuals designing traction drives and electronic controls for subways, but one cannot long escape from the real world. Many of the initial problems faced by BART were due to selection of inexperienced contractors who used untried and untested techniques. When certain BART engineers warned against this, they were fired, and eventually BART authorities were required by law to pay damages to these courageous, “whistle-blowing” professionals.

Finally, it is patently impractical to set up a complete ITS somewhere for a lengthy test period, prior to installing it in its final location. This means that components and subsystems must be carefully field-tested prior to final installation. It further means that extraordinary care must be given to the system aspect as opposed to the component aspect of the analysis. Time spent on computer simulation of the operation of the system in the preliminary design phase, long before bending metal, will more than repay itself, for example. Such a computer simulation should be specifically designed to test system performance aspects.

For example, it is possible to mock up on computers interface systems and system controls. Then various conditions could be entered into the simulated system, without the user’s knowledge, to test his and the system’s response. It should also be possible to vary vehicle volumes, passenger loadings, route choices, station locations, and so on, on the simulated system to test the response to off-design-center operating conditions. The analyst should be able to demonstrate that as off-design-center conditions become more and more pronounced, the system undergoes graceful degradation, as opposed to sudden and catastrophic collapse. Yet rarely, if ever, is such a comprehensive simulation study actually conducted in practice that actually involves the human–computer interface (HCI).

For example, suppose a rapid transit system is to be controlled by a central control computer that is programmed to dispatch units in accordance with historical traffic

variations. Suppose a main artery near the city center is cut off in a sudden emergency. What will the central computer do? Or suppose the central computer itself fails. Does the whole system halt in a catastrophic collapse? The alternative to “catastrophic collapse” is “graceful degradation.” If control degenerates to separate sector computers and then back to the individual units operated by hand, at reduced speed in the face of a major emergency, performance of the system has gracefully degraded.

It is apparent that ITS are often constructed and operated with little or no thought given to overall policy questions such as those we have just raised. It also seems likely that traditionally trained transportation designers and operators would ignore or resist policy-oriented analyses if they were made. Should this surprise or dismay the system analyst? Not at all. It is the normal state of affairs, *even though we know that these problems will occur!*

In Chapter 6 of Smith’s book on RAND (Smith, 1966), he gives an excellent description of a pivotal study done by RAND on the location of bases of the Strategic Air Command (SAC) of the U.S. Air Force. This was one of the earliest studies anywhere in which a clear policy-oriented approach was adopted. This approach heavily influenced RAND’s subsequent development of a “strategic sense” and may be viewed as the progenitor of the modern policy-oriented system study. A. J. Wohlstetter, the task leader, was faced with precisely the same problems in beginning this analysis and then persuading the Air Force decision makers to accept and act on the conclusions of the study as the analyst of a mass transit system or any other large-scale system would face in working with real-world decision makers. Smith’s text, and especially Chapter 6, should be required reading for all analysts of large-scale systems.

1.6 SYSTEMS INTEGRATION

We have pointed out that confusion exists as to the meaning of the term “systems analysis.” This confusion has been partially resolved by coining a new phrase “systems integration.” *Systems integration* is a logical, objective procedure for applying in an efficient, timely manner new and/or expanded performance requirements to the design, procurement, installation, and operation of an operational configuration consisting of distinct modules (or subsystems), each of which may embody inherent constraints or limitations.

This definition of SI contains a number of key terms. “Logical, objective procedure” means that the process is defensible to external critics and that all of the steps have an audit trail built in. “Efficient and timely” imply that the process will not be unduly burdened with delays and bureaucratic procedures that increase cost to the client and delay deployment of the system. “Design, procurement, installation, and operation” indicates that the SI process will be employed throughout the entire process. It further implies that life-cycle costing will be considered and that retro-fits, extension of system capability, and the like will be built-in. The concept of “distinct modules” with inherent limits or constraints is central to the concept of SI. Systems Integration would be unnecessary if the entire configuration to be deployed were a stand-alone

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device without intimate connections with other devices previously deployed or to be deployed under a later procurement, and if the device were designed and constructed *de novo* by a single party with complete design responsibility. No such animal exists in the modern world, of course, and thus the ubiquitous necessity for SI.

At a tactical level, SI is involved with ensuring that specific hardware components will fit together smoothly in a configuration. Indeed at this level, SI is often referred to as “configuration management.” But at a broader, more strategic level, SI is concerned with interpreting overall performance needs of a sponsor into technical performance specifications and then the creation of a full options field from which to select those option profiles that best meet the client’s needs.

A number of pitfalls exist in the process. Among them are the following:

- Failure to provide a clear audit trail through the SI process.
- Breaks or discontinuities in the SI process caused by intuitive leaps from a general requirements level to a specific hardware configuration, without objective development of the steps in the process.
- Failure to assess completely the full range of client requirements including operation of the proposed system over the full time horizon required.
- Failure to evaluate full life-cycle costing.
- Failure to provide in advance for maintenance and periodic upgrades and retrofits during the system life cycle.

As we continue with our detailed discussion of the phases of systems analysis, we will see that this new term “systems integration” is synonymous. Over the last two decades, the term “system architecting” has also become prevalent. Defined as “the art and science of designing and building systems,” it follows the same analogy as systems integration; once again, *for our purposes*, we will use the term interchangeably with systems analysis (Rechtin and Maier, 1997).

