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Economic Systems Analysis and Assessment

Cost, Value, and Competition in Information and Knowledge Intensive Systems, Organizations, and Enterprises

Andrew P. Sage and William B. Rouse

WILEY

ECONOMIC SYSTEMS ANALYSIS AND ASSESSMENT

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PREFACE

The purpose of this book is to provide a background in the fundamentals of economic systems analysis and assessment that is appropriate for engineers and managers concerned with the systems engineering and management of systems that are generally information technology intensive. It is assumed that readers of this book will have previously studied mathematics through calculus and differential equations, and that they have some background in linear algebra. No prior background in mathematical programming or economics is assumed, although a modest exposure to undergraduate microeconomics will be very helpful. The objectives of this book include a salient discussion of engineering economic systems that will be relevant for those who need or desire to use the subject matter in their professional practice. This book will also support those who must communicate and broker the results of engineering economic systems analyses and assessments between the many professionals having a stake in definition, development, and deployment of information technology intensive systems. Finally, this book provides a thorough grounding in investment analysis and assessment, particularly for technology portfolios, capacity improvement and expansion, and mergers and acquisitions to acquire technologies and/or capacity.

The book itself is comprised of five major parts as follows:

1. ***Microeconomics.*** We provide a concise overview of classic microeconomics including production and the theory of the firm; theory of the consumer; market equilibria and market imperfections; and normative or welfare economics, including imperfect competition effects and consumer and producer surplus. Chapters 2 to 5 contain this presentation. We also discuss some behavioral economics issues in this part, particularly in Chapter 5. These chapters are as follows:
   - **Chapter 1:** Introduction to Economic Systems Analysis and Assessment
   - **Chapter 2:** Production and the Theory of the Firm
   - **Chapter 3:** The Theory of the Consumer
   - **Chapter 4:** Supply–Demand Equilibria and Microeconomic Systems Analysis and Assessment Models
   - **Chapter 5:** Normative or Welfare Economics, Decisions and Games, and Behavioral Economics
2. ***Program Management Economics.*** We discuss economic valuation of programs and projects including investment rates of return,

cost–benefit and cost–effectiveness analysis, earned value management, cost structures and estimation of program costs and schedules, strategic and tactical pricing issues, and capital investment and options. There is one lengthy chapter in this part:

- **Chapter 6:** Cost–Benefit and Cost–Effectiveness Analyses and Assessments

3. ***Cost Estimation.*** Cost estimation technologies involve precedented and unprecedented development, commercial off-the-shelf (COTS) software, software reuse, application generators, and fourth-generation languages. Contemporary cost estimation methods are evaluated in terms of openness of underlying models, platform requirements, data required as inputs, output, and accuracy of estimates provided by the models. COCOMO I and II, and COSYSMO are examples of a cost model, function point cost estimation models. Cost is estimated for systems of systems engineering. There is a single chapter in this part:
   - **Chapter 7:** Cost Assessment
4. ***Strategic Investments in an Uncertain World.*** The final part of our economic systems analysis and assessment efforts is concerned with valuation of major investments such as technology portfolios and large-scale capacity expansions, as well as mergers and acquisitions. Here we provide a chapter that addresses alternative methods for valuation of firms including Stern–Stewart's EVA, Holt's CFROI, and various competing methodologies. Chapter 9 considers option-based valuation models including classic real option models (Black–Scholes) and extensions for multistage options with more robust portfolio assumptions. Valuation of information technology intensive enterprises is also addressed. Overall, this part provides a discussion of valuation methods for managing strategic investments in an uncertain world:
   - **Chapter 8:** Approaches to Investment Valuation
   - **Chapter 9:** Real Options for Investment Valuation
5. ***Extensions to the Work.*** There are many extensions possible to economic systems analysis and assessment. There are needed extensions to the classic microeconomics of economic systems analysis and assessment to enable satisfactory treatment of the increasing returns to scale, network effects, and path-dependent issues generally associated with contemporary ultra-large-scale telecommunications and information networks. Investing in the training and education, safety and health, and work productivity of humans is another very important issue. In our concluding chapter of this work, we present a very brief discussion of these issues:
   - **Chapter 10:** Contemporary Perspectives

We sincerely hope that readers find our discussions of economic systems analysis and assessment of value to their work in systems and software engineering, systems and enterprise management, and related areas.

