Previous Page

and are subsequently developed through the steps illustrated in Figure 1.13. Figure 1.19 emphasizes that there are system engineering activities that lead into the software development process.

Numerous models have been introduced through the past few decades, with the objective of providing a logical approach to the overall process of system design and development. The few identified here are only representative of the total population. Most of these models are directed primarily to the system acquisition process only and/or to some element of the system (such as software); hence, they lack a certain degree of "completeness." If implemented properly, they are excellent in terms of accomplishing their intended objectives. However, it should be recognized that their application may be limited unless utilized within the broader spectrum of system engineering described in Section 1.2.4.[21]

1.2.9 System Engineering in the Life Cycle

The system engineering process is applicable in all phases of the life cycle, as illustrated in Figure 1.12. In the early stages of conceptual design, the emphasis is on understanding the true needs of the consumer (user) and in developing the actual "requirements" for the system. These requirements, which constitute the "baseline" that needs to be established from the beginning, must be "traceable" from the top and on down to the component level as necessary. This top-down approach (with the appropriate feedback incorporated), reflected in the left side of the Vee diagram in Figure 1.11, is critical for the successful implementation of a system engineering program. It is the establishment of these early requirements that has a great impact on the ultimate life-cycle cost for a given system (see Figure 1.5).

Given the basic requirements, the emphasis then shifts to an iterative process of synthesis, analysis, design optimization, and validation. Trade-off studies are conducted, with the objective of providing a well-balanced system design. There are many different design objectives that must be met, some of which may be somewhat conflicting, and the role of system engineering is to identify, prioritize, integrate, and to cause the development of a system configuration that will meet all customer requirements in a timely, effective, and efficient manner. Such an ultimate configuration must consider the system in "total" to include the development of the production, maintenance and support, and retirement/material recycling capabilities as shown in Figure 1.10.

System engineering activities continue through the construction and/or production phase to ensure that the "designed" system configuration is compliant with the ini-

[21]There are numerous other models, including prototype models, the Sashimi Model, the Scrum Model, the Handcuff Model, the Hollywood Model, the Evolutionary Development Model, and so on. A good reference covering some of these models (in a summary manner) is R. S. Scotti and S. S. Gulu Gambhir, "A Conceptual Framework for a Customer-Centered System Development Life-Cycle Model," *Proceedings of the 6th Annual Symposium* (Seattle, WA: International Council on Systems Engineering, INCOSE, 1996), p. 547. The reader may also refer to the Vee model, Tufts Systems Engineering Process Model, Plowman's Model, and INCOSE's model, described in *INSIGHT* Vol. 5, no. 1, published by INCOSE, April 2002, pp. 7–16.

tially specified requirements. Next, there is an ongoing and iterative process of *assessment* (and validation) throughout the operational use and maintenance support phase, and