Systems Management

for Information Technology and Software Engineering

Andrew P. Sage

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SYSTEMS MANAGEMENT FOR INFORMATION TECHNOLOGY AND SOFTWARE ENGINEERING

ANDREW P. SAGE
School of Information Technology and Engineering
George Mason University
Fairfax, Virginia

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Preface

This book discusses some fundamental considerations associated with the engineering of large scale systems, or *systems engineering*. We begin our effort by first discussing the need for systems engineering, and then providing several definitions of systems engineering. We next present a structure describing the systems-engineering process. The result of this is a *lifecycle model* for systems engineering processes. This process may also be called a product line. An organization generally has a number of processes associated with various functional areas of the organization. At a very general level, we may identify processes for research, development, test and evaluation of new and emerging technologies. We may also identify the process for acquisition or production of a system. And, we may speak of a process for planning and marketing. These are the three primary organizational processes that we examine here.

This systems management text discusses important concerns for the trustworthy development of process related approaches for the development of trustworthy systems, especially but not exclusively from the perspective of information technology, information systems engineering, and software systems engineering. The special and dominant focus of the book is the systems management of processes for information technology and software development organizations. This involves a number of very relevant issues associated with systems architectures and integration, quality assurance and management, organizational leadership and learning, process reengineering and process maturity, metrics, software economics, and cost and operational effectiveness analysis for the management of large information technology and software intensive systems.

There are many ingredients associated with the development of trustworthy systems. From a top down perspective, the following ingredients are surely present.

- process development life cycles
- process risk and technical direction for risk management
- metrics for systems management
- metrics for cost and operational effectiveness evaluation, and process cost estimation
- strategic quality assurance and management, or total quality management, and process and product development standards for quality
- organizational cultures and leadership, and process maturity
- reengineering at the level of systems management, process, and product.

These comprise the principal chapters in this book and will follow an introductory chapter that summarizes the book structure, function, and purpose.

Other ingredients could be easily identified. For the most part, however, these seven subject matters can be considered as *top level* supports for the objective of obtaining trustworthy and productive systems engineering products that are of high quality. Although we will be concerned with systems of hardware and software that support a variety of applications, our primary focus will be on information technology and software development areas. While most of our discussions will specifically focus on software, the ultimate applications for the constructs to be described are broader than the very important area of software development.

This text is written both for graduate students and practitioners in industry and government who are concerned with systems engineering, and such related areas as engineering management. It should also have value for other engineering areas that offer courses in systems management, such as in business administration and technology management. Prerequisites for the text are moderate. It will generally be assumed that the reader has a fundamental background common to Bachelor of Science degree recipients in the USA. Perhaps more importantly, some appreciation for the engineering design of large systems is assumed. The book is not specific to any particular engineering specialty. Doubtlessly, the experiences of the author in software systems engineering, decision support systems engineering, information systems engineering, systems management of emerging technologies, and command and control systems engineering have influenced the presentation. However, advanced level courses in these areas are not at all needed for the presentation contained here and what we discuss is ultimately as relevant to construction management, water resource management, and manufacturing management, as it is to information technology and software engineering productivity.

ANDREW P. SAGE

Fairfax Virginia
August 1, 1994

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Chapter 1

An Introduction to Systems Engineering and Systems Management

This chapter provides a perspective on all of systems engineering and, within that, systems management. This is a major challenge for a single short chapter. We believe that some appreciation for the overall process of systems engineering will lead naturally to a discussion of the important role for systems management and the applications of this to information technology and software development processes. Following our introductory comments, we briefly describe the organization of the text.

Here, as throughout the book, we are concerned with the engineering of large scale systems, or *systems engineering* [1]. We are especially concerned with strategic level systems engineering, or systems management. We begin our effort by first discussing the need for systems engineering and then providing several definitions of systems engineering. We next present a structure describing the systems engineering process. The result of this is a *lifecycle model* for systems engineering processes. This is used to motivate discussion of the functional levels, or considerations, involved in systems engineering efforts: *systems engineering methods and tools, systems methodology,* and *systems management.*

Figure 1.1 illustrates the natural hierarchical relationship among these levels. There will be some discussions throughout this chapter and the others on systems engineering methods and systems methodology. Our primary focus, however, is on systems management and technical direction of efforts that are intended to ultimately result in appropriate information technology and software engineering products or services. These products result from an appropriate methodology, an appropriate set of systems engineering methods and tools, and the resulting product line or process effort. These are guided by efforts at systems management as suggested in Figure 1.1, and as we will discuss throughout this text.

