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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*Economic Systems Analysis and Assessment*,
by Andrew P. Sage and William B. Rouse

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.

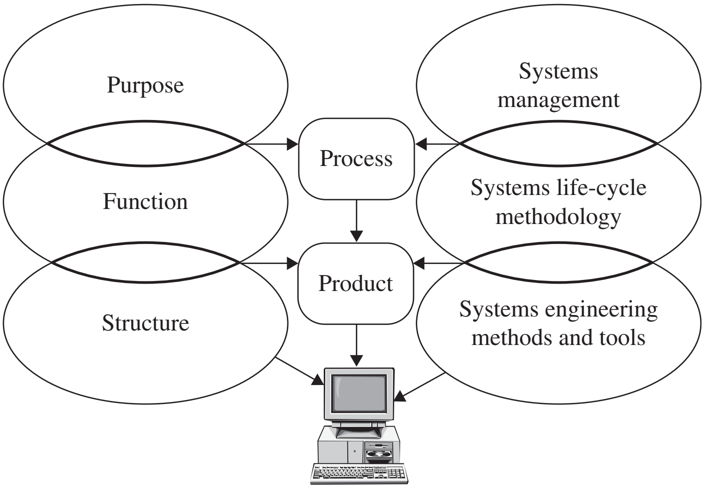

**Figure 1.1.** The Evolution of Process and Product from Purpose, Function, and Structure and the Three Levels of Systems Engineering: Systems Management, Methodology, and Methods and Tools.

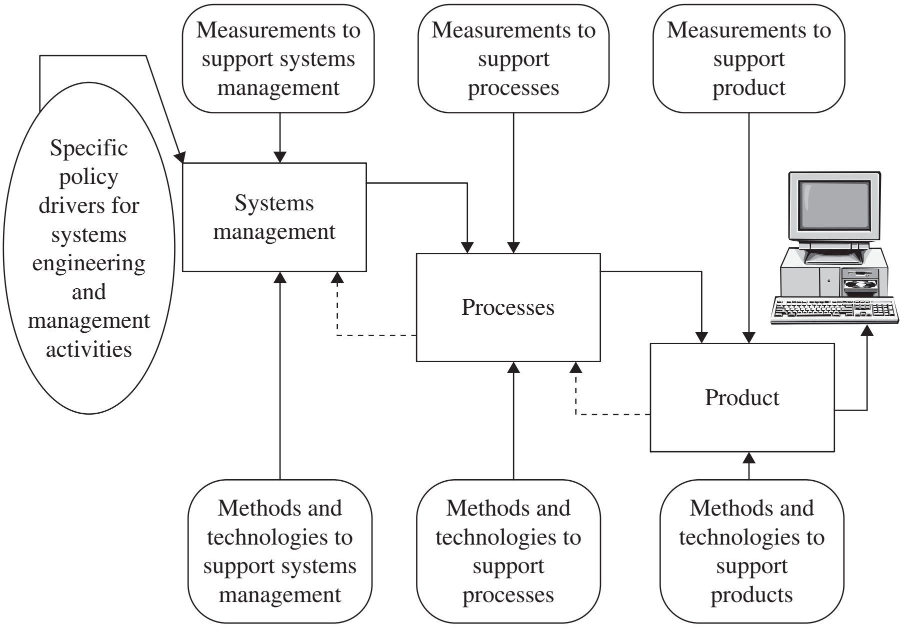

**Figure 1.2.** Three-Level Systems Engineering and Management Perspective on the Engineering of Systems.

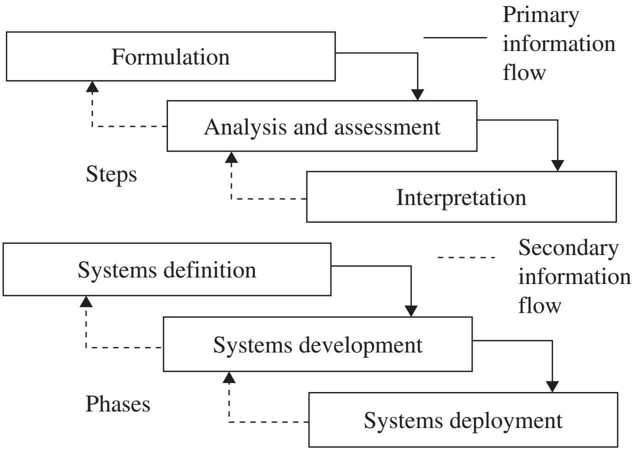

**Figure 1.3.** The Three Basic Steps and Phases of Systems Engineering.

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.

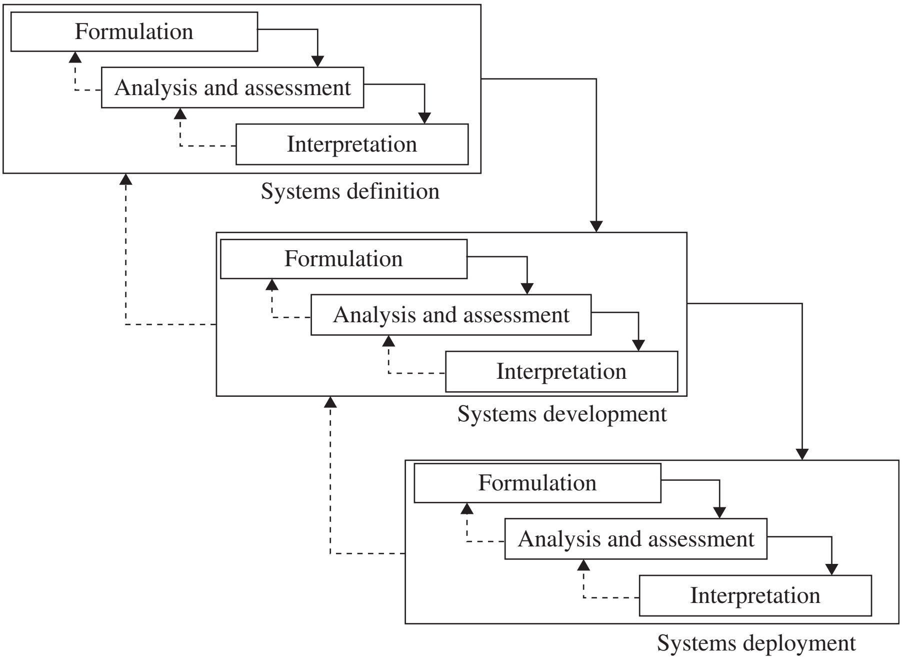

**Figure 1.4.** A Systems Engineering Framework Comprised of Three Phases and Three Steps Per Phase.

| | 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.

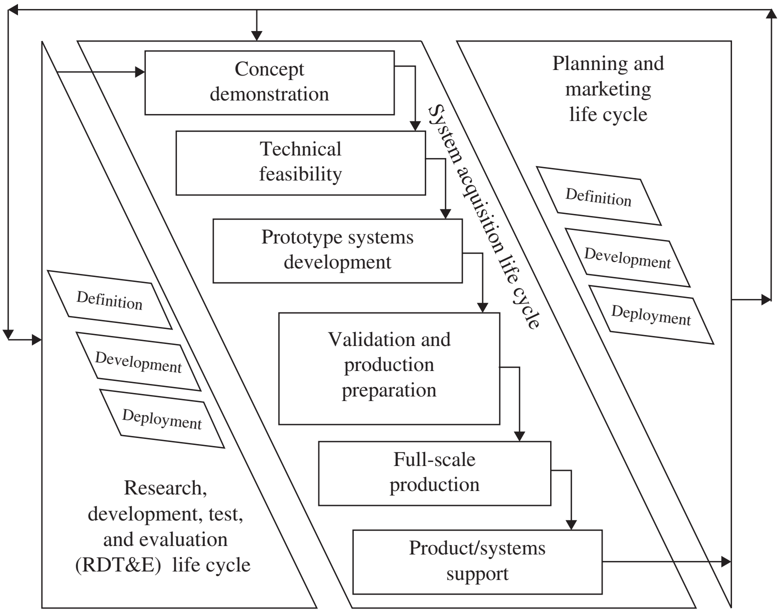

**Figure 1.6.** Interactions across the Three Primary Systems Engineering Life Cycles.

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

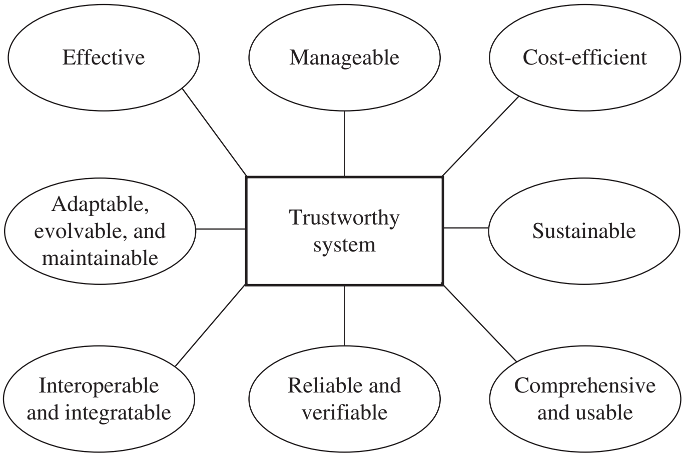

**Figure 1.7.** Attributes of a Trustworthy Systems Engineering Product or Service.

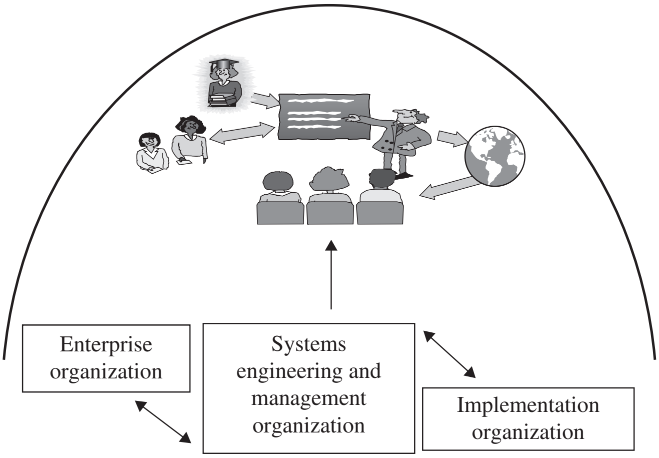

**Figure 1.8.** Systems Engineering as a Broker of Information and Knowledge.

act, in part, as brokers of information between a client group and those responsible for detailed design and systems production. Knowledge and use of the principles of economic systems analysis are especially important in achieving this needed brokerage.