1.7 WHAT MAKES A “SYSTEMS ANALYSIS” DIFFERENT?

Almost the whole of the remainder of this text will be devoted to the systems analysis (SA) methodology and how to perform an SA. But, before we begin, we wonder if this notion of system analysis is merely a mental discipline or a training regime through which we put ourselves, or if, on the other hand, there are distinctive marks or attributes that an external observer could use to detect that SA has been used. Even if it were only a mental discipline, SA could be valuable. For example, “Zen” is said to help warriors and athletes, even though it is “only” a mental attitude. We will argue that the SA methodology is more than just an attitude, however.

Even if there are external marks to SA, these marks might be of no functional value. For example, the marks might be only cosmetic, as when special jargon (of which we have a considerable amount) is used. However, we will argue that the marks of SA are more than cosmetic. There are recognizable characteristics in a well-done SA

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that enable an external observer to recognize it as such. Not every SA will display all of these marks, but the fewer that are evident, the further the analysis diverges from a paradigmatic system study. The following distinguishing eight marks define a systems study.

1. The "Top-Down" Nature of the Study. The well-done system analysis starts with an analysis of the general goals of the effort and proceeds to the specific. This is a reversal of the approach often advocated in engineering design. The reader will find a comparison of the "top-down" approach and the "bottom-up" incremental approach in Chapters 2 and 3. These two design philosophies are sometimes considered antithetical, but this not so. One does not choose one or the other in a systems analysis. In SA, top-down alternates with bottom-up, in an iterative manner.

2. A Goal-Centered Approach. The goal-oriented approach contrasts with the step-by-step or chronological or "laundry-list" approach. A system analysis starts by determining the situation or condition after the system under design is complete and operating successfully and works backward from there to determine the specifications of the intermediate links. This approach is discussed in detail in Section 2.2.

3. Rational, Objective Basis for Analysis. Rationality and objectivity are hallmarks of the scientific method and in engineering design. By "rational" we mean based on carefully gathered evidence weighed and analyzed using a logical procedure, and by "objective" we mean fair, balanced, unbiased, and free from personal whim. These features are not common in the political arena. Lawyers, for example, are not constrained by these criteria. A legal brief will include all of the arguments for a given position, even if some of the arguments are self-contradictory. The reader of such a brief is expected to pick any of the arguments that are pleasing, provided only that support for the advocate's position is obtained.

4. An Analytic/Quantitative Component plus a Policy Component. Operations research (OR, or equivalently management science, decision analytics, etc.) is a major component of SA, as we will see. OR contributes the analytic, quantitative component to systems analysis. The addition of the policy component makes SA unique. See Section 1.3.

5. A Generalized Problem, which Includes the Problem Setting. The word "generalize" here means to expand or broaden the scope of, as opposed to the alternate meaning of "generalizing from the particular to a broader class." A properly done SA always includes a consideration of the problem environment. It includes consideration of all of the stakeholders, non-users as well as users. By "generalized problem" we mean a core of mathematical quantification and analysis, plus the addition of human factors considerations and the policy component where indicated, all in the context within which the issue at hand is embedded, and specifically including the client on whose behalf the analysis is being conducted. See Section 3.2 for a more complete explanation of the rationale for "generalizing" the problem.

6. Optimization, often through Analytical Modeling and Simulation. Identification of the critical parameters of the problem and calculation of their optimum setting to maximize the index of performance is a basic characteristic in SA. Often this

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iteration and optimization is best accomplished by use of computer simulation. See Section 5.10.

7. Explicit Analysis of the Operative Values Assumed, and Declaration of the Analyst's Biases or Interests. Effective handling of the policy component in an SA requires that the operative value system be analyzed. This is the so-called "axiological component" of the analysis.

8. Problem/Client Orientation rather than Technique or Abstract Orientation. SA is client-oriented not technique-oriented. Maslow (1969) makes the importance of this distinction abundantly clear. Neither OR studies nor SA are conducted for their intrinsic value or the entertainment of the analysts.

This listing isn't designed to justify or explain these marks of SA. The remainder of the text is designed to do that. Here we merely wish to point out the unique characteristics of the SA approach, so that the reader can be alert for them as they occur in the text. Whether SA is effective and where it should be applied will also be made clear (one hopes!) in the remaining chapters.

1.8 DISTANT ROOTS OF SYSTEMS ANALYSIS

Frederick Winslow Taylor is among the earliest of the zealots in the cult of industrial efficiency, and by his somewhat extreme stands he made himself a favorite target, beginning in his lifetime and continuing to the present. As Ellul (1964,1973) points out, Taylor viewed "the shop" as a totally autonomous entity. He had no concern for the purpose to which the product produced would be put or for the external goals of the shop workers. Only efficient production mattered. This analytic suboptimization approach is still common, but it lacks contextual integrity. One should read Taylor's own words to get the flavor (Taylor, 1911).

Taylor is the exemplar of what McGregor (1960) labeled "Theory X" management style. Taylor viewed workers as objects rather than as individuals, but he should not be viewed as deliberately ignoring the human content of work. That is a concept developed only many years after Taylor's death. While one might expect opposition to Taylor's new method by many workers, we are surprised that Taylor failed to be acclaimed widely by managers. Copley (1923) makes clear in his laudatory biography that Taylor had considerable difficulty in winning converts among employers. His undivided allegiance to pure efficiency drove away many of those whose profits he would have served. Only an inherited income allowed him to continue his crusade.

One may note with interest that the military services were early converts to Taylorism. In 1907, there were efforts to apply Taylor's methods at the Brooklyn Navy Yard. The military were also among the first to use operations research in World War II. In the conventional wisdom, the military mind is not often credited as a flexible or innovating instrument, yet the fact remains it led the way in scientific management and operations research. Why?