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CONTENTS

CHAPTER 1

INTRODUCTION TO ECONOMIC SYSTEMS ANALYSIS AND ASSESSMENT: COST, VALUE, AND COMPETITION IN INFORMATION AND KNOWLEDGE INTENSIVE SYSTEMS, ORGANIZATIONS, AND ENTERPRISES

1.1 INTRODUCTION

This book is about one of the fundamental concerns in the engineering and management of systems of all types, and especially those with a major telecommunications and information network focus: the economic behavior of these systems. We discuss the very important role of economics in shaping our lives and designing our activities and institutions to achieve economic (and other) objectives. The purpose of this book is to present those fundamentals of classic and modern microeconomic systems analysis and assessment that are most necessary in the engineering and management of systems of machines, humans, and organizations that are effective and efficient, and equitable as well. We desire to equip ourselves to answer three fundamental questions:

1. What should be produced and how much of it should be produced?
2. How should the goods be produced?
3. Who should get the goods and services that are produced?

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The first of these questions relates to *effectiveness*, the second to *efficiency*, and the third to *equity* concerns. There are a number of related concerns. Many other questions, and their answers, are also important. We are generally concerned with why, where, and when artifacts as well as what, how, and who. For example, we surely wish to ensure sustainability, by preserving the natural resource basis to enable continued satisfaction of human needs in an equitable manner over time. There are also issues that affect marketing of our products, as well as with research and development to enable the production of innovative products (and services). Thus, we wish to examine a plethora of issues associated with the engineering of economic systems.

This chapter will provide an overview of our undertakings. We will first summarize a framework for systems engineering and illustrate the important role of the economics of a firm in maximizing profits and that of the economics of the consumer in maximizing satisfaction by allocating resources, all within the constraints of finite resources. Then we will provide an introductory discussion of the microeconomics of firms and consumers operating together in various markets. Our presentation will stress the information base and other conditions necessary to ensure what we will call a perfectly competitive economy.

These conditions will, as will be apparent, typically not prevail. Various distortions from perfect competition will then result. Our discussions will concern normative economics—how individuals and organizations should ideally behave from an axiomatic perspective to best achieve identified objectives. We will also discuss descriptive economics—how individuals and organizations actually behave. Finally, we will discuss prescriptive economics—how individuals and organizations should behave in realistic settings. This chapter provides a relatively detailed outline of this work and our objectives in writing it.

1.2 A FRAMEWORK FOR SYSTEMS ENGINEERING AND MANAGEMENT

A central purpose of systems engineering is to assist clients in organizing knowledge that contributes to the efficiency, effectiveness, equity, and explicability of decisions and associated resource allocations. Systems engineering methodology provides a framework for the formulation, analysis, and interpretation of issues and problems that lead to the resolution of issues of large scale and scope. Within this framework, content, concepts, and methods are selected. The systems process, in which client(s) and analyst(s) cooperate to establish useful policies, plans, or designs, involves three fundamental steps:

1. *Formulation* of the issue or problem,
2. *Analysis* of the (impacts of) alternatives, and
3. *Interpretation* of results for the value systems of relevant stakeholders, thereby leading to the *evaluation* and *prioritization* of alternatives as well as the *selection* and *implementation* of selected alternative(s).

The systems engineering process is typically characterized by

1. a systematic, rational, and purposeful course of action;
2. a holistic approach in which issues or problems are generally examined in relation to their environment, as well as to due attention to the causal or symptomatic, institutional, and value aspects of the issue under consideration; and
3. the eclectic use of methods and knowledge based on the normative theory of systems science and operations research, as well as the behavioral theory of systems and organizational management.

The typical product of a systems engineering study is a plan to implement a decision, or a plan to implement another phase of a systems study that will ultimately result in such a plan. Economic concerns are vital in developing appropriate plans. It is the study of engineering economic systems analysis that is of interest here. This study is all the more valuable if we first embed it within a discussion of the entire systems process.