Systems engineering processes are to a very large extent based on frameworks for systems methodology and design. The framework chosen here consists of three dimensions:

- logic dimension, which consists of three fundamental steps;
- time dimension, which consists of three basic life-cycle phases; and
- life-cycle dimension, which consists of three stages or life cycles.

An important fourth dimension, which we may call a perspectives dimension, is also discussed in this chapter. This is comprised of the three basic perspectives of user enterprise, systems management and technical direction, and implementation.

We envision a three-level performance hierarchy for systems engineering phased efforts, as shown in Fig. 1.3. This three-level structured hierarchy comprises a systems engineering life cycle and is one of the ingredients of systems engineering methodology. It involves

- systems definition,
- systems development, and
- systems deployment.

The structural definition of systems engineering we posed earlier indicates that we are concerned with a framework for problem resolution that, from a formal perspective at least, consists of three fundamental steps for a systems engineering activity:

- issue formulation,
- issue analysis and assessment, and
- issue interpretation.

These are conducted at each of the life-cycle phases that have been chosen for the definition, development, and deployment efforts that lead to the engineering of a system. Regardless of the way in which the systems engineering life-cycle process is characterized, and regardless of the type of product or system or service that is being designed, all characterizations of the phases of the systems engineering life cycles will necessarily involve

1. *formulation* of the problem—in which the needs and objectives of a client group are identified, and potentially acceptable design alternatives, or options, are identified or generated;
2. *analysis and assessment* of the alternatives—in which the impacts of the identified design options are identified and evaluated or assessed; and
3. *interpretation* and selection—in which the options, or alternative courses of action, are compared by means of interpretation and comparison of the assessed impacts of the alternatives and how the client group values these. The needs and objectives of the client group are necessarily used as a basis of this selection. The most acceptable alternative is selected for implementation or further study in a subsequent phase of systems engineering.

Our model of the steps of the logic structure of the systems process is based on this conceptualization. These three steps can be, and generally are, disaggregated into a number of other more detailed steps. Each of these steps of systems engineering is accomplished for each of the life-cycle phases. As is the case with respect to the life-cycle phases, it is generally needed to have iteration and learning associated with these steps. This strongly suggests that evolutionary life-cycle approaches, as extensions of the waterfall models illustrated here, will generally be very desirable. In a later Chapter 10, we explicitly consider this in the form of evolutionary economic analysis.

As we have noted, there are generally three different systems engineering life cycles. These relate to the three different stages of effort that are needed to deliver a competitive product or service to the marketplace:

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

Thus we may imagine a three-dimensional model of systems engineering that is comprised of steps associated with each phase of a life cycle, the phases in the life cycle, and the life cycles that comprise the coarse structure or stages of systems engineering. Figure 1.9 illustrates this across three distinct but interrelated life cycles, for the three steps, and the three phases that we have described here. This is one morphological framework for systems engineering. As we have noted, it will generally be necessary to expand the three steps and three phases we indicate here into a larger number of steps and phases. Often,

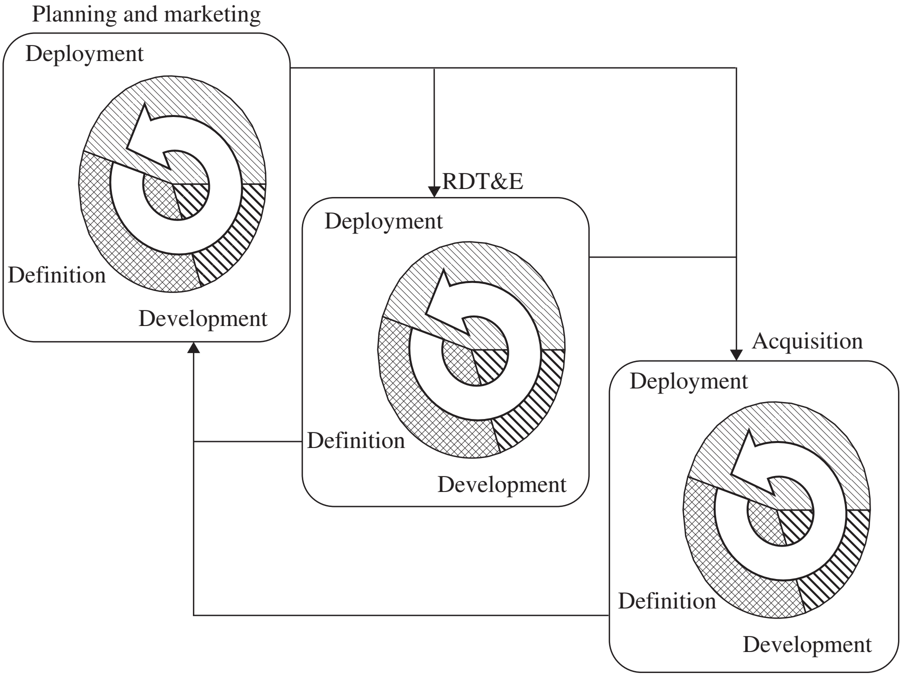

**Figure 1.9.** Major Systems Engineering Life Cycles with Three Phases within Each Life Cycle.

also, there will be a number of concurrent RDT&E and systems acquisition efforts that will be needed to ultimately bring about a large-scale system.

It is necessary that efforts across these three life cycles be well integrated and coordinated, or else difficulties can ensue. Figure 1.10 represents the relationships across these life cycles. The systems planning and marketing life cycle yields answers to the question: What is in demand? The RDT&E life cycle yields answers to the question: What is (technologically) possible (within reasonable economic and other considerations)? The acquisition life cycle yields answers to the question: What can be developed (from an efficiency, effectiveness, trustworthiness, and sustainability perspective)? It is only in the region where there is overlap, in an *n*-dimensional space, that responsible actions should be implemented to bring about programs for all three life cycles. This suggests that the needs of one life cycle should not be considered independently of the other two. Figure 1.10 represents this conceptually in a two-dimensional Venn-diagram-like representation of the possibility space for each life cycle. Effort should be undertaken to address only the issues within the ellipse represented by the thicker exterior.

Each of the logical steps of systems engineering is accomplished for each of the life-cycle phases. There are generally three different systems engineering life cycles or stages for a complete systems engineering effort, as we have indicated. Thus we may imagine a three-dimensional model of systems engineering that is comprised of steps associated with each phase of a life cycle, the

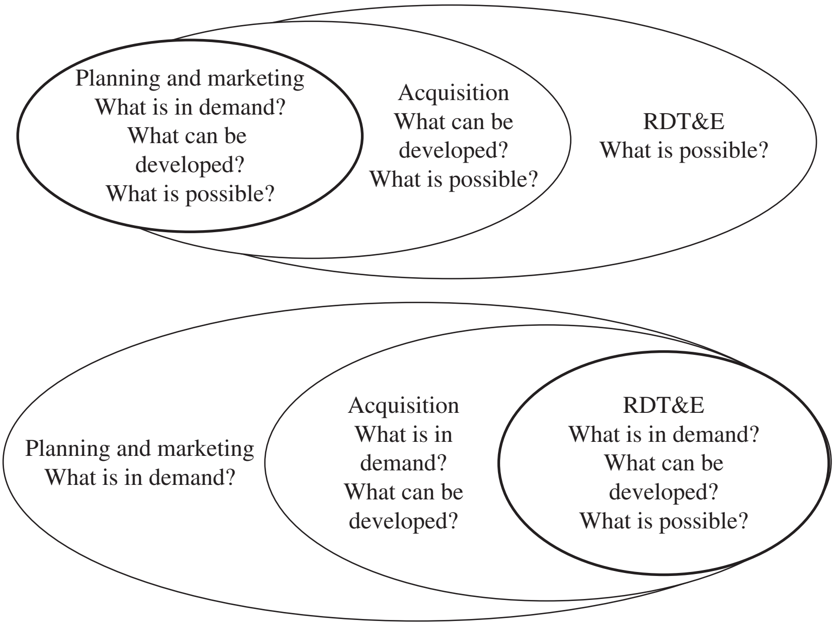

**Figure 1.10.** Illustrations of the Need for Coordination and Integration across Life Cycles.

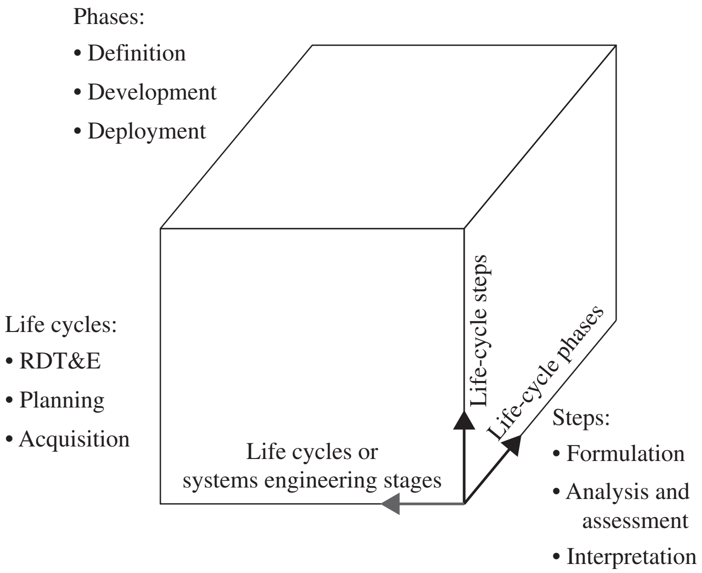

**Figure 1.11.** Three-Dimensional Framework for Systems Engineering.

phases in the life cycle, and the life cycles or stages of a complete systems engineering effort. Figure 1.10 illustrates this framework of steps, phases, and stages as a three-dimensional cube. This is one three-dimensional framework, in the form of a morphological box, for systems engineering. The word morphology is adapted from biology and means a study of form. As we use it, a methodology is an open set of procedures for problem solving. Consequently, a methodology involves a set of methods, a set of activities, and a set of relations between the methods and the activities. To use a methodology we must have an appropriate set of methods. Generally, these include a variety of qualitative and quantitative approaches from a number of disciplines that enable formulation, analysis, and interpretation of the phased efforts that are associated with the definition, development, and deployment of both an appropriate process and the product that results from this process. Associated with a methodology is a structured framework with which particular methods are associated for the resolution of a specific issue.