Taylor's invention of time and motion study, the efficient design of the workplace, development of optimized tools (from shovels to cutting steel), work scheduling,

1.9 IMMEDIATE PRECURSORS TO SYSTEMS ANALYSIS 15

and incentive pay for workers allowed him to demonstrate spectacular increases in productivity where his methods were introduced. However, his dogmatism, arrogance, and unwillingness to persuade or explain, his demands for absolute loyalty from his associates, his efforts to stamp out heretical variations of his methods, his need for complete control, and his obsessive dedication to work make him a suitable subject for retrospective psychoanalysis. He appears to have had a well-developed martyr complex and to have viewed his work as a calling of supreme importance, so much so that he dedicated his life, his fortune, and ultimately his health to the cause.

Taylorism, or “scientific management” as he wished it to be called, made steady progress before World War II and became better known as industrial engineering and industrial management. The importance of increasing productivity was a lesson successfully taught by Taylor, and as less fanatic persons with broader and more humane concerns became involved and as the disciplined resistance of organized labor began to be felt, the worst excesses of early Taylorism in the American factory were trimmed away. Nevertheless, even today one carries a clipboard and stopwatch out onto a machine shop floor at one’s own risk. Taylorism was probably appropriate for the educational and social maturity of workers 100 years ago, but it is widely felt to be inappropriate and retrograde today. The Tayloristic mind set continues to be ubiquitous among American engineering educators.

1.9 IMMEDIATE PRECURSORS TO SYSTEMS ANALYSIS

The period immediately prior to World War II in Great Britain, circa 1937–1940, saw the development of what was called “operational research”; later, in the United States, this was called “operations research” (OR). When the threat of Hitler was real, but before massive involvement by Great Britain, it became apparent to Churchill and his close advisors that only by deploying its severely limited forces in the most efficient manner could England hope to survive. Radar had been developed and the Spitfire was in production, but the number of operational units was severely limited.

Because of the traditional close connection of government leaders and the universities in Britain, Churchill felt comfortable in turning to a family friend who was professor of physics at Cambridge, Professor Lindemann (later Lord Cherwell). Lindemann drew Sir Henry Tizard, Sir Watson-Watt, and other academics into aiding the war effort (Birkenhead, 1962). Mathematicians and physicists were asked how best to deploy available weaponry in military operations.

This was new. Scientists were accustomed to being called upon to develop new weapons, but the matter of organizing their use lies at the heart of military science, it would seem. It is hard to see how a more conventional mind than Churchill’s would have conceived such audacity. Statistical analysis groups were set up and controlled experiments were run (Morse, 1970). Bombing patterns were modified, and ocean convoy procedures were changed as a result of these studies. Because of the academic background of the early OR practitioners, a great deal of elegant and

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useful mathematics came into play: statistical analysis, queueing theory, probability theory, and so forth. See Chapter 1 of D. J. White's *Operational Research* for examples of typical military OR problems of the period (White, 1985).

New mathematics such as linear programming, dynamic programming, game theory, and decision analysis were later developed. OR began to influence industrial engineering and management after the war and crept into industrial practice. Because of the interesting theory involved, OR found a home in university curricula soon after the War. Courses were offered at Hull University by Swann; soon afterward, 1958–1959, the first graduate-degree program in OR was offered at Birmingham (D.J. White, personal communication).

Another, separate contribution of scientists and engineers in World War II was the development of the techniques of automatic control. As weapons became faster, larger, and more powerful, it became increasingly less practical to operate them by hand. The aerodynamic pressures on the control surfaces of large, high-speed bombers grew so great that mechanical boosters were necessary. Multiple machine guns mounted in these bombers were so heavy that gunners could not move them unaided. The gun turrets of naval warships had to be stabilized against ocean-wave motion if the guns were to be effective. Late in the war, automatic navigation systems for aircraft and ships, as well as ways of allowing radar automatically to direct weapons fire, were sought.

For these and other applications, design engineers first thought that simple mechanical and hydraulic boosters could be used to substitute for the muscles of humans. But in many cases when the boosters were added, the mechanisms failed to operate as expected. Sometimes the units did not work at all and in other cases the units went into wild, uncontrollable oscillations before destroying themselves. Many potentially valuable devices were rendered useless by these mysterious failures. For months it appeared that a fundamental limitation dictated by unknown laws of nature was at work.

Help came from an unexpected source. For a number of years, telephone engineers at the Bell Laboratories had been attempting to understand the oscillations set up in electronic amplifiers needed for long-distance telephony. Beginning with H. S. Black's investigations on the theory of negative feedback (Black, 1934) and culminating in the classic work of Bode (Bode, 1945), the theoretical principles for analyzing and stabilizing feedback systems were laid bare. Workers at Bell Labs and at General Electric Laboratories reduced the theoretical principles to practice. Dramatic stories can be told of the stabilization of the B-29 bomber fire control system and of the Navy gyroscopically controlled gun laying systems, after unstable devices were in production and being installed on operational units. The best overall documentation of this wartime effort remains Volume 25 of the Radiation Laboratory series (James et al., 1947).

From this beginning, the theory of feedback has been developed to include complex systems with many interacting elements and with humans as integral parts of various loops. Following the war, as analog computers became widespread in university and industrial research laboratories, feedback automatic-control theorists and others developed an intense interest in the concept and practice of dynamic computer

1.10 DEVELOPMENT OF SYSTEMS ANALYSIS AS A DISTINCT DISCIPLINE 17

simulation models of whole industrial processes, cities, and, some say, the world. See Sections 5.10–5.16.