A very important fundamental concept of systems engineering is that all systems are associated with life cycles. These are of several types: we have a life cycle for the engineering of the system, and another life cycle for the use of the system. Similar to all natural systems that exhibit a birth–growth–aging–death lifecycle, human-made systems also have a life cycle. Generally, this life cycle consists of three essential phases: *definition* of the requirements for a system, *development* of the system itself, and *deployment* of the system in an operating environment. Each of these may be described by a larger number of more fine-grained phases. These three phases are found in all intentional systems evolutionary efforts. Most realistic life-cycle processes comprise more than three phases. One of the major contributions of systems engineering is in adopting an appropriate perspective for the life cycles associated with engineering the system.

This life-cycle perspective should also be associated with a long-term view toward planning for systems evolution, research to bring about any new and emerging technologies needed for this evolution, and a number of activities associated with actual systems evolution, or acquisition. Thus, we see that the efforts involved in the life-cycle phases of definition, development, and deployment need to be implemented across three life cycles that comprise:

- systems planning and marketing;
- research, development, test, and evaluation (RDT&E); and
- systems acquisition or procurement.

We briefly examine these life-cycle phases here. Discussions of the methods for systems engineering are very important. Here we emphasize economic systems analysis and its application to telecommunications and information networks. We emphasize that these discussions would be incomplete if they are not associated with some discussion of systems engineering life cycles, processes, or methodology and the systems management efforts that lead to selection of appropriate processes.

Systems engineering is a 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 assessment, and interpretation of the impacts of action alternatives on the needs perspectives, the institutional perspectives, and the value perspectives of their clients or customers.

The key words in this definition are formulation, analysis and assessment, and interpretation, which form an integral part of systems engineering. We may exercise these in a formal sense, or in an experientially based intuitive sense. These are the components comprising a structural framework for systems methodology and design. We need a guide to formulation, analysis and assessment, and interpretation efforts, and systems engineering provides this through embedding these three steps into life cycles, or processes, for systems evolution.

Systems management and integration issues are of major importance in determining the effectiveness, efficiency, and overall functionality of systems designs. To achieve a high measure of functionality, it must be possible for a systems design to be efficiently and effectively produced, used, maintained, retrofitted, and modified throughout all phases of a life cycle. This life cycle begins with need conceptualization and identification, through specification of systems requirements and architectures, to ultimate systems installation, operational implementation, evaluation, and maintenance throughout a productive lifetime.

For our purposes, we may also define systems engineering as the definition, design, development, production, and maintenance of functional, reliable, and trustworthy systems within cost and time constraints. It is generally accepted that we may define things according to

- structure,
- function, or
- purpose.

Often, definitions are incomplete if they do not address structure, function, and purpose. Our continued discussion of systems engineering will be assisted by the provision of a structural, functional, and purposeful definition of systems engineering as follows:

Structure. Systems engineering is an appropriate combination of methods and tools, made possible through a suitable methodology and systems management procedures, in a useful process-oriented setting that is appropriate for the resolution of real-world problems, often of large scale and scope.

Function. Systems engineering is a management technology to assist clients through the formulation, analysis and assessment, and interpretation of the impacts of proposed policies, controls, or complete systems on the need perspectives, institutional perspectives, and value perspectives of stakeholders to issues under consideration.

> ***Purpose.*** The purpose of systems engineering is information and knowledge organization that will assist clients who desire to define, develop, and deploy total systems to achieve a high standard of overall quality, integrity, and integration as related to performance, trustworthiness, reliability, availability, and maintainability of the resulting system.

Each of these definitions is important and an understanding of all three is generally needed, as we have noted. In our three-level hierarchy of systems engineering there is generally a nonmutually exclusive correspondence between function and tools, structure and methodology, and purpose and management, as illustrated in Fig. 1.1. A systems engineering process results from efforts at the level of systems management to pick an appropriate methodology, or appropriate set of procedures, or a process for engineering a system. A systems engineering product, or service, results from this process, or product line, together with an appropriate set of methods and metrics. These are illustrated in Fig. 1.2.