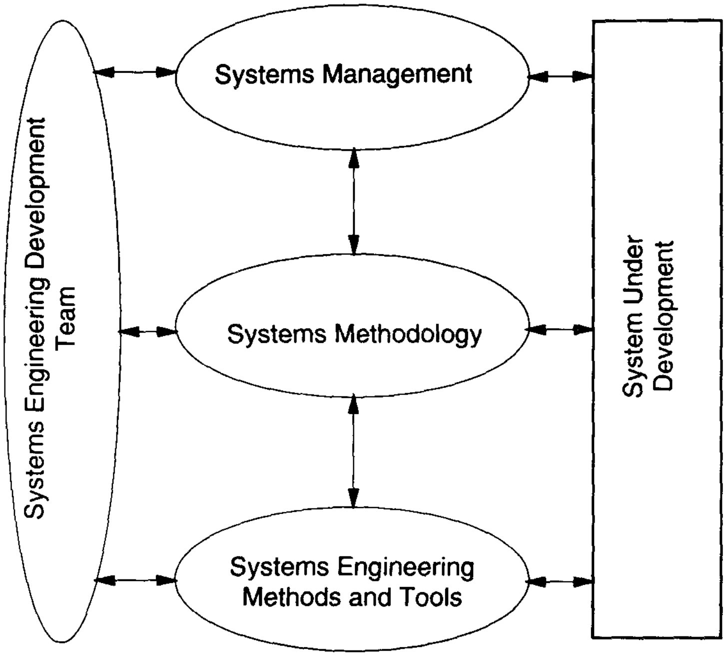

Figure 1.1 Conceptual illustration of the three levels for systems engineering.

1.1 SYSTEMS ENGINEERING

Systems engineering is a management technology. Technology is organization, application, and delivery of scientific knowledge for the betterment of a client group. This is a functional definition of technology as a fundamentally human activity. A technology inherently involves a purposeful human extension of one or more natural processes. For example, the stored program digital computer is a technology in that it enhances the ability of a human to perform computations and, in more advanced forms, to process information.

Management involves the interaction of the organization with the environment. A purpose of management is to enable organizations to better cope with their environments such as to achieve purposeful goals and objectives. Consequently, a management technology involves the interaction of technology, organizations concerned with both the evolution and use of technologies, and the environment. Figure 1.2 illustrates these conceptual interactions.

Information is the glue that enables the interactions shown in this figure. Information is a very important quantity, which is assumed to be present in the management technology that is systems engineering. This strongly couples notions of systems engineering with those of technical direction or systems management of technological development, rather than exclusively with one or more of the methods

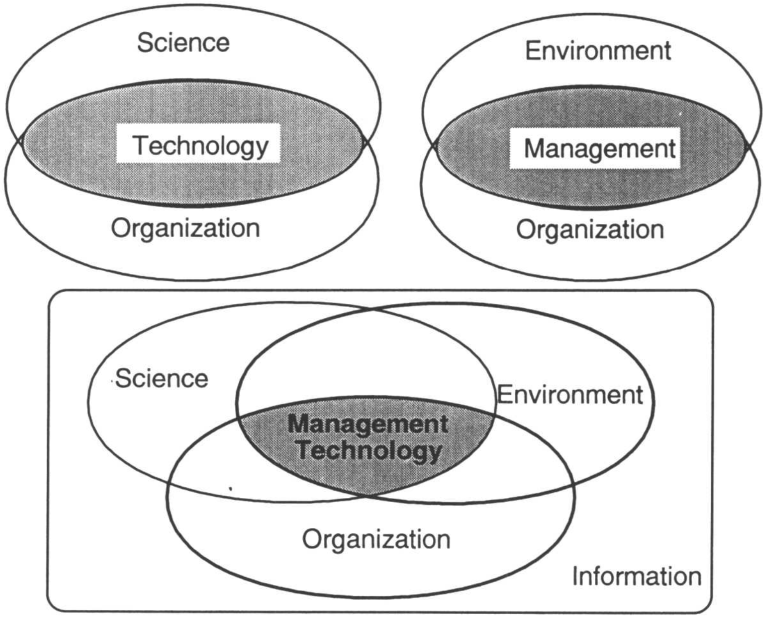

Figure 1.2 Systems engineering as a management technology.