One further precursor of system analysis remains to be mentioned . . . econometrics. John Maynard Keynes was a seminal figure in economics in the period between World Wars I and II (Harrod, 1951). He early conceived that by manipulating and controlling certain parameters of a nation's economy, one could influence almost all other segments of the nation's economic life. When one proposes to influence the economy of a nation, much more is needed than merely qualitative descriptions of the processes involved. Keynes played a leading role in beginning the conversion of economics from a qualitative, descriptive art into a quantitative science that continues today. Keynes influenced the transition to quantitative economics or econometrics, not only by his prolific writing, but also by playing an active role in the British government. He was also fortunate in attracting several brilliant and prolific individuals to become early followers, among them P. A. Samuelson (Stiglitz, 1966).

In 1941 Leontief published his classic work on input–output models, which is still widely used (Leontief, 1941). The Leontief economic model of a nation is a static representation. It provides within itself no predictive capability, although, of course, a series of such static descriptions can be used as a basis for extrapolation. Yet the immense expense of collecting even these static coefficients for a model of the United States that is sufficiently disaggregated to be of value is staggering. Even with the resources of the U.S. Government, data for 1967 were not published until 1974 (U.S. Department of Commerce, 1974)! Despite these difficulties, econometricians have pushed forward into dynamic modeling of the nation's economy. Among the leaders of this more recent effort was Lawrence Klein and his Wharton model (Klein, 1950; Klein and Goldberger, 1955; Anonymous, 1975). With increased use of advanced statistical techniques, dynamic modeling, and so on, econometrics and operations research now began to find common ground (Teil et al., 1965).

Industrial management, operations research, automatic control system design, and econometrics appear to the systems analyst as precursors to his generalized discipline. Yet active practitioners of each of these specialties might resent the implication that they are somehow being superseded by a new group of generalists. Thus we need to remind ourselves that it is all in one's point of view. Perhaps we system analysts ought to acknowledge our "parent disciplines" rather than calling them precursors.

1.10 DEVELOPMENT OF SYSTEMS ANALYSIS AS A DISTINCT DISCIPLINE: THE INFLUENCE OF RAND

Operations research emerged from World War II as a new and exciting approach to the organization of large-scale groups to accomplish specific goals. But why limit OR to the operational deployment of men and machines? Why not use it as well for discovering what new devices and processes are needed to meet defined goals? The need for a rational, objective process of analysis of all factors is especially relevant in the development of large weapons systems such as guided missile systems and in private

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industry in such complex undertakings as long-distance telephone networks and airline operations. The name “operations research,” always rather confining, seems inappropriate for this newer, broader mission, which includes operations as only one portion of the cycle of bringing a new device into being and using it efficiently. Terms such as “system analysis,” “system design,” “systems engineering,” and the “system approach” began to be more commonly used.

When many diverse parts of a large-scale system must be designed so as to work together in a harmonious whole, and especially when it is difficult or impractical to test the parts in advance of final assembly, a systematic approach is almost mandatory. The U.S. Air Force and AT&T were among the first organizations to recognize this. The Air Force set up a system command to study the overall problem of bringing the intercontinental ballistic missile into the U.S. defense arsenal, and in 1948 it sponsored the formation of the RAND Corporation (Smith, 1966). RAND’s charter was to develop and apply the system approach to a wide range of Air Force problems. RAND’s independence allowed it the necessary freedom to develop the skills needed for solving large, long-range problems without day-to-day interference and diversion of personnel to meet tactical emergencies. Later it was recognized that these new system skills being developed by RAND were of general applicability.

The Air Force supported RAND as an external contractor and it enjoyed rather wide freedoms. RAND paid excellent salaries, provided pleasant working conditions in a nonmilitary atmosphere, and addressed challenging problems of its own selection from a shopping list proposed by the Air Force. One of the difficulties of professional life in a think tank such as Arthur D. Little, SRI, Calspan, Battelle, and so on, is the need continually to “sell one’s time.” This can lead to compromises in the kind of work undertaken and the quality of the results (Dickson, 1971). RAND was free of this concern.

RAND was a prime mover in the development of such theory as linear programming, decision theory, dynamic programming, Monte Carlo simulation, game theory, and PPBS (Planning and Performance Budgeting System). Its counsels were sought at the highest strategic levels. A young systems professional at RAND could influence the course of world events, a heady experience. Smith, in his well-done book, credits RAND with the original development of policy-oriented system analysis. RAND began its work as a project office in Douglas Aircraft Company, doing standard operations research tasks for the Air Force.

In the early years. . . RAND studies tended to be engineering efforts or else analyses of rather low-level problems akin to what operations researchers did in World War II. The studies were elaborately mathematical in nature and showed little concern for integrating a number of complex variables, some qualitative in nature, into a broad context of some future ‘system’ whose contours and implications in terms of military effectiveness can only be dimly foreseen.

[Smith, 1966, p. 103]

Gradually, however, RAND personnel began to develop what Smith calls “a strategic sense.”

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Something of a revolution took place in the 1950s which transformed the typical RAND systems analysis from a narrowly technical product into a novel application of numerous professional skills to a broad policy problem.

[Smith, 1966, p. 104]

While the proportion of broad-scale policy analysts at RAND never exceeded 15% of the professional staff at any one time, Smith argues that this policy flavor, or “strategic sense,” is what set RAND’s system studies apart from the more traditional, narrowly technical OR studies done by other organizations of the period, and which in effect created the wholly new area of policy science (Smith, 1966, p. 105).

In the 1960s, the influence of RAND began to wane. Competing organizations such as SDC, MITRE, and ANSER were spun off from RAND, but none were given as long a leash. The Viet Nam war was divisive for RAND. Daniel Ellsberg of the “Pentagon Papers” fame was a former RAND employee. Air Force support was cut back, and RAND sought and received permission to seek funding from other sources. This was a period of great social ferment, and when Mayor Lindsay invited RAND to set itself up in New York City and to apply system techniques to the organization of snow removal and garbage collection, RAND obliged. However, RAND/NYC found that urban problems are more complex than aerospace system problems (Szanton, 1972).