We have illustrated three hierarchical levels of systems engineering in Fig. 1.1. These are associated with structure, function, and purpose, as also indicated in Fig. 1.1. The evolution of a systems engineering product, or service, from the chosen systems engineering process is illustrated in Fig. 1.2. The systems engineering process is driven by systems management, and there are a number of drivers for systems management, such as the competitive strategy of the organization. The basic activities of systems engineers are usually concentrated on the evolution of an appropriate process to enable the definition, development, or deployment of a system or on the formulation, analysis, and interpretation of issues associated with one of these phases. Figure 1.3 illustrates the basic systems engineering process phases and steps.

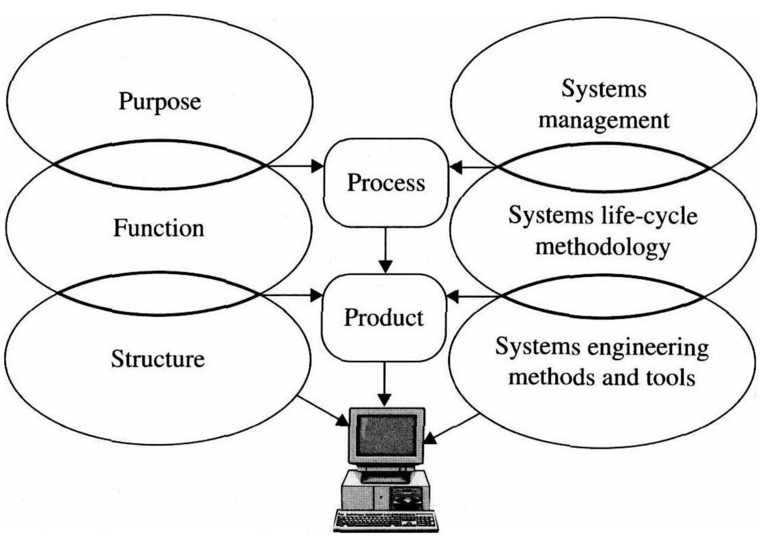

Figure 1.1. The Evolution of Process and Product from Purpose, Function, and Structure and the Three Levels of Systems Engineering: Systems Management, Methodology, and Methods and Tools.

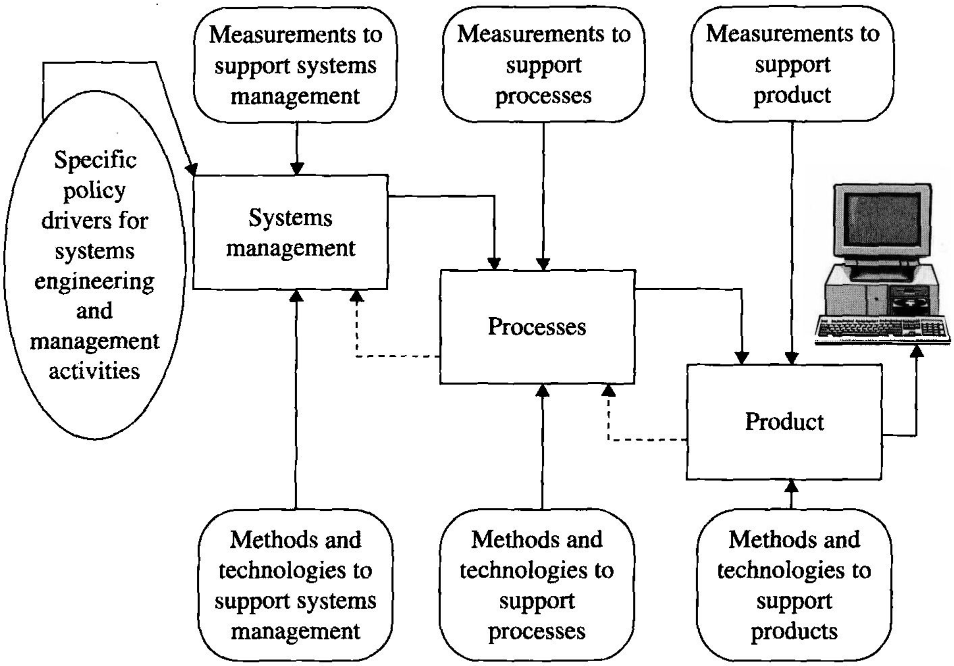

Figure 1.2. Three-Level Systems Engineering and Management Perspective on the Engineering of Systems.