of systems engineering, important as they may be for the ultimate success of a systems engineering effort. It suggests that *systems engineering is the management technology that controls a total system lifecycle process, which involves and which results in the definition, development, and deployment of a system that is of high quality, trustworthy, and cost effective in meeting user needs*. This process-oriented notion of systems engineering and systems management will be emphasized here.

Figure 1.3 illustrates our view that systems engineering knowledge is comprised of the following [2]:

1. Knowledge *perspectives,* which represent the view that is held relative to future directions and realities in the technological area under consideration.
2. Knowledge *practices,* which represent the accumulated wisdom and experiences that have led to the development of standard operating policies for well structured problems.
3. Knowledge *principles,* which generally represent formal problem-solving approaches to knowledge, generally employed in new situations and/or unstructured environments.

Clearly, one form of knowledge leads to another. Knowledge perspectives may create the incentive for research that leads to the discovery of new knowledge principles. As knowledge principles emerge and are refined, they generally become imbedded in the form of knowledge practices. Knowledge practices are generally

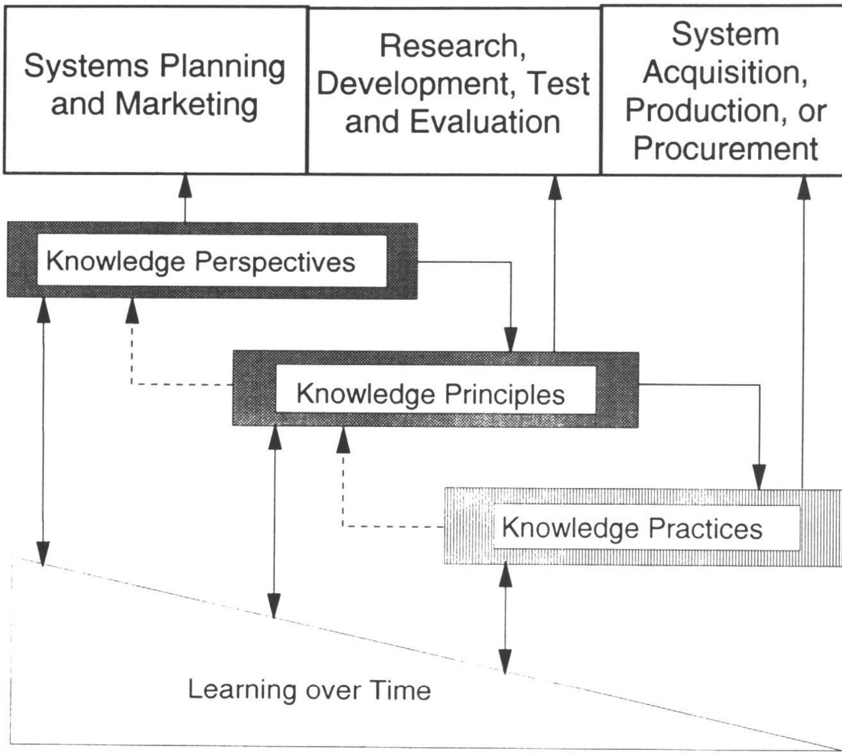

Figure 1.3 Systems engineering knowledge types.

the major influences of the systems that can be acquired or fielded. These knowledge types interact together, as suggested in Figure 1.3, which illustrates how these knowledge types support one another. In a nonexclusive way, they each support one of the principal lifecycles associated with systems engineering. Figure 1.3 also illustrates a number of feedback loops that are associated with learning to enable continual improvement in performance over time. This supports our view, and a major premise of this text, that it is a serious mistake to consider these lifecycles in isolation from one another.