Urban goals are often left obscure on principle, RAND/NYC discovered to its befuddlement. The client is ill-defined, and lethargy, the *status quo*, and discrete incrementalism are the rule in urban bureaucracies. RAND/NYC funding stopped in 1973. The RAND/NYC experience seems to teach several things. Certainly, RAND’s system approach to social problems was superior to the earlier and equally well-intentioned State of California effort to enlist aerospace contractors to address pressing public issues at the state level (Gibson, 1977, pp. 59–91). Yet there remained much of the naïve, ingenuous, academic, abstract flavor in the RAND/NYC studies and little of the experienced, realistic, slightly cynical, but still hopeful veteran. Perhaps the RAND/NYC program needed fewer fresh Ph.D. Eagle Scouts and more Kojaks.

RAND alumni moved into positions of influence throughout the Defense Department and into universities, carrying with them linear programming, queuing theory, dynamic programming, decision analysis, benefit–cost analysis, and the whole analytic tool kit now so familiar in operations research. RAND also helped define the general steps to be taken in a system analysis, including explicit development of goals and quantitative indices of performance, the development of alternative scenarios, trade-off studies, and the like.

Opposition came from simple inertia and reluctance to change. Other opposition to the “systems approach” was and is generated by the behavior of system analysts themselves. If one goes into an existing organization with an arrogant attitude of superiority, one is not likely to gain the cooperation of the old timers. There is also informed opposition to inflated claims of incompetent charlatans posing as skilled professionals. And finally there is opposition from those who understand quite clearly that an objective, careful analysis of the current situation is likely to uncover the existence of sloppy, comfortable or self-serving behavior and require a change of

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ways. Stockfish (1970) provides an anecdotal description of some of these sources of opposition to the installation of the system approach.

Other laboratories in the United States were also developing and utilizing the new tools in addition to RAND; of course, the Willow Run Research Center of the University of Michigan is among them. Out of Willow Run came the first comprehensive text on the design of large-scale systems, Goode and Machol (1957). Five years later, Hall's classic text (Hall, 1962) appeared, based on his work at Bell Labs. Hall introduced for the first time a comprehensive, integrated general methodology for the analysis and synthesis of large-scale systems.

HISTORICAL CASE STUDY: IIASA (A)

By the early 1970s, excessive claims and subsequent failures had generated a critical reassessment of the system approach. Prominent among SA critics is Hoos (1972). Hoos does not attempt to be objective but rather adopts an adversarial position. Nevertheless, several of Hoos' arguments are well-taken. One of these has to do with the choice of an optimizing criterion. Hoos charges that analysts often pick a criterion for optimization simply because it is easy to measure rather than because it truly measures the desired goals.

Hoos concentrates on the mistakes made by some of those former aerospace system analysts who turned to social system design when the aerospace industry took a downturn in the 1960s, and one must admit that she was offered a number of ripe targets. She missed one major target in particular, however. Robert MacNamara is a prototypical system analyst in the RAND tradition, and he forced PPBS on the Defense Department when he was Secretary under JFK and LBJ. It was this PPBS style that developed the justly infamous body-count criterion in Viet Nam. Some of these same problematic metrics still continue to exist in the 2003 (and on) war in Iraq.

Former aerospace persons do not have a monopoly on creating system errors, however. Computer simulations in particular and urban system studies in general have attracted the ire of Brewer (1973). Brewer documents the selling of computer simulation studies for the cities of San Francisco and Pittsburgh by two different system teams in the 1960s. Neither simulation worked, and Brewer's analysis shows why.

A current model of a large-scale systems organization, and one on which it may still be necessary to reserve judgment after almost 35 years of wandering, is the International Institute of Applied System Analysis (IIASA) (Anonymous, 1972). Founded in 1972 as an element in East-West political "detente," and with a prominent scholar and RAND alumnus as director, IIASA was supported by the United States, the Soviet Union, and about a dozen other nations. Austria refurbished Schloss Laxenburg, a former Habsburg hunting lodge on the outskirts of Vienna, and invited IIASA to occupy it. Located near Baden and the Vienna Woods and restored to its original Baroque grandeur, the Schloss provides a sumptuous, almost decadent atmosphere within which system analysts their wonders to work.

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A defender of the founding director points out that it is a miracle that IIASA exists at all. It was clearly to be an instrument of international diplomacy and a gesture toward detente, yet, in practice, IIASA analysts were buffered from political interference, for which the founding director may deserve credit. A good, if not distinguished, professional staff was assembled and individuals were encouraged to go about self-chosen tasks at Louis XIV desks, surrounded by purple velvet walls embossed with gold fleur-de-lis, and multilingual secretaries were employed; coffee and cakes were served *mit schlag*, by uniformed staff, in the courtyard or on the terrace. A corps of para-professional assistants substituted for graduate students; computers, a library, and free chauffeured limo service to and from downtown Vienna were available.

A management system analysis, of the sort invented at RAND, would have uncovered a number of organizational problems faced by IIASA. Here are several such issues that were evident but unsolved during IIASA's first decade.

1. Absence of Goals Structure. IIASA had no discernible goals structure. By "discernible" one means evident from a close reading of the available IIASA literature, including its rather large number of glossy publicity pieces, or from personal conversations with IIASA professionals and administrators of the period, or as revealed in seminars and lectures given by IIASA officials, some videotaped and widely distributed.