Of course, systems engineering is comprised of much more than just a methodological framework, or frameworks. In an earlier three-level view of systems engineering, we indicated that we can consider systems engineering efforts at the levels of

- systems engineering methods and tools, and associated metrics;
- systems methodology, or life-cycle processes; and
- systems management.

We suggested Figs. 1.1 and 1.2 as illustrative of this representation of systems engineering. This is also an important dimension to a systems engineering framework, as is the situation assessment that occurs for issue recognition, and the individual and organizational learning that should occur as systems engineering efforts evolve over time. We could expand on these concepts greatly, and this has been accomplished in several of the references cited in the bibliography at the end of this chapter. It is our hope that the basic concepts illustrated here will serve as a suitable introduction to the principles of systems engineering and management for appreciation of its implications for the engineering of economic systems, which is the major focus of this work and the subject we address in the remainder of this chapter and the rest of the book.

Our major concern here will be the analysis and assessment of a systems effort, especially those portions that involve the microeconomic concerns of the interactions between firms and consumers in markets and the evaluation and prioritization of alternative projects, especially as they concern telecommunications and information networks.

There are several points that merit further discussion here. First of all, neither systems engineering and management nor economic systems analysis efforts within systems engineering and management are processed in a sequenced linear way. They involve a process in which iteration plays a central part. Insights obtained from one part of the effort might lead to a revision of approaches taken earlier, making iteration and feedback necessary. Second, the steps and phases outlined are helpful as a guide, not as a restrictive format. Flexibility in the procedures and methods used is a central feature of systems engineering and management. It should be noted, however, that each of the steps and phases outlined above represents an important ingredient in a systems engineering effort, and omission or neglect of any step increases the risks of failure. Third, since systems engineering is a process in which people work together to realize the various steps and phases of the effort, the selection of an appropriate combination of capable analysts, experts, or other participants, and methods or aids in the process, is at least as important as adherence to the several steps of the systems engineering framework. Figure 1.12 presents a conceptual flowchart of the steps in a typical systems engineering process. These steps are conducted across each of the phases in the process.

In this section, we have presented an essential introduction to systems engineering. Our purpose here is primarily to present some of the essential underlying concepts. The references related to systems engineering in the selected bibliography at the end of this chapter provide much supporting detail.

## 1.3 THEORY OF THE FIRM

Chapter 2 will be concerned with the classic theory of the firm. We will adopt as a fundamental hypothesis the assumption that the goal of a firm is to maximize profit. To do this, the firm will need to know the costs of production. These costs will depend on the market conditions extant for the three fundamental

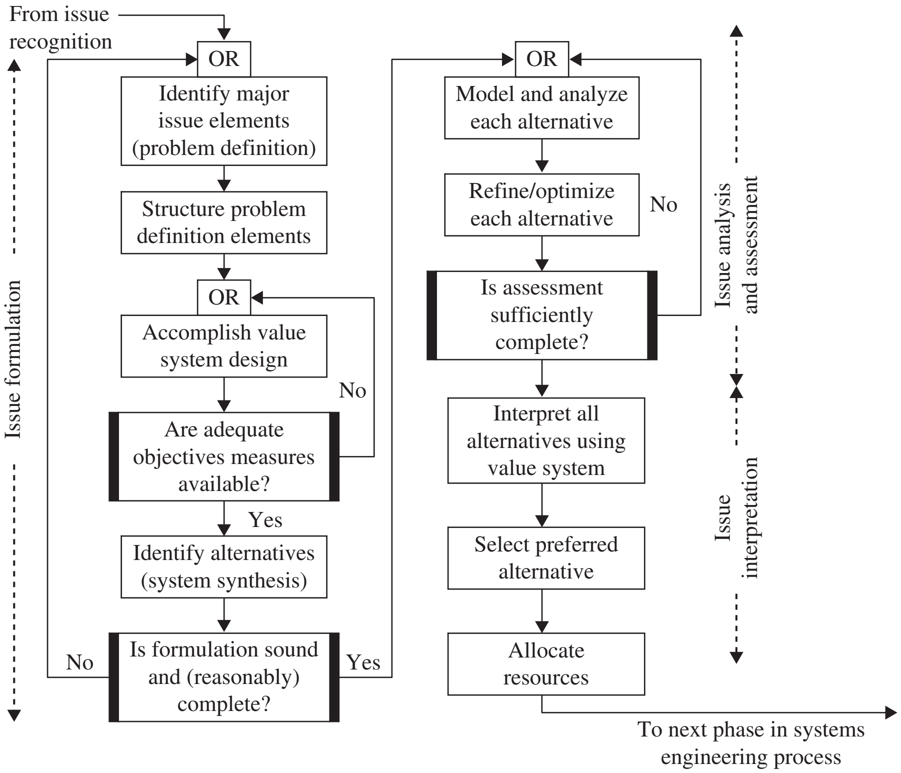

**Figure 1.12.** Prototypical Flowchart of Steps in the Systems Engineering Process.

types of classic economic resources: land,[1] capital, and labor. In much of the literature on modern economic systems, information and knowledge are considered to be the fourth fundamental resource. We will develop the classic theory of the firm in Chapter 2, and introduce newer concepts in the later chapters.

If we know the way in which the quantity of a product depends on the input of land, capital, and labor to production, then it becomes possible to determine the cost of a given quantity of produced goods in terms of the unit costs of the inputs to production and the quantity of these inputs that are used. If we use amounts $T$, $K$, and $L$ of land, capital, and labor, respectively, and if the known wages[2] of these factor input to production are given by $w_T$, $w_K$, and $w_L$, then the costs of production are

$$C(T, K, L) = w_T T + w_K K + w_L L + F \tag{1.1}$$

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[1] "Land" is the classic economic term that implies all raw materials and natural resources.

[2] It is interesting to conjecture on the meaning of the wages for capital. It turns out that the difference between the wages for capital and capital represents interest.

where $F$ denotes the fixed—initially set up—costs of production. The revenue to the firm for selling a production quantity $q$ at a fixed price $p$ is

$$R = pq \tag{1.2}$$

The quantity of goods produced by the firm is related to the input factors of production (land, capital, and labor) by the production relation

$$q = f(T, K, L) \tag{1.3}$$

The profit to the firm is the difference between the revenue and the production costs, or

$$\Pi = R - C \tag{1.4}$$

There are several important and relevant questions we might pose here:

1. How can we maximize profit to the firm?
2. How can we minimize costs of production of a given quantity of the product?
3. Are there circumstances under which we will not produce?

It turns out that the answers to the first two questions are equivalent. To obtain maximum profit, we maximize $\Pi$ given by Equation 1.4, subject to the equality constraints of Equations 1.1 through 1.3. The result of doing this is that we obtain a production or supply curve for the producer that gives the quantity of goods that will be produced as a function of the price received for the goods (or services). To minimize production costs we minimize the costs of production, which is given by $C$ in Equation 1.1 subject to the equality constraints of Equations 1.2 and 1.3. Doing this results in a relation for the minimum production cost $C(q)$ for producing a quantity of goods $q$. The answer to the third question is that we should produce as long as we can obtain a nonnegative profit.

We will explore issues such as these in considerably greater detail in Chapter 2. A number of extensions will be undertaken. In particular, we will consider the case where there is a sole producer of a given product who has perfect information about consumer demand for the product. This situation is known as a monopoly. This will be the first of several situations that we will examine in which one or more of the conditions for "perfect economic competition" are violated.

One very important notion is that of return to scale in production. If increasing all factors of production by some amount $\lambda > 1$ increases the quantity produced by the same amount, we say that the production function possesses constant returns to scale (CRS):

$$\text{CRS}: \lambda q = \lambda f(T, K, L) = f(\lambda T, \lambda K, \lambda L), \quad \lambda > 1 \tag{1.5}$$

In the case where increasing all factors of production by the same positive amount $\lambda > 1$ results in a produced amount that is less than $\lambda$ times the initial amount, we have decreasing returns to scale (DRS):

$$\text{DRS}: \lambda q = \lambda f(T, K, L) > f(\lambda T, \lambda K, \lambda L), \quad \lambda > 1 \tag{1.6}$$

The majority of classic production functions possess either DRS or, in a very few cases, CRS. When we examine information and knowledge intensive products, such as software, in our later work, we will generally find that they possess increasing returns to scale (IRS), such that increasing all factors of production by an amount $\lambda > 1$ results in a production quantity that is greater than $\lambda$ times the amount initially produced:

$$\text{IRS}: f(\lambda T, \lambda K, \lambda L) > \lambda f(T, K, L) = \lambda q, \quad \lambda > 1$$

There are many very interesting properties of these information intensive products that are often called *network effects*: consumption externalities, switching costs and lock-in, and many issues that affect compatibility, standards, and complementarity of these products. These are generally a result of these positive or increasing economies of scale in production.

## 1.4 THEORY OF THE CONSUMER

Why should a firm produce a product or service? One answer is that there is a *demand* for the product or service, because the firm is *effective* in fulfilling some (perceived) need, and that the firm is *efficient* in producing it and can make a profit by doing so. In Chapter 3 we examine various aspects of the economic theory of the consumer. We assume that the consumer has a utility function that expresses the satisfaction received from the possession or consumption, a term used by economists to also include savings or investment, of a bundle of goods and services. The consumer is assumed to have a utility function

$$U = U(x_1, x_2, \ldots, x_N) = U(\mathbf{x}) \tag{1.7}$$

where $\mathbf{x} = [x_1, x_2, \ldots, x_N]^{\mathrm{T}}$ is a bundle of goods and services or commodity bundle. There is a price vector $\mathbf{p} = [p_1, p_2, \ldots, p_N]^{\mathrm{T}}$ that represents the fixed price that has to be paid for a unit of each of the $N$ goods and services.