It is on the basis of the appropriate use of these knowledge types that we are able to accomplish the technological system planning and development and the management system planning and development that lead to an innovative product or service. All three types of knowledge are needed. We will soon discuss these three different lifecycles for technology evolution:

System Planning and Marketing

Research, Development, Test and Evaluation (RDT&E)

System Acquisition, Production, or Procurement

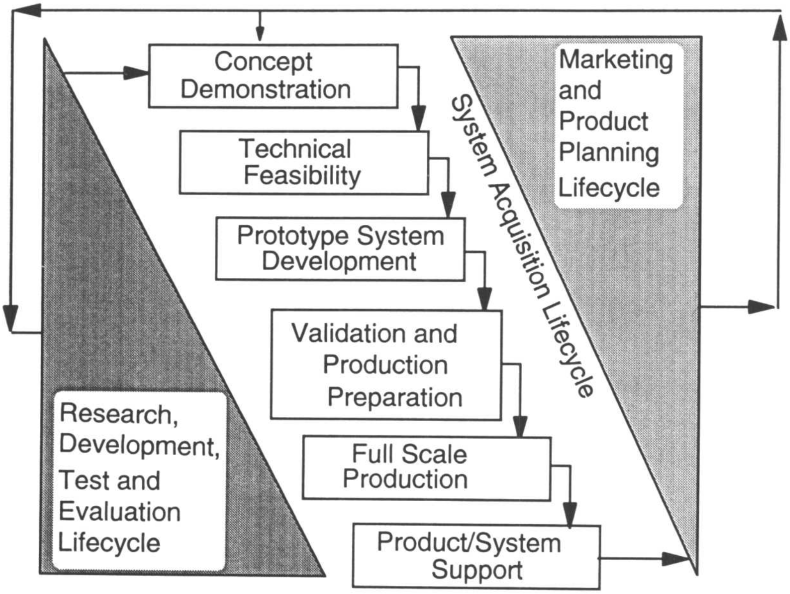

Figure 1.4 Interactions across the three primary systems engineering lifecycles.

These are each generally needed, and each primarily involves use of one of the three types of knowledge. We will discuss these briefly here and will illustrate how and why these make major but nonexclusive use of knowledge perspectives, principles, and practices. Figure 1.4 illustrates interactions across these lifecycles for one particular realization of a system acquisition lifecycle.

It is important when studying a new area to define it. We have provided one definition of systems engineering thus far. It is primarily a structural definition. A related definition, in terms of purpose, is that *systems engineering is management technology to assist and support policy making, planning, decision making, and associated resource allocation or action deployment*. Systems engineers accomplish this by quantitative and qualitative *formulation, analysis,* and *interpretation* of the impacts of action alternatives upon the needs perspectives, the institutional perspectives, and the value perspectives of their clients or customers. Each of these three steps is generally needed in solving systems engineering problems.

1. Issue *formulation* is an effort to identify the needs to be fulfilled and the requirements associated with these in terms of objectives to be satisfied, constraints and alterables (i.e., things that can be changed) that affect issue resolution, and generation of potential alternative courses of action.
2. Issue *analysis* enables us to determine the impacts of the identified alternative courses of action, including possible refinement of these alternatives.
3. Issue *interpretation* enables us to rank order the alternatives in terms of need satisfaction and to select one for implementation or additional study.

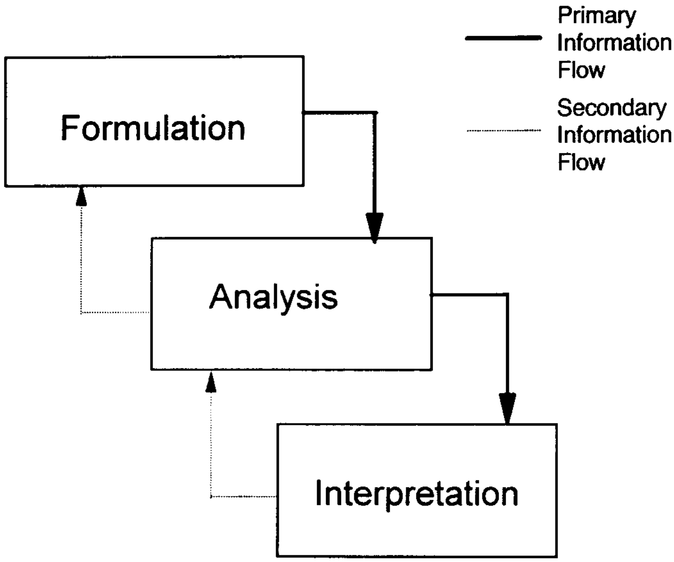

Figure 1.5 Conceptual illustration of formulation, analysis, and interpretation as the primary systems engineering steps.