Problems for study appear to have been accepted or rejected on the basis of the personal whim of individual professional staff members. Some important problems were chosen for study by IIASA individuals and groups. However, this choice appears to have been based on personal interest.

2. Absence of System Approach. Despite its name, IIASA did not practice any definable system approach. Many of the professional staff vigorously denied that any such thing as a "systems methodology" exists. This produced certain tensions between IIASA personnel and the systems community.

3. Absence of Systemic Management Structure. Admittedly, to gather professionals from over a dozen nations with as many languages and social backgrounds and to expect immediate consensus is unreasonable. Yet the IIASA professionals do (i.e., should, if properly recruited) share a common background of interest in system analysis. They are volunteers who should understand the need for collegial cooperation. Thus a minimal sense of order should have been relatively easy to achieve.

Yet three years after it opened its doors, IIASA management had permitted more than 10 major study areas to be established. Because there were 70 professionals, only half of whom were in residence at IIASA, the average group could expect to have only about three resident professionals working on a problem. A competent manager should understand that this is hardly sufficient to make an international impact.

The allocation of resources was overbalanced toward technical support personnel and under-allocated toward library and database resources. Short-term professional appointments appeared to have been the rule; furthermore, the comings and goings, while adding a pleasant sense of excitement and a little-needed excuse for another party, interfered with sustained work on important problems. A short-term visitor, no

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matter how distinguished, working on his own problem added nothing to the solution of IIASA-selected problems and indeed could and did interfere with their solution by requiring attention and resources and by distracting those few professionals who had been persuaded to give up work on their own problem to work on a team problem.

Study topics were often unwisely chosen. A project on the causes of Austrian highway fatalities stumbled because the professional responsible finished his tour of duty and left IIASA before the data could be assembled and shipped to the Schloss. Often the nominal group leader absented himself in body or spirit. Some group leaders were away from the Schloss for months at a time, and other leaders apparently felt no responsibility for coordinating the direction of their group. More than one group "leader" simply appropriated group resources to apply to his own problem and his own publications.

All of these problems are perfectly simple to forestall or to correct, given a reasonable management structure. Most developed simply from inexperience in the predominantly young professional staff, who generally were on their first independent professional assignment.

4. Failure to Internalize Appropriate Goals. IIASA saw itself as something of an international political football. Whether this is true or false, in fact, is irrelevant to the following argument. But, as a matter of fact, some outside observers would argue that IIASA has been remarkably free of outside interference. What some naïve young IIASA professionals interpreted as interference seems to some external observers to have been a minimum of concern by donor nations as to how their tax dollars are spent.

One could argue that the professional staff members at IIASA had not internalized an acceptable professional goals structure. When some of these people were asked by a visitor if they would explain the overall professional goals at IIASA, they replied that they are unable to do so, but added that the question seemed irrelevant because each individual was interested only in "doing my own thing."

When one visitor asked if this refusal to generate an appropriate goals structure might not interfere with continued funding, he was told, "Don't be silly, two million dollars a year (the initial U.S. contribution) is a cheap price to pay for East-West detente." This is a "let them eat cake" response that lacks all contextual integrity. It indicates a cynicism that saps a commitment to acceptable professional goals. It is clear that this attitude was dangerous for IIASA, but even more so for young professionals who expected to have a successful career elsewhere.

5. Failure to Build Constituencies. Several natural constituencies exist for IIASA. Unfortunately, none of these were cultivated. IIASA publications policy was confused and was addressed toward unfocused and conventional academic clienteles, not necessarily a part of the natural system constituency. What are some examples of natural constituencies? The most obvious is satisfied clients. If IIASA could produce applied system studies, which are declared effective by users, this would provide important rationale for continued support.

A second natural constituency is the international body of system practitioners in industry, government, and universities. If these individuals could be persuaded to view IIASA as the paradigmatic systems institute, it would be a mark of public esteem

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and recognition. If, in addition, IIASA were to demonstrate ideal methodologies and excellent performance in practice, it would act to raise and unify standards of system practice worldwide.

By failing to perform so as to attract the support of these natural professional constituencies, IIASA will be forced into the role of international political whore in order to solicit funds for reasons not related to its professional performance. Thus to view itself as a political football was not only to cripple its own resolve, but also to produce a self-fulfilling prophecy.

As econometricians and other social scientists became interested in the concepts and the utility of feedback theory and computer simulation following World War II, they extended the ideas, without proof, to fields that ranged far afield from the design of engineering systems, or so-called “hard systems.” The attempts to apply these tools and concepts to “soft system” design, urban systems, governmental systems and social systems in general have not proven as successful as they have been in the design of electromechanical and aerospace systems. The terms “hard systems” and “soft systems” are used in the literature analogously to the conventional terms “hard science,” i.e., rigorously quantitative such as mathematics, physics, and chemistry, and “soft science,” i.e., nonquantitative such as psychology, and sociology.

Soft systems are those in which people and their sociology play a major role. We have not learned to describe actions of societies with simple linear differential equations, but systems of such equations describe the electromechanical world quite nicely. Some politicians said in the 1970s:

“If we can put a man on the moon, why can’t we cure poverty in our cities?”

One answer is:

“Because the mathematics and physical laws that govern space flight have nothing whatever to do with poverty in the cities and other urban affairs.”

But urban systems and other soft systems have an undeniable fascination, and we system analysts, instead of turning our backs, have attempted to do what we can (Gibson, 1977). We can see that the RAND effort to add a policy orientation to its OR work began to lead us into the “soft” system arena. However, the RAND policy orientation generally entered, prior to its NYC misadventures at least, only into the interpretation of the results or the constraints on the problem, not into the essential core of the analysis. RAND did not recognize this distinction, however, until it was too late.