The consumer is assumed to be greedy and selfish, in that "more" of any given good or service is always better than "less." Sadly, the consumer has limited resources and cannot pay more than some fixed "income" $I$ for these. The fundamental problem of the consumer is to maximize utility, given by Equation 1.7, subject to the resource constraint

$$I \geq \sum_{i=1}^{N} p_i x_i = \mathbf{p}^{\mathrm{T}} \mathbf{x} \tag{1.8}$$

We will explore various facets of consumer behavior in attempting to maximize the effectiveness of limited resources in maximizing satisfaction. The result of resolving the maximization of utility with a constraint on disposable income is the demand curve for a consumer. Figure 1.13 shows six supply–demand

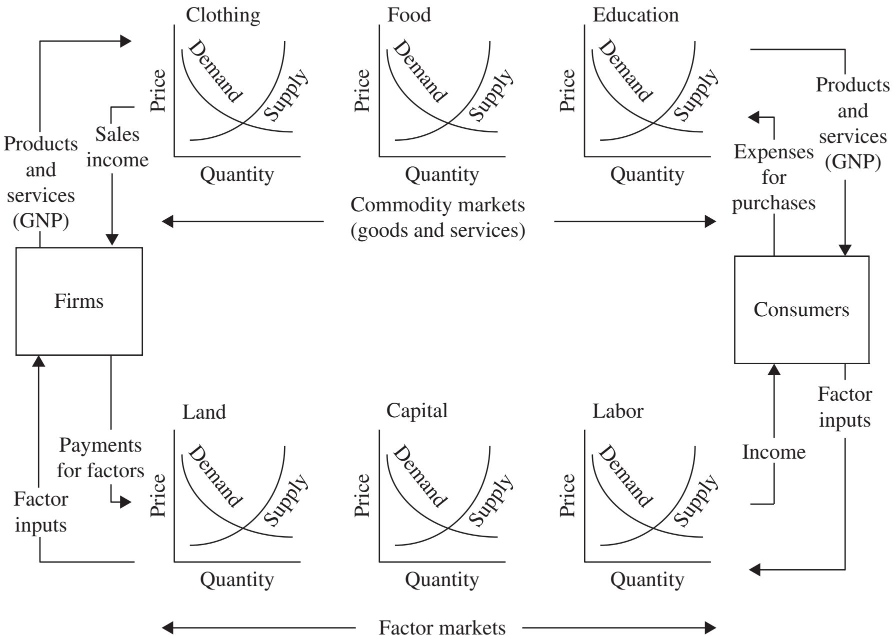

**Figure 1.13.** Simple Flows in Economic Systems.

curves for various factors and consumer goods and services in a classic representation of a (free-market) economic system where there are DRS, which is the classic case. We will have much more to say about these relationships in Chapter 3. In our later chapters, we will also explore the many issues associated with information and knowledge intensive networks and products where there are IRS.

## 1.5 THE INTERACTION OF THE THEORIES OF FIRMS AND CONSUMERS: MICROECONOMIC MODELS OF ECONOMIC ACTIVITY

Chapters 2 and 3 discuss the theories of firms and consumers. In Chapter 4 we will extend these concepts to microeconomic models that describe the behavior of economic agents such as firms, consumers, and resource owners in a (free) market economy. We will be primarily concerned with the conditions that prevail in a market system that is in equilibrium and in which no imperfections (monopolies, externalities, etc.) exist. Microeconomic models such as these serve primarily as guides to the behavior that will result in the greatest satisfaction for each economic agent.

The foundation for a microeconomic model is a set of relations that describe

1. the price and quantity of goods and services that will be desired by a consumer who is maximizing their utility;
2. the price and quantity of goods and services that will be desired by a firm that is maximizing its profits; and
3. the general conditions characterizing the markets in which firms and consumers interact.

These relations are combined to determine the equilibrium market conditions that will result in the greatest mutual satisfaction for all firms and consumers in the economic system. This equilibrium is, mathematically, the intersection of the supply and demand curves for products and the intersection of the supply and demand curves for the factor inputs to production.

Microeconomic models provide insight into the workings and effects of "ideal" market systems and can be used to evaluate alternative policies designed to regulate economic behavior or alter economic conditions. They can be used to investigate the effects of changes in such elements as preferences of consumers, technologies of firms, and the availability and costs of the various factor resource inputs to production.

Typical final results or products of the use of supply−demand models of microeconomic activity include

1. a quantitative model describing the interaction of some set of economic agents, including firms and consumers, in a market economy;
2. a determination of the market conditions that will exist in equilibrium when all economic agents are deriving maximum satisfaction;
3. increased understanding of the workings and effects of a free-market system;
4. a set of relations describing the quantity of commodities and resources that each economic agent will desire for a given price; and
5. a determination of those economic decisions that will result in maximum utility for the consumers and maximum profit for the firms.

The first step in building a microeconomic model of the supply−demand relations describing economic activity is to identify the basic components of the economic system under consideration. These components will generally include

1. a "consumption sector," generally represented by a set of consumers or households;
2. a "production sector," generally represented by a set of firms;
3. a set of final goods, commodities, or services; and
4. a set of economic resources that are the factor inputs to production.

Generally these consist of capital ($K$), land ($T$), and labor ($L$). The set of relations that provide the foundation for a microeconomic model are derived from theoretical considerations of

1. the economic behavior of firms (Chapter 2),
2. the economic behavior of households (Chapter 3), and
3. the equilibrium conditions that prevail in the markets where households and firms exchange resources and commodities (Chapter 4).

Let us provide some more perspective on each of these.

***The Economic Behavior of Productive Units.*** The role of a firm in a classic economic system generally consists in buying factor inputs in the form of land, capital, and labor; producing goods and services from these resources; and finally selling these goods to households and other firms for consumption. In economic systems, it will be necessary for some firms to use goods and services produced by other firms as factor inputs to their own production. For example, a firm that manufactures television sets may purchase components from another firm that manufactures electronic parts. It is assumed that associated with each firm is a *production function* that describes the maximum amount of final goods a firm can produce for a given quantity of factor inputs. The form of this production function will depend on the firm's technology and productive capacity. The *profit* of a particular firm is the total value of goods and services sold (revenues) minus the cost of producing these commodities. It is assumed that the basic goal of the firm is to maximize profits subject to the constraints on its technology and capacity as reflected in its production function. The solution to this optimization problem will result in the quantity of commodities produced and sold for consumption for given and assumed fixed prices.[3] This will be the supply curve for the firm in question. The solution to this profit maximization equation will also result in a factor demand equation. We will obtain a relation that gives the demand for factor inputs to production in terms of their prices. Of course, we could postulate a supply equation for a firm with several unspecified parameters. Regression techniques could, in principle, be used to identify parameters such that we identify a supply curve for a given firm as it operates in practice.

***The Economic Behavior of Consumers.*** The role of the household or consumer in an economic system generally consists in selling resources, such as labor, or factor inputs for production to firms and in buying commodities (final goods) for consumption with the income received from selling these factors. The utility function describes the amount of satisfaction a household derives from the possession of a given set of commodities and a given set of factor inputs. The form of this utility function will depend on the tastes and preferences of each consumer or household. Each consumer will also have a budget constraint, which reflects the total amount of income a household has to spend on final

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[3] The firm is assumed to be a price taker in the sense that it accepts prices, which may vary over time, of course, as given. The firm is "too small" to attempt to control prices.

goods and services. The income of a household comes from the sales of factor inputs and from the ownership of firms. The basic goal of a household is to maximize its utility function subject to the budget constraint.[4] The solution to this optimization problem identifies an "optimum" quantity of commodities demanded for consumption and an "optimum" quantity of factor inputs supplied to firms for given commodity and factor input prices. The quantities that are optimum for a particular household will depend on its resources and preferences as reflected in its utility function and budget constraint. For example, consumers will sell factor inputs, such as labor for wages, to increase their incomes. Consumers will also derive some utility from unsold factor inputs. Labor hours not supplied by a consumer can be interpreted, for example, as leisure time.

***Market Equilibrium Conditions***. An economic market is in *equilibrium* when the quantity of all the goods and services demanded is equal to that which is supplied. In microeconomic models in which firms, consumers, factor inputs, and commodities are all involved, equilibrium conditions require that the following two conditions hold:

1. For each final good or commodity produced, the total quantity supplied by all firms is equal to the total quantity demanded by all households. This gives rise to a set of commodity market clearing equations.
2. For each economic factor input to production, the total quantity supplied by all households is equal to the total quantity demanded by all firms. This gives rise to a set of factor market clearing equations.

After the basic structure of the model has been identified according to the issue formulation guidelines presented earlier, data need to be collected and used to determine the precise forms of the production function and consumers' utility functions. Utility functions might be reconstructed from observed past behavior or elicited in a more direct form. Statistical techniques, such as regression analysis and estimation theory, are also useful in constructing models of production functions for firms and utility curves for consumers.

The next step in the construction of a microeconomic supply–demand model is to actually solve the equations describing economic equilibrium. In theory, this requires the solution to the optimization problem for each household and each firm, subject to constraints and the market clearing conditions. The resulting solution will give the quantities of commodities and factor inputs that will, theoretically, be exchanged in equilibrium, together with the market prices at which they will be exchanged. This information can then be used to

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[4] The household also accepts prices as given; it needs such a small fraction of any available product or service that it cannot control price.

investigate the effects of changes in such factors as consumer preference, firm technology, income distribution, market structure, and resource availability on equilibrium market conditions. It can be used to evaluate the consequences of alternative policies designed to regulate or improve existing economic conditions. Figure 1.13 illustrates, conceptually, the results that we might obtain from the construction of a simple microeconomic model. In Fig. 1.13 there are two fundamental feedback loops: one involving the flow of products and the other involving the flow of capital. We will expand on this diagram in Chapter 4. Here it is especially important to note the flows into and out of the firms and consumer sectors. The input to the firms is the income due to sales and the factors for production; the output from the firms is the products of goods and services, the aggregate total of which is generally termed the gross national product (GNP), although the term gross domestic product (GDP) is now more common, and payments for the factor inputs to production.