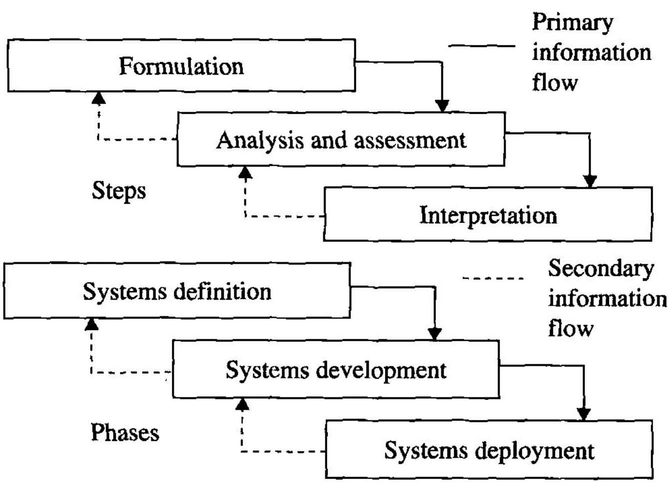

Figure 1.3. The Three Basic Steps and Phases of Systems Engineering.

Generally, these are combined to illustrate the occurrence of each of the three steps of systems engineering within each of the three phases, as represented in Fig. 1.4. A three-element-by-three-element matrix structure representation of a systems engineering framework is also possible as shown in Fig. 1.5.

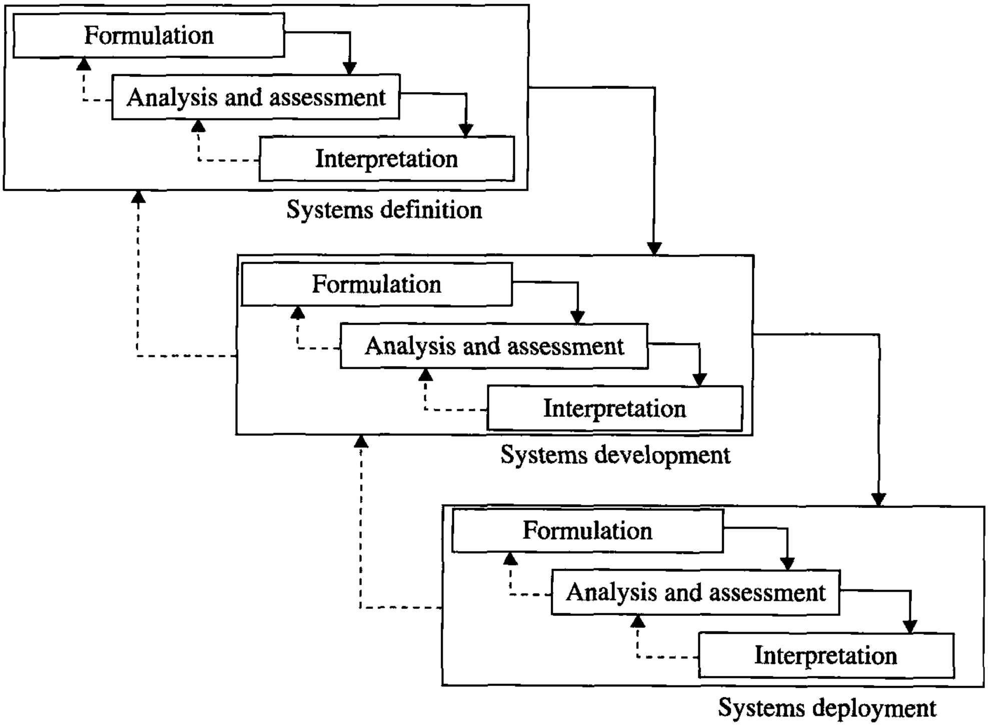

Figure 1.4. A Systems Engineering Framework Comprised of Three Phases and Three Steps Per Phase.