The differences and similarities between “hard” and “soft” systems have attracted the attention of a wide range of thinkers (Tominson and Kiss, 1984), and progress is being made in ameliorating the difficulties. When we think about it, perhaps the distinction between hard and soft is one that latter-day analysts developed for their own convenience. After all, operations research originated in people-oriented problems in

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World War II. We drew away from these people-oriented or client-oriented problems to suit our own analytic convenience.

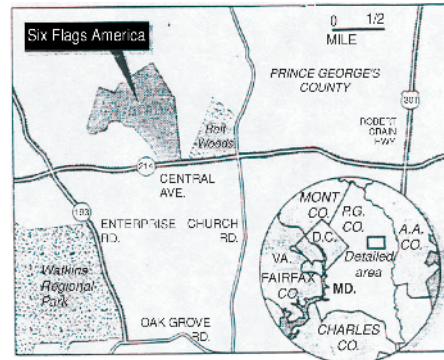
Where is systems analysis today? Ubiquitous. All industries and government agencies have people engaged in the practice of systems analysis. Such people may work under varied titles—operations analyst, systems analyst, “manager,” systems architect, systems engineer, business analyst, operations specialist, and so on; the list goes on and on.⁴ In the course of the following chapters we give approaches, insights, and examples beneficial to anyone engaged in the design and analysis of systems.

EXERCISES

- 1.1 The World Bank made a major intervention during the period 1950–1962 into the economy of Colombia by lending it an amount almost equal to 20% of its annual GNP to reconstruct its national transportation system. However, this intervention had important and unforeseen cross-impacts. Read Haeefe (1969) on the matter for class discussion. This seems to be an exemplar of some of the dangers inherent in broad-scale social planning for third-world nations without careful controls and detailed analysis by local experts.
- 1.2 Review the discussion concerning the Washington Metro Rail expansion discussed for Northern Virginia, which would expand Metro through Tyson’s Corner to Dulles Airport. Discuss the complexities associated with this proposal and the likely issues that must be addressed in order for a successful system modification.

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THE WASHINGTON POST
Metro
Traffic Stalls Six Flags Fun for Many
Jackie Spinner
Washington Post Staff Writer

FIGURE 1.3 Ted's fax.

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Traffic overwhelmed the main highway serving the new **Six Flags** America amusement park in Prince George's County yesterday as the number of parkgoers grew so large that parking lots ran out of room and frustrated families began leaving their cars on shoulders and nearby grassy areas.

The four-lane Route 214—one of the main arteries through the central part of the county—was clogged for hours between St. Michael's Drive and Church Road, angering visitors as well as residents trying to run weekend errands.

Weekend congestion has been an off-and-on problem since the old Adventure World park reopened May 8 with the new **Six Flags** brand name and a \$40 million expansion.

Park officials acknowledged that they have been overwhelmed by the record-setting number of visitors who have flocked to the revamped park. Officials had expected 7,000 people on opening day, when 21,000 turned out.

Visitors have raved about the new attractions based on Warner Bros. and DC Comics characters. Crowds started arriving yesterday a half-hour before the park opened at 10:30 a.m. By 4:15 p.m., parking had run out and gates to the lots were closed, forcing customers to begin looking for space on the shoulders and grass along Route 214—which in turn caused problems for police, who said the practice was illegal.

"It was a mess. It's terrible," said Steven Kiefner, of Baltimore, who found a spot near a church a half-mile from the park.

There are 5,000 parking spaces at the amusement park, and attendants squeezed hundreds of other cars onto the site wherever they could find space. Park officials said they are considering converting an employee lot into customer parking, among other options.

"The system temporarily broke down," said John Mulcahy, marketing director for **Six Flags** America. "It's growing pains. It's a matter of working with other agencies to get a handle on it."

The congestion yesterday afternoon confounded park and police officials, who had believed that the problem had been resolved a week ago when the timing of the traffic signal at the park entrance was changed to allow more cars during each cycle to make the left-hand turn from eastbound Route 214. Traffic was not nearly as bad last weekend as it was on opening day.

But the backups returned yesterday—particularly for those attempting the left-hand turn.

Mulcahy said the slowdowns intensified when parking attendants failed to open additional lots to accommodate a surge in traffic about noon. Cars were squeezed together under trees and on grassy hills. Even some of the overflow lots were full an hour after the park opened.

Maryland State Police Sgt. Michael Hawkins said officers were sent to the scene to monitor the situation and to help determine whether other traffic signals along Route 214 will have to be adjusted.

"They have only one entrance there, and that can't happen for an amusement park this size. They are going to have to add an extra entrance or widen 214. It's just not working," Hawkins said.

Karen Wright, an Upper Marlboro resident, could not believe the traffic jam that awaited her on 214, also called Central Avenue, when she left the Giant Food supermarket in Mitchellville Plaza about 1 p.m.

"Without **Six Flags**, it was bad enough," she said. Now, "it's outrageous."

Katherine Isaac, a District resident, got out of the traffic to fill her car with gas at a Mobil station at Enterprise Road. She was on her way to see her son play baseball. She was already an hour late and did not expect to make it there before the end of the game.

"It's ridiculous that I have to sit in this traffic," she said.

Greg Waul avoided the gridlock by navigating the back roads from his home in Bowie to the barbershop at the Mitchellville Plaza. He said the traffic on Central Avenue was worse yesterday than what it is during a normal rush hour.

"This is bad, especially for a Saturday," he said. "You don't expect this on a weekend. I guess **Six Flags** is doing all of this. It wasn't like this when it was Adventure World."

CASE STUDY: FUN AT SIX FLAGS?