Microeconomic models can be used to gain insight into the behavior of economic systems, as well as to assess the impact of alternative policies designed to alter or regulate behavior. They can also be used to determine market structures that will result in some desired utilization of resources. Thus microeconomic models may be useful for identifying alternatives, as well as for the analysis of their impacts. A simple example will illustrate some of the concepts involved in constructing a microeconomic model.

**Example 1.1:** We shall construct a microeconomic model based on a very simple economy consisting of two firms and two consumers. We will present much more detailed and realistic models in our later chapters. Imagine that in this small market system firm 1 buys labor from the consumers to make clothes to sell to the consumers, while firm 2 buys oil from the consumers to produce food to sell to the consumers. The generic questions we wish to answer are: How much food and how much clothing will each consumer purchase, and how much labor will each firm use? To construct a model that can answer these questions, we make some definitions and assumptions.

We use the following terminology. We let

$C$ = clothes produced by firm 1

$F$ = food produced by firm 2

$L_1$ = labor bought by firm 1

$L_2$ = labor bought by firm 2

$C_1$ = clothes bought by consumer 1

$F_1$ = food bought by consumer 1

$C_2$ = clothes bought by consumer 2

$F_2$ = food bought by consumer 2

$P_C$ = price of one unit of clothing

$p_F$ = price of one unit of food

$w_L$ = wage per unit of labor

$\Pi_1$ = profit of firm 1
$\Pi_2$ = profit of firm 2
$U_1$ = utility of consumer 1
$U_2$ = utility of consumer 2

The question naturally arises as to the time interval or horizon over which these prices, quantities, and profits are valid. The answer is that a specified planning interval over which incomes are obtained, goods produced, etc., must be identified. The models of firms and consumers should be valid for that interval. Since this is intended to be a simple illustration of economic analysis, we do not need to specify these here.

We also need a brief description of the production, consumption, and market mechanisms.

***Production.*** We assume that firm 1 can make units of clothing for units of labor purchased in such a way that its production function is given by $C = 8(5L_1)^{0.5}$. The profits of firm 1 are the value of the clothes sold minus the cost of the labor required to produce the clothing. Thus, the profit for this firm is given by the relationship

$$\Pi_1 = p_C C - w_L L_1$$

Similarly, firm 2 can produce units of food from each unit of labor in such a way that its production function is given by the relationship $F = 8(10L_2)^{0.5}$ and its profits are given by the relationship

$$\Pi_2 = p_F F - w_L L_2$$

***Consumption.*** We assume that each consumer initially owns 40 units of labor, *all* of which is sold to the firms, so that the income of each consumer is given by $I = 40w_L$. We assume that consumer 1 is partial to clothes and derives satisfaction from the consumption of clothes and food according to the utility function for consumer 1 given by

$$U_1 = (C_1)^{0.75}(F_1)^{0.25}$$

Also, assuming that consumer 1 spends all of the income earned, the purchase of clothing and food will be subject to the budget constraint

$$I = 40w_L = p_C C_1 + p_F F_1$$

Consumer 2 prefers food and has utility and budget equations given by

$$U_2 = (C_2)^{0.25}(F_2)^{0.75}$$
$$I = 40w_L = p_C C_2 + p_F F_2$$

***Market Equilibrium.*** In equilibrium, the quantities of labor, clothing, and food supplied must equal the respective quantities demanded. In the market for labor, then, the total quantity of labor purchased by the two firms must be equal to the quantity of labor provided by the consumers. This is represented by the factor market clearing equation:

$$L_1 + L_2 = 40 + 40 = 80$$

Similarly, the quantities of clothes and food purchased by the households must equal the quantities produced by firms 1 and 2, respectively. Thus the commodity market clearing equations are

$$C = C_1 + C_2$$
$$F = F_1 + F_2$$

We can now set up the optimization problems that must be solved to determine the quantities of goods and resources that will be exchanged when each firm and household is maximizing its own satisfaction function, profit for the firms, and utility for the consumers. Each firm must maximize profit subject to the production constraint, whereas each consumer must maximize utility subject to the budget constraint. We have four optimization problems:

| | |
|---|---|
| *Firm* 1 | *Firm* 2 |
| Maximize $\Pi_1 = p_C C - w_L L_1$ | Maximize $\Pi_2 = + p_F F - w_L L_2$ |
| subject to $C = 8(5L_1)^{0.5}$ | subject to $F = 16(5L_1)^{0.5}$ |
| *Consumer* 1 | *Consumer* 2 |
| Maximize $U_1 = (C_1)^{0.75}(F_1)^{0.25}$ | Maximize $U_2 = (C_2)^{0.25}(F_2)^{0.75}$ |
| subject to $p_C C_1 + p_F F_1 = 40 w_L$ | subject to $p_C C_2 + p_F F_2 = 40 w_L$ |

Also, we have two sets of clearing equations, one each for the commodity and factor markets.

Commodity market clearing equations:

$$C = C_1 + C_2$$
$$F = F_1 + F_2$$

Factor market clearing equation:

$$L_1 + L_2 = 80$$

■

These are the basic equations for this economic model. Attempts to indicate the full details concerning the solution to this problem would take us into subjects we will explore thoroughly in Chapter 4; we will therefore only indicate the highlights of our solution procedure here. It is easy to find the commodity bundles that maximize the utility of consumers 1 and 2. We obtain

$$\hat{F}_1 = \frac{10w_L}{p_F}, \hat{C}_1 = \frac{30w_L}{p_C}$$

$$\hat{F}_2 = \frac{30w_L}{p_F}, \hat{C}_2 = \frac{10w_L}{p_C}$$

where we use the symbol ^ to indicate optima.

By using the commodity market clearing equations, we obtain from the foregoing

$$\hat{C} = \hat{C}_1 + \hat{C}_2 = \frac{40w_L}{p_C}$$

$$\hat{F} = \hat{F}_1 + \hat{F}_2 = \frac{40w_L}{p_F}$$

As we should intuitively expect, these commodity demand relations show that the quantity of each product demanded decreases with increasing price of the commodity. To obtain maximum profit for each firm we find the quantity produced such that we have the necessary condition for profit maximization: $\partial\Pi_1/\partial C = \partial\Pi_2/\partial F = 0$. We easily obtain

$$\hat{C} = \frac{160p_C}{w_L}, \quad \hat{F} = \frac{160p_F}{w_L}$$

As we would intuitively expect, the quantity of the commodity that is produced increases with the price the firm can get for it.

We note that the first two relations for $\hat{C}$ and $\hat{F}$ are demand relations, whereas the latter two relations are supply relations. Economic equilibrium requires that these two be equal. We obtain as conditions for economic equilibrium $w_L = 2p_C = 4p_F$. This simply says that one of the prices, or the labor wage, can serve as a "numeraire" or "anchor" on which all other prices are based. We should not expect otherwise, as a little thought will show. Thus we may as well let $w_L = 1$ and get $p_C = 0.5$ and $p_F = 0.25$.

We already incorporated the factor market clearing equation when we wrote the budget constraint for each consumer, as this constraint included the clearing equation. Thus, all the necessary relations

1. the equations for optimality of the firm,
2. the equations for optimality of the consumers, and
3. the market clearing equations

have now been obtained. We obtain as the equilibrium relations the results $\hat{C}_1 = 60$, $\hat{C}_2 = 20$, $\hat{F}_1 = 40$, and $\hat{F}_2 = 120$.

In Chapter 4, we will provide a relatively general discussion of market equilibria and the effects that market imperfections, such as due to monopolist firms, may produce on equilibria.

## 1.6 WELFARE OR NORMATIVE ECONOMICS

Welfare or normative economics is that branch of microeconomics that is primarily concerned with the allocation of resources among competing uses. The purpose of welfare or normative economics is to determine patterns of resource allocation, commodity distribution, and economic organization that will result in maximum economic welfare for the economic system as a whole. As such, it is a part of what may be called *normative economics*. In deciding what distribution of resources among the members of a society is most desirable or equitable, ethical value judgments must be made. In Chapters 2 to 4 we are concerned primarily with efficiency and effectiveness; in Chapter 5 we are also concerned with equity. There are a number of issues associated with equity, the notion of sustainable development being a very important one of these. We will provide an introductory discussion of these generalized equity concerns in Chapter 5.

The basis for normative or welfare economics consists of a set of mathematical relations that describe

1. the satisfaction derived by each consumer from the possession or consumption of given quantities of goods and resources;
2. the productive capacity of the economic system for transforming economic resources into consumable goods or services; and
3. the level of general economic welfare associated with each distribution of goods and resources among the individual economic agents in the system.

These relations can be embedded into an optimization problem, the solution of which will determine a resource allocation and commodity distribution pattern yielding maximum economic *efficiency*, maximum economic *effectiveness*, and maximum *equity*, all according to the specified welfare function. We will show in Chapter 5 that it is not possible to optimize equity independently of efficiency and effectiveness concerns. The converse is also true.

The intent of a welfare economics application is often to determine policies that will enhance or increase the general economic welfare. Examples of application areas include policies pertaining to the income distribution among citizens, the allocation of raw materials among alternative productive uses, the distribution of consumable energy, government funding of public projects, and issues that concern sustainability.

The typical final results or product of a welfare or normative economic study may include

1. a quantitative model describing the allocation, utilization, and consumption of economic resources and commodities by consumers and firms;
2. a mathematical relation that assigns an index of social desirability or general economic welfare to each resource allocation and commodity distribution pattern in the economic system;

3. a determination of the economic configuration for which the social welfare function will attain a maximum value;
4. a determination of economic decisions that will result in maximum satisfaction for individual consumers;
5. a determination of resource allocations and utilizations to best ensure sustainable development;
6. a determination of how each consumer's satisfaction contributes to the overall social welfare; and
7. an increased understanding of the workings of the economic system under consideration.

All of this seems very desirable; however, there are major requirements for the large-scale application of welfare economics concepts. These include

1. a set of utility functions that represent each consumer's tastes and preferences with respect to the possession or consumption of given quantities of resources and commodities;
2. an aggregate production function representing the total productive capacity of the economic system such that we know the maximum quantity of consumable goods that can be produced for given amounts of resources available for productive use;
3. a social welfare function that maps levels of utility attained by individual consumers into an overall measure of social economic welfare;
4. a set of relations that describe the sustainable development concepts to be incorporated; and
5. a specification of the information and knowledge sources on which the welfare economics model is based.

Not all normative or welfare economics models will fully incorporate all of these issues. In particular, sustainable development issues are not incorporated in many classic welfare functions.

The first step in building a welfare economics model is to identify the components of the economic system under consideration. These components will generally include

1. a set of commodities or final (consumable) goods,
2. a set of economic resources used as factor inputs to the production of final goods,
3. a set of consumers who sell resources (e.g., labor) to firms and who buy final goods for consumption, and
4. a set of firms that produce final goods using factor inputs.

The construction of a welfare economics model will require the determination of

**a**. consumer preferences,
**b**. production functions, and
**c**. an overall economic welfare function.

We describe these three concepts in more detail here.

***Consumer Preferences.*** Associated with each consumer is a utility function that describes the level of satisfaction derived from the consumption of goods and services. The form for this function depends on the relative preferences and tastes of the consumer, the amount of resources with which the consumer is endowed, and the preferences of the consumer with respect to the factor inputs that they supply to firms and those which are retained for other uses, such as hours devoted to leisure. Generally, the utility function describes the level of satisfaction a consumer attains for a given state of the economy.

***Productive Capacity of Firms.*** Each firm produces final goods from factor inputs subject to the constraints on its technology and productive capacity. The production functions of all the firms in the economic system can, in principle, be combined to form an aggregate production function that describes the total productive capacity of the system. This aggregate production function gives the maximum quantity of consumable goods that the system can produce for given amounts of available resources.

***General Economic Welfare.*** The utility function of all consumers in the economic system is used to determine a *social welfare function* that describes the overall desirability of a given economic state. The form of this function depends on the relative contribution of each consumer's satisfaction level to the level of economic welfare of the whole system, and thus depends on very subjective value judgments. The premise is that the maximum value of an appropriately constructed social welfare function results from an economic state in which the distribution of resources and goods among consumers is the most *equitable* one.

After the major components of the model have been identified, the next step is to obtain data or other information that enables issue formulation. Production functions may be determined on the basis of past economic or technological information; consumer utility functions might be derived either by reconstruction of past behavior or by direct elicitation, while, generally, a direct attempt will be made to elicit a social welfare function for those interested in the results of the analysis.

The next step is to solve the resulting mathematical optimization problem, namely, to maximize the social welfare function subject to the productive capacity constraint represented in the aggregate production function. The result is called the *welfare optimum*.

Solutions to problems of welfare economics systems analysis are generally closely associated with decision analysis issues, and we will examine both normative and behavioral issues in the concluding part of Chapter 5. It is essential that this be done to incorporate descriptive realities. Microeconomic models are often helpful in determining the structure of the economic system with which the welfare economics model is concerned. Welfare economics models often supply very useful inputs to a cost–benefit analysis effort in which a measure of the economic desirability of several alternative projects is to be evaluated. The conceptual value to be obtained from welfare or normative economics models is very great, even though it will be necessary to incorporate behavioral realities obtained through such approaches as decision regret and prospect theory to obtain realistic solutions.

## 1.7 PROGRAM AND PROJECT MANAGEMENT ECONOMICS

Cost–benefit analysis is fundamentally concerned with the evaluation of alternative projects that will enhance individual, institutional, national, or international welfare so as to enable the selection of one or more of them for implementation. It is natural to ask: How is this different from welfare or normative economics? An answer is that the goals of the two are much the same. Welfare economics is much more concerned with adjusting parameters associated with a single policy alternative such that they are the best in maximizing a given or identified (scalar) welfare function. In the cost–benefit approach it is desired to evaluate a number of proposed alternative courses of action. It is recognized that welfare economics and other microeconomic approaches will provide very useful conceptual frameworks for the evaluation of proposed alternatives, but that not all of their prescriptions can be followed precisely. Cost–benefit analysis is a method for evaluating the net balance of benefits and costs, as these evolve over time, that are associated with proposed plans or projects. Both quantifiable and nonquantifiable effects are taken into account, as well as various intangible and secondary effects of proposed activities. Indirect methods, based on concepts such as consumer surplus and shadow pricing, are used to infer benefits and costs when there is no direct indication that appears either realistic or valid.

In conducting a cost–benefit analysis, it is first necessary to identify the costs and benefits of the impacts of the proposed alternatives. These are then quantified and discounted over time to obtain the net present values of benefits and costs. An assessment of the costs and benefits of a project that are not easily converted into economic costs and benefits may be more appropriately treated through a cost–effectiveness analysis. In this approach, effectiveness indices are based on the noneconomic "costs" and the economic and noneconomic benefits of proposed projects. Cost–benefit and cost–effectiveness analyses are very practical methods to conduct project appraisals. As such, this is very appropriate material with which we can continue our study of economic systems analysis, and we present a rather detailed discussion of the many subjects related to systems engineering and program management economics. In particular, in Chapter 6 we discuss economic valuation of programs and projects, including investment rates of return, cost–benefit and cost–effectiveness analyses, earned value management, cost structures and estimation of program costs and schedules, strategic and tactical pricing issues, and capital investment and options.

## 1.8 CONTEMPORARY ISSUES CONCERNING INFORMATION AND INFORMATION TECHNOLOGY ECONOMICS

Fundamentally, information technology (IT) is concerned with improvements in a variety of human problem-solving endeavors through design, development, and use of technologically based systems and processes that enhance the efficiency and effectiveness of information and associated knowledge in a variety of strategic, tactical, and operational situations. Ideally, this is accomplished through critical attention to the information needs of humans in problem-solving tasks and in the provision of technological aids, including computer-based systems of hardware and software and associated processes, that assist in these tasks. Information technology activities and efforts complement and enhance, as well as transcend, the boundaries of traditional engineering through emphasis on the information basis for engineering.

Information technology is comprised of hardware and software that enable the acquisition, representation, storage, transmission, and use of information. Success in IT is dependent on being able to cope with the overall architecture of systems, their interfaces with humans and organizations, and their relations with external environments. It is also very critically dependent on the ability to successfully convert information into knowledge.

The initial efforts at provision of IT-based systems concerned implementation and use of new technologies to support office functions. These have evolved from electric typewriters and electronic accounting systems to include very advanced technological hardware, such as FAX machines and personal computers to perform functions as electronic file processing, accounting, and word processing. Now, networking is a major facet of IT.

In the early days of human civilization, development was made possible through the use of human effort, or labor, primarily. Human ability to use natural resources led to the ability to develop based not only on labor but also on the availability of natural resources, land being a classic example. At that time, most organizations were comprised of small proprietorships. The availability of financial capital during the Industrial Revolution led to this being a third fundamental economic resource, and also to the development of large, hierarchical corporations. This period is generally associated with centralization, mass production, and standardization.

In the later part of the Industrial Revolution, electricity was discovered and the semiconductor was invented. This has led to the information age, or the IT age. Among the many potentially critical IT-based tools are database machines, e-mail, artificial intelligence tools, facsimile transmission (FAX) devices, fourth-generation programming languages, local area networks (LAN), integrated service digital networks (ISDN), optical disk storage (CD-ROM) devices, personal computers, parallel processing algorithms, word processing software, computer-aided software engineering packages, word processing and accounting software, and a variety of algorithmically based software packages. There are many others, and virtually anything that supports information acquisition, representation, transmission, and use can be called an IT product. This includes the Internet.

Major availability of technologies for information capture, storage, and processing has led to information, as well as its product knowledge, becoming a fourth fundamental economic resource for development. This is the era of total quality management, mass customization of products and services, reengineering at the level of product and process, and decentralization and horizontalization of organizations, and systems management. While IT has enabled these changes, much more than just IT is needed to bring them about satisfactorily. In this book, we fill focus our attention primarily on IT and its use by individuals and organizations to improve their productivity.

Many commentators have long predicted the coming of the information age and its characteristics are described in a number of contemporary writings. For example, Alvin Toffler writes of three waves: the agriculture, industrial, and information or knowledge ages. Within these are numerous subdivisions. For example, the information age could be partitioned into the era of vertically integrated and stand-alone systems, process reengineering, total quality management, and knowledge and enterprise integration. Information and knowledge are now fundamental resources that augment the traditional economic resources: land and natural resources, human labor, and financial capital. Critical success factors for success in the third wave, or information age, have been identified and include strategy, customer value, knowledge management, business organization, market focus, management accounting, measurement and control, shareholder value, productivity, and transformation to the third wave model for success. There are numerous other methods of partition. The information age could be partitioned into the age of mainframe computers, minicomputers, microcomputers, networked and client-server computers, and the age of knowledge management.

Major growth in the power of computing and communicating, and associated networking is quite fundamental and has changed relationships among people, organizations, and technology. These capabilities allow us to study much more complex issues than was formerly possible. They provide a foundation for dramatic increases in learning and both individual and organizational effectiveness. In large part, this is due to the networking capability that enables enhanced coordination and communication among humans in organizations. It is also due to the vastly increased potential availability of knowledge to support individuals and organizations in their efforts. However, information technologies need to be appropriately integrated within organizational frameworks if they are to be broadly useful. This poses a transdisciplinary challenge of unprecedented magnitude if we are to move from high performance IT to high performance organizations.

In years past, broadly available capabilities never seemed to match the visions proffered, especially in terms of the time frame of their availability. Consequently, despite these compelling predictions, traditional methods of information access and utilization continued their dominance. In the past years, the pace has quickened quite substantially and the need for integration of IT issues with organizational issues has led to the creation of a field of study sometimes called "organizational informatics," or more recently "knowledge management," the objectives of which generally include

- capturing human information and knowledge needs in the form of systems requirements and specifications;
- developing and deploying systems that satisfy these requirements;
- supporting the role of cross-functional teams in work;
- overcoming behavioral and social impediments to the introduction of IT systems in organizations; and
- enhancing human communication and coordination for effective and efficient workflow through knowledge management.

The Internet, World Wide Web, and networks in general have become ubiquitous in supporting these endeavors. However, organizational productivity is not necessarily enhanced unless attention is paid to the human side of developing and managing technological innovation to assure that systems are designed for human interaction. These are, of course, major objectives for systems engineering and systems management.