	Formulation	Analysis and assessment	Interpretation
Definition	Activity 1	Activity 2	Activity 3
Development			
Deployment			Activity 9

Figure 1.5. Illustration of Nine Activity Cells for a Simple Two-Dimensional Systems Engineering Framework.

A systems engineering framework, from a formal perspective at least, consists of three fundamental steps: issue formulation, issue analysis, and issue interpretation. These are conducted at each of the life-cycle phases that have been chosen to implement the basic life-cycle phased efforts of definition, development, and deployment. There are three general systems life cycles, as suggested by Fig. 1.6:

- research, development, test, and evaluation (RDT&E);
- acquisition (or production, or manufacturing, or fielding);
- planning and marketing.

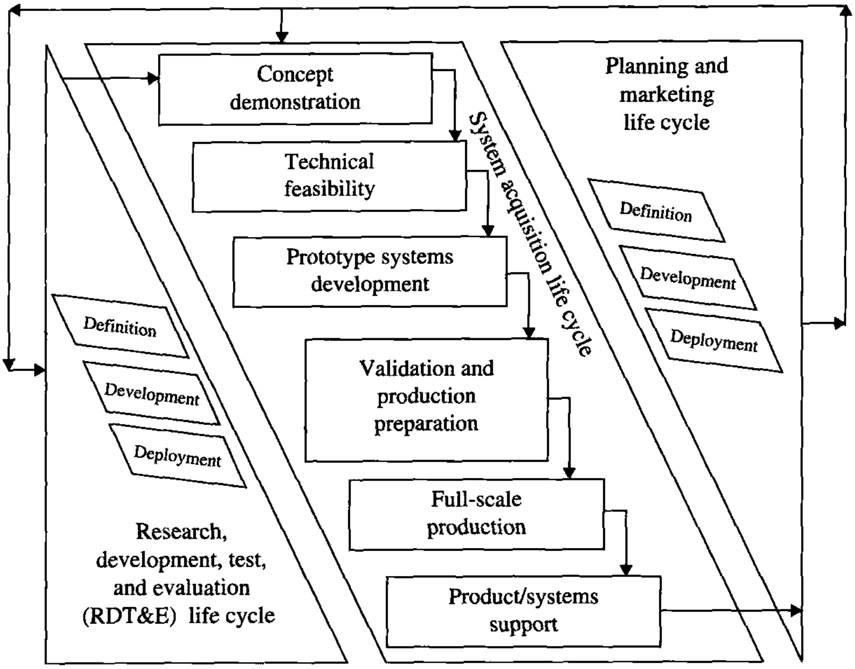

Figure 1.6. Interactions across the Three Primary Systems Engineering Life Cycles.

Systems engineers are involved in efforts associated with each of these life cycles and the associated functions, often in a technical direction or systems management capacity. The detailed life-cycle phases are shown only in the systems acquisition life cycle in the figure. Only the three basic phases are shown for the RDT&E life cycle, and the planning and marketing life cycle. An objective in this is to engineer trustworthy and sustainable systems that have such desirable attributes as those shown in Fig. 1.7.

There are a number of frameworks that we might use to characterize systems engineering and management efforts. Without a sound and well-understood process for the acquisition or production of large systems, it is very likely that there will be a number of flaws in the resulting system itself. Thus, the definition, development, and deployment of an appropriate process, or a set of processes, for the engineering of systems are very important. To undertake a study of systems engineering methods only and their potential use to support the engineering of trustworthy systems, without some understanding of systems engineering processes, is likely to lead to very unsatisfactory results.

Systems engineers provide a needed interface between the client or stakeholder group, or enterprise, to which an operational system will ultimately be delivered, and a detailed design and implementation group, which is responsible for specific systems production and implementation. Figure 1.8 illustrates this view of a systems engineering team as an interface group that provides conceptual design and technical direction to enable the products of a detailed design group to be responsive to client needs. Thus, systems engineers