This particular listing of three systems engineering steps and their descriptions is rather formal. Often, issues are resolved this way. The steps of formulation, analysis, and interpretation may also be accomplished on as "as if" basis by application of a variety of often useful heuristic approaches. These may well be quite appropriate in situations where the problem solver is experientially familiar with the task at hand and the environment into which the task is imbedded [1].

We may apply these systems engineering steps to a variety of situations, which should enable us to develop an appreciation for systems engineering efforts and problem solving. Generally, there is iteration among the steps and they follow, more or less, in the sequence illustrated in Figure 1.5.

The key words in this definition are formulation, analysis, and interpretation. In fact, all of systems engineering can be thought of as consisting of formulation, analysis, and interpretation efforts, together with the systems management and technical direction efforts necessary to bring this about. We may exercise these in a formal sense or in an *as if* or experientially based intuitive sense. These are the stepwise or microlevel components that comprise a part of the structural framework for systems methodology.

In our first definition of systems engineering, we indicated that systems engineers are concerned with the appropriate *definition, development,* and *deployment* of systems. These comprise a set of phases for a systems engineering lifecycle, as illustrated in Figure 1.6. There are many ways to describe the lifecycle phases of the systems engineering process, and we will describe a number of them in Chapter 2. Each of the lifecycle models, and those that are outgrowths of them, are comprised

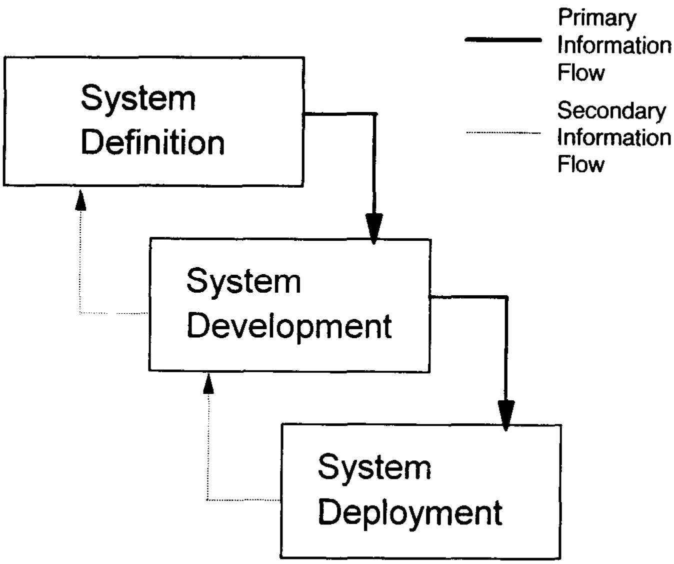

Figure 1.6 Conceptual illustration of the three primary systems engineering lifecycle phases.

of these three phases. For pragmatic reasons, a typical lifecycle will contain more than three phases, as we shall soon indicate.

1.2 THE IMPORTANCE OF TECHNICAL DIRECTION AND SYSTEMS MANAGEMENT

In order to resolve large scale and complex problems, or manage large systems of humans and machines (technology), we must be able to deal with important contemporary issues that involve and require the following:

1. Many considerations and interrelations.
2. Many different and perhaps controversial value judgments.
3. Knowledge from several disciplines.
4. Knowledge at the levels of principles, practices, and perspectives.
5. Considerations involving planning or definition, development, and deployment.
6. Considerations that cut across the three different lifecycles associated with systems planning and marketing, RDT&E, and system acquisition or production.
7. Risks and uncertainties involving future events that are difficult to predict.
8. A fragmented decision-making structure.