There are several ways in which we can define IT. The U.S. Bureau of Economic Analysis appears to define it in terms of office, computing, and accounting machinery. Others consider IT as equivalent to information processing equipment, which includes communications equipment, computers, software, and related office automation equipment. Still others speak about the technologies of the information revolution and identify such technologies as advanced semiconductors, advanced computers, fiber optics, cellular technology, satellite technology, advanced networking, improved human computer interaction, and digital transmission and digital compression. We would not argue about the content in this list, although we would certainly add software and middleware technology to this list. It could be argued that software is intimately associated with advanced computers and communications. This is doubtlessly correct; however, there is still software associated with the integration of these various technologies of hardware and software to comprise the many IT-based systems in evidence today and which will be in use in the future.

The information revolution is driven by technology and market considerations and by market demand and pull for tools to support transaction processing, information warehousing, and knowledge formation. Market pull has been shown to exert a much stronger effect on the success of an emerging technology than technology push. There is hardly any conclusion that can be drawn other than that society shapes technology or, perhaps more accurately stated, technology and the modern world shape each other in that only those technologies that are appropriate for society will ultimately survive.

The potential result of this mutual shaping of IT and society is knowledge capital, and this creates needs for knowledge management. The costs of the IT needed to provide a given level of functionality have declined dramatically over the past decade—especially within the past few years—due to the use of such technologies as broadband fiber optics, spectrum management, and data compression. A transatlantic communication link today costs one-tenth of the price that it did a decade ago, and may well decline by another order of magnitude within the next three or four years. The power of computers continues to increase and the cost of computing has declined by a factor of 10,000 over the past 25 years. Large central mainframe computers have been augmented, and in many cases replaced, by smaller, more powerful, and much more user-friendly personal computers. There has, in effect, been a merger of the computer and telecommunications industries into the IT industry and it is now possible to store, manipulate, process, and transmit voice, digitized data, and images at very little cost.

Current industrial and management efforts are strongly dependent on access to information. The world economy is in a process of globalization and it is possible to detect several important changes. The contemporary and evolving world is much more service oriented, especially in the more developed nations. The service economy is much more information and knowledge dependent and much more competitive. Further, the necessary mix of job skills for high-level employment is changing. The geographic distance between manufacturers and consumers, and between buyers and sellers, is often of little concern today. Consequently, organizations from diverse locations compete to provide products and services. Consumers potentially benefit as economies become more transnational.

The IT revolution is associated with an explosive increase of data and information, with the potential for equally explosive growth of knowledge. Information technology and communication technology have the capacity to radically change production and distribution of products and services and, thereby, bring about fundamental socioeconomic changes. In part, this potential for change is due to progressively lowered costs of computer hardware. This is associated with reduction in the size of the hardware and, therefore, with dematerialization of systems. This results in the ability to use these systems in locations and under conditions that would have been impossible just a few years ago. Software developments are similarly astonishing. The capabilities of software increase steadily, the costs of production decrease, reliability increases, functional capabilities can be established and changed rapidly, and the resulting systems are ideally and often user friendly through systems integration and design for user interaction. The potential for change is also brought about due to the use of IT systems as virtual machines, and the almost unlimited potential for decentralization and global networking due to simultaneous progress in optical fiber and communication satellite technology.

The life cycle of IT development is quite short and the technology transfer time in the new "postindustrial," or knowledge-based, society brought about by the information revolution is usually much less than that in the Industrial Revolution. Information technology is used to aid problem-solving endeavors by using technologically based systems and processes and effective systems management. Ideally, this is accomplished through

- critical attention to the information needs of humans in problem-solving and decision-making tasks; and
- provision of technological aids, including computer-based systems of hardware and software and associated processes, to assist in these tasks.

Success in IT and engineering-based efforts depends on a broad understanding of the interactions and interrelations among the components of large systems of humans and machines. Moreover, a successful IT strategy also seeks to meaningfully evolve the overall architecture of systems, the systems' interfaces with humans and organizations, and their relations with external environments.

As discussed, the most dominant recent trend in IT has been more and more computer power in less and less space. Gordon Moore, a founder of Intel, noted that since the 1950s the density of transistors on processing chips has doubled every 18 to 24 months. This observation is often called "Moore's law." He projected that doubling would continue at this rate. Put differently, Moore's law projects a doubling of computer performance every 18 months within the same physical volume. The implication of this is that computers will provide increasingly impressive processing power. The key question, of course, is what we will be able to meaningfully accomplish with all of this power.

Advances in computer technology have been paralleled by trends in communications technology. The ARPAnet emerged in the 1960s, led to the Internet Protocol in the 1970s, and the Internet in the 1980s. Connectivity is now on most desktops, e-mail has become a "must have" business capability, and the World Wide Web is on the verge of becoming a thriving business channel. The result is an emerging networking market. Telecommunications companies are trying to both avoid the obsolescence that this technology portends and figure out how to generate revenues and profits from this channel. The result has been a flurry of mergers and acquisitions in this industry.

That the price of computing has dropped to half approximately every two years over the last two decades or so is nothing short of astounding. Had the rest of the economy matched this decline in prices, the price of an automobile would be in the vicinity of $10. Organizational investments in IT have increased dramatically and now account for approximately 10% of new capital equipment investments by U.S. organizations. Roughly half of the labor force is employed in information-related activities. On the other hand, productivity growth seems to have continually declined since the early 1970s, especially in the service sector that comprises about 80% of IT investments. This situation implies needs to effectively measure IT contributions to productivity, identify optimal investment strategies in IT, and enhance IT effectiveness through knowledge management for enhanced productivity.

Although IT does indeed potentially support improvement of the designs of existing organizations and systems, it also enables fundamentally new ones, such as virtual corporations and major expansions of organizational intelligence and knowledge. It does so not only by allowing for interactivity in working with clients to satisfy present needs, but also through proactivity in planning and plan execution. An ideal organizational knowledge strategy accounts for future technological, organizational, and human concerns, to support the graceful evolution of products and services that aid clients. Today, we realize that human and organizational considerations are vital to the success of IT. This is clearly the network age of information and knowledge. One of the major challenges of today is that of capturing value in the network age. Associated with these changes are a wide range of new organizational models. Distributed collaboration across organizations and time zones is becoming increasingly common. The motivation for such collaboration is the desire to access sources of knowledge and skills not usually available in one place. The result of such new developments in IT as network computing, open systems architectures, and major new software advances has been a paradigm shift that has prompted the reengineering of organizations; the development of high performance business teams, integrated organizations, and extended virtual enterprises; and the emergence of loosely structured organizations. These are the issues we examine in the later part of this book, specifically in Chapters 7 through 10.

## 1.9 ECONOMIC PITFALLS IN THE ENGINEERING OF SYSTEMS

In any problem-solving effort, we must be careful to state the critical assumptions on which our developments and solution procedures are based. If this is not done, or not done carefully, it is an easy task to obtain “solutions” that are false because they are based on a set of assumptions that are different from those characteristic of the original problem or issue. In this section, we will state some of the assumptions on which our developments will be based and present some critical points associated with them.

In Chapters 2 to 4 we develop a number of results based on a perfectly competitive economy. There are six critical assumptions:

1. In the market for each and every good or service, there are a large number of relatively small producers and consumers.
2. All firms in the same industry produce similar goods of comparable quality. No consumer has any reason to prefer the output of one firm over that of another; products and services are completely standardized among firms that make the product or service; and there is no brand loyalty among consumers.
3. Resources are completely mobile. Owners of productive resources (land, capital, labor) or factor inputs to production are free to put them to whatever use they find will yield them maximum return. People can work in or sell their resources to any industry they wish. No barriers exist to prevent the establishment of a firm in any industry, or to prevent any firm from leaving an industry.

4. Each economic agent has perfect information and knowledge. All firms and all consumers know with certainty all present and future prices; each knows their own characteristics (production functions and utilities). There are no uncertainties.
5. Each economic agent (producer or consumer) is an optimizer; each acts to maximize satisfaction. Thus each consumer acts to maximize its utility and each firm acts to maximize its profits.
6. There are no price controls. Prices may move up or down freely, subject only to market pressures.

If the above six conditions hold, and they are really rather idealistic, it is easy to show that

a. prices and the quantity of goods produced and consumed are determined by the market-demand equilibrium; and
b. all goods are produced and sold at the lowest possible price, at least in the long run after transients have died out.

Surely, not all of these six conditions will always exist. We examine cases where they do not exist in our detailed treatments to follow. When condition 1 does not exist, a monopoly or monopsony may well result: Firms will have knowledge of how prices will vary with demand and will be able to control the entire quantity produced (monopoly), or suppliers of labor will be able to exert similar control (monopsony). When condition 2 does not hold, we need to consider similar products as if they were separate and develop different supply and demand relationships for the different brands of a product. The nonexistence of condition 2 gives rise to the profession of marketing.

When conditions 4 and 5 do not hold, as is often the case, we need to consider various aspects of game theory and behavioral theories of the firm and of the consumer. When conditions 3 and 6 do not hold, we can impose various controls and constraints on admissible solutions. We do this in several places in this book. We do, for example, consider the effects of taxes and price controls.

In some cases additional conditions hold; then additional simplifications result. These conditions include the following:

a. Individuals are "selfish." Each person's feelings are determined only by personal consumption. People are devoid of both sympathy and envy. The fortunes and misfortunes of others do not affect a person's feelings of satisfaction or dissatisfaction.
b. Individuals are "greedy." More is always better, at least never worse. A person never achieves satiation and always feels better off by consuming more.
c. Preferences are such that the rate at which additional amounts of one good, $x$, may be substituted for another, $y$, to retain the same level of utility diminishes with increasing amounts of the good $x$; that is, diminishing marginal rates of substitution between goods exist. Indifference curves of constant utility are convex to the origin.

**d**. There are no externalities, such as cases in which the increased production of one firm results in decreased production ability for another firm.
**e**. There are no production processes that exhibit IRS in the sense that increased production quantity will always result in increased profits.
**f**. All goods and services are exchanged in markets, and all markets are in steady-state equilibrium.
**g**. There are no public goods; there are only private goods that are consumed by a single individual or household.
**h**. There is neither government taxation nor government subsidization of the production or consumption of any good or service.