May 1999. Ted returned from his yearly retreat week deep in the woods (without his cell phone) to find urgent messages in his e-mail, voice mail, and mailbox—there had been some problems at the amusement park over the weekend. His boss, Mary, requested a meeting in her office @ 9:00 AM. Given that it was 8:15 AM, Ted had less than one hour to prepare some thoughts.

Recalling that his college roommate, Bill, was a senior consultant with IQC (International Quality Consultants), Ted decided to get some quick help with the problem. He phoned Bill, and to his surprise, Bill actually answered the phone. Unfortunately for Ted, Bill answered the phone from a base camp on Mt. Everest where he was beginning his month-long climb (Bill was one of the several subscribers to Iridium and was, therefore, reachable anywhere in the world). Bill told Ted that he could fax any information he had to one of his top young people, Lisa, who would send him back some thoughts in the next 30–45 minutes. Ted thanked Bill and wished him luck on his climb, and as he was hanging up he wondered what the odds were that Bill would survive the climb and he began working through the probabilities . . .

Lisa received Ted's fax (a brief newspaper article—shown in Figure 1.3) and Bill's request to help as she was settling down to get an early jump on an RFP that was due next week. So much for the RFP—she had at most 45 minutes to put something together and get it to Ted.

HISTORICAL CASE STUDY: IIASA (B)⁵

Glenn Perrier, a consultant for Crystal Banditz, was sitting in his office early one Spring morning in 1985, soon after he had joined the firm, looking out over the Potomac at the White House. His boss, Tom McNeil, walked in and remarked with a smile: “Glenn, I have an assignment that I think is just right for you. I got a call this morning from Tony Sarducci over at the Department of Energy and he wants us to take a look at the International Institute of Applied Systems Analysis (IIASA).”⁵

Glenn took his feet off the desk and responded, “I've never heard of IIASA, Tom. What's it all about, and what's it got to do with DOE?”

“IIASA is an international organization located near Vienna, Austria, that performs large-scale systems studies. It has been funded by the Soviets, ourselves, the Brits, the Germans, Canadians, etc. Anyway, the American Academy of Arts and Sciences took over the role as the American Member of IIASA after the Reagan Administration decided that the National Science Foundation wouldn't be allowed to continue to pay the \$2.3 million in annual dues. The Academy is a private organization and is currently supporting its membership in IIASA by getting contributions from individual private foundations. It recently proposed that Federal agencies such as the Department of Energy be allowed to contribute to IIASA if they wish.”

“So where do we come in?”

“IIASA hired a new Director, Thomas Lee, in October of last year who seems to be a decent manager. He is an old GE type and was a student of Harold Chestnut, a

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well-known system engineer. Tony wants us to check him out to see if he has things moving in the right direction over there. Tony's afraid his boss might be premature in contributing DOE money to IIASA. In order to protect his boss, and himself, he has agreed to let us charge a few hours to our standing work order with DOE to check it out. I'll need to tell him something by next week."

"Is that going to be enough time for us?"

"There may not be enough time for us, but that's all the time you have."

Tom started to walk out when Glenn shot to his feet and said with some dismay, "Wait a minute, Tom, I'm new here, and I have no idea of what you want. I need some guidance."

Tom stood thinking for a moment and obviously he was somewhat annoyed at the need to spoon-feed Glenn. Then he seemed to say to himself, "O.K., just this once."

"Well, Glenn, this is a systems house and we expect our professionals to be able to work on their own. We don't have the time or inclination to keep you under a tight leash. I suppose that the first thing you should do is to find out something of the background of IIASA. I seem to remember that it was a product of detente and that some guy from Harvard was the first director. Tony gave me the copy of the IIASA house organ I just gave you. It has an article by Lee in it (Lee, 1984).

I'll expect a 20-minute presentation by you in my office next Thursday afternoon. It won't be formal, but I will need some explicit points to give to Tony, and I'll need some recommendations for him as well."

Questions on IIASA (B)

1. Precisely what is the problem at IIASA?
2. Who has the problem?
3. Why did IIASA get into trouble?
4. What does Lee intend to do about it?
5. What will be the internal impacts of Lee's initiatives?
6. What will be the external impacts of Lee's initiatives?
7. Are there general lessons to be learned from the IIASA experience?

References for IIASA (B)

- Anonymous (1981). U.S. announces pullout from IIASA in Vienna. *Science*, Dec. 11. p. 1222.
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- Anonymous (1982). British join U.S. in IIASA pullout. *Science*, Sept. 10. p. 987.
- Lee, T. H. (1984). Director's corner. *OPTIONS*, newsletter of the International Institute of Applied Systems Analysis, Laxenburg, Austria.
- Holden, C. (1984). IIASA wins support. *Science*, Oct. 12. p. 150.

28 INTRODUCTION**NOTES**

1. Some definitions of a system do not require goal-directed behavior, especially some from General Systems Theory; see Flood and Carson (1993).
2. See, for example, Buede (2000), Blanchard (2004), Sage and Armstrong (2000), Sage (1992), Daellenbach (1994), and Blanchard and Fabrycky (1998).
3. Military standard MIL-STD-499B, never formally released, was designed to address systems engineering as a whole. The prior standard that was released, MIL-STD-499A, focused on the management function of systems engineering. See Honour (1998).
4. See the International Council on Systems Engineering (INCOSE; www.incose.org) for an extensive collection of publications on systems engineering, standards, and so on, and current working groups and information on issues such as SE certification.
5. This case does not necessarily illustrate either good or bad management and is meant solely to provide a basis for classroom discussion. The inclusion of DOE in the case and the existence of Crystal Banditz Inc. are totally apocryphal.