If conditions 1–6 and a–h are satisfied, then we may establish the very important result that all goods and services have market prices, and that the market prices are exactly equal to the corresponding shadow prices, such that the shadow price and the market price have true social values.

Even though some of these conditions may not hold, we can often predict, by determining which assumptions are violated, the direction in which the observed price will deviate from the "shadow price" or price that represents true value. When prices do not exist, which is often the case when there are no markets for goods and services like national defense, public schools, or parks, we can suggest measurement guidelines to assist the systems analyst in making approximations. A great deal of information is needed to determine concepts like "value" and "willingness to pay," information that is generally not readily available. All of this complicates the subject of economic systems analysis. This does not make it either an impossible or a sterile subject by any means, but it does suggest that we must be keenly aware of potential limitations, especially with respect to difficulties of observation and measurement and with respect to the fact that there are indices of performance other than utility and profit, and that there is much literature that shows that humans do not have the cognitive stamina to optimize in unaided situations. This also strongly suggests the need for parsimony as well as perception in the organization of the knowledge bases of economic and other activities that support systems engineering and management in both the private and public sectors.

In a seminal paper, now three decades old, Oskar Morgenstern identified 13 points in contemporary economic theory that, if ignored, act as pitfalls in economics and in sound systems engineering applications of economic concepts. Ten of Morgenstern's points are of special concern in this book. Slightly modified in some instances to conform to the thrust of our discussions, these ten points are as follows:

1. ***Control of Economic Variables.*** The maxima of profit and utility that we so ardently seek in much of Chapters 2 to 4 may make good sense and be truly attainable if we can identify and have control over all the variables on which the maxima, or minima, depend. Often no single economic agent "controls" all of the essential parameters in a study. Game theory and distributed information control studies could, in

principle, resolve difficulties due to multiple agent control issues; but these subjects introduce their own rigidities.

2. ***Revealed Preference Theory.*** In principle, it is possible to observe the behavior of a consumer operating under budget constraints and to determine the priority order or ranking of the consumer's preferences. In practice, this is extraordinarily difficult. There is, for example, no way of being sure that an observed order is complete. The time sequences in which commodities are obtained are important, as there are questions of price changes over time, different expected lines of various commodities, changes in income streams over time, and complications due to purchasing "bundles" of commodities at one time rather than individual goods.
3. ***Pareto Optimality.*** Much of our discussion in Chapter 5 will be based on the assumption that an improvement or increase in one person's utility with no decrease in anyone else's utility is an improvement for all of society. In the simplest case, the utility of each individual is independent of everyone else's. A question of interest is: How do we find out that there has been an improvement or a decrease? We can ask people or we can make a judgment based on observation. But how do we know that people are not denying that they are better off in the hopes of getting still greater returns? Or perhaps people are not able to state truthfully whether they are better off or not under some changed resource allocation. If one infers that a person is better off with some change in allocation of resources, is that not making the interpersonal comparison of utilities the concept of Pareto optimality seeks to avoid? Our view here is that we are, and we resolve this dilemma by asserting that interpersonal comparisons of utility are necessary for any practically successful group decision-making effort.
4. ***Tatonnement.*** In the assumed behavior that leads to general economic equilibrium, initially assumed strategies for buyers and sellers will either lead to equilibrium or they will be modified. This mechanism of groping for stable prices is known as tatonnement. This involves the use of various production rules, heuristics, or standard operating policies. But will the equilibrium be stable and unique? Even if the equilibrium is stable and unique, will it be reached in any finite time? We will not be able to develop dynamic economic models to the extent needed to answer these questions here. Generally accepted answers seem to be that any realistic economic model will exhibit stable equilibria. The question of multiple equilibria is an interesting one, as it offers the opportunity to alter social and national welfare for the better by shifting the economy from one stable equilibrium point to another. The existence of multiple equilibria would require a sudden jump in economic variables such as price. This seems to have occurred, for example, with respect to gold and oil prices over the

past decade. Does this indicate a jump-type phenomenon indicating multiple equilibria, such as could be modeled with catastrophe theory? Or does it represent the faster than normal change in a single stable equilibrium point over time? Either view is possible, although the latter seems more so in keeping with most economic thought. And what about the time required to reach a stable equilibrium? Is this within a human lifetime? Will the equilibrium that is reached be a perfectly competitive one, or will coalitions of individuals be formed who agree on prices at which they will sell or purchase goods? Questions such as these need, in effect, to be answered in the process of issue formulation and impact analysis, which are essential parts of economic systems analysis.

5. ***Fixation on Free or Perfect Competition.*** Most of our work is based on what has traditionally been called "perfect competition." The popular use of the word *competition* implies struggle, maneuvering, bargaining, negotiation, compromise, and conciliation. But free competition, as used in the traditional economic sense, implies that no one really has any influence on anything; everyone accepts prices as given and adapts to maximize utility and/or profit. Surely, a lesson in this is that we are dealing with what we may call *economic rationality* only in our work here. We do this with no shame at all, since economic rationality is very important. But we must remember that while economic rationality presumes technological rationality, there are other forms of rationality—social, political, and legal, for example—that are noncommensurate or at least not necessarily commensurate with economic rationality. Each must be considered in effective systems engineering practice.
6. ***Resource Allocation.*** Most of the resource allocation efforts that we will discuss assume perfect competition conditions. But there are monopolies, oligopolies, monopsonies, and oligopsonies, as well as governments, that use bargaining, negotiation, and finally voting to allocate resources, rather than the economic "market mechanism." These influences are surely important and we cannot regard answers obtained using the methods of economic systems analysis only as necessarily *the* answers, for we do not live in an economic system, but in a socio-legal-political economic system.
7. ***Substitution.*** A good that is a substitute for another good is said to have the same (economic) value. We must be careful with this concept, for while it is often valid, a particular context may make it not valid. In particular, the relationship between one good and others that are present in the commodity bundle is important, as is the form of the utility function. If a utility function is given by $U = x_1^{0.5}x_2^2$, then the utility of $\mathbf{x}^T = [1 \;\; 2]$ is the same as that of $\mathbf{x}^T = [16 \;\; 1]$. This does not say that 15 units of $x_1$ are worth 1 unit of $x_2$, but, rather, at 2 units of $x_2$

and 1 unit of $x_1$, a decrease of 1 unit of $x_2$ is balanced out by a gain of 15 units of $x_1$. It would seem that only in the additive form $U = a_1x_1 + a_2x_2$ could we talk about so many units of $x_1$ being worth 1 unit of $x_1$.

8. ***Supply and Demand.*** We shall spend much time in the beginning chapters deriving supply curves of products for firms and factor inputs to production for consumers, and demand curves of products for consumers and factor inputs to production for firms. The notion of time is curiously absent, yet obviously time is present. We desire food and newspapers every day, whereas we purchase automobiles and stereos only every few years. Only if we are careful with respect to the consideration of time periods will we be able to obtain the correct interpretation of our supply–demand curves. Suppose, for example, that the demand curve for product $x$ is given by $p = a - bx$. If the price is initially $p_1$, we buy a quantity $x_1 = (a - p_1)/b$. Suppose the price suddenly drops to $p_2$. Will we buy quantity $x_2 = (a - p_2)/b$? The answer is generally no, since we have just bought quantity $x_1$ at price $p_1$. We should expect to, perhaps, purchase some additional amount $0 \le \overline{x_2} \le x_2 - x_1$ such that the total amount purchased will be $x_1 \le x_1 + \overline{x_2} \le x_2$. Only if we purchase quantity $x_1$ at price $p_1$ in one demand period and our need for the good is reconstituted, and if our income remains the same such that the demand remains the same, will we purchase amount $x_2$ at price $p_2$ when the time shifts to a different time period. Different people have different reconstitution time periods. The important notion of consumer surplus, which we will find very useful for cost–benefit studies, is very affected by this notion. What we have said here is equally applicable to supply curves and producer surplus concepts.

9. ***Indifference Curve Concepts and Uncertainty.*** Generally we base indifference curves on concepts of value and preference for goods that are received with certainty. This is a fundamental part of the theory of the consumer. These notions of value have been shown to be correct under conditions of certainty, but need to be modified somewhat to allow the consideration of risk. Basically, there is a relative risk aversion function that can be used to transform the value function for outcomes received with certainty to outcomes received with some known probability. Attempts to fully explore these notions would take us into the very interesting and important subject of decision analysis, which we will explore later in this book.

10. ***Theory of the Firm.*** Our theory of the firm is based on productive units that maximize their profit. This concept fits well for many producers of "hardware." But what about the service sector? There it may fit well or hardly at all. Maximizing profit is the primary objective of many consulting firms, but surely not all of them. Is the primary objective of a ballet company or theater group to maximize profit? Surely not! And even if the foremost desire of the owner of a firm making hardware is

> to maximize profit, is it the objective of all of the managers of the firm? Probably not! There are behavioral theories of the firm and satisficing theories of human behavior that add a greater amount of reality and rationality to the behavior of the firm than that exclusively contained in the economically rational theory that we develop here. It is reasonable for the reader to ask, then why are we studying all of this economic rationality? The answer is that what we develop here is one viewpoint on rationality and a very important one. It is more developed at present than political rationality concepts, social rationality concepts, legal rationality concepts, and organizational rationality concepts. These other rationality concepts can and must, and do, augment economic rationality concepts; they cannot replace it.

In Chapters 2 through 5, we will discuss many of these pitfalls from the vantage point of classic microeconomic systems analysis. Chapter 6 is concerned with many of these issues from the perspective of systems engineering program and project management. In a real sense, Chapter 6 is a transition chapter that also brings in some of the issues associated with information and knowledge economics as driven by the IT revolution. The last three chapters are concerned with information and knowledge as a fourth fundamental economic resource that now affects the engineering and management of systems of all types. Chapter 10 briefly discusses some of the contemporary issues we have not been able to explore in this book.

## 1.10 SUMMARY

In this chapter we described some of the rationale behind this book and provided an introduction to many of the concepts to follow. We will hopefully have an interesting journey that is relevant to the engineering of economic and productive systems of all types, especially those that are information and knowledge intensive.

## PROBLEM

1. Pick a contemporary issue of interest to you that has strong economic components. Describe the concerns associated with this issue from the perspectives discussed in this chapter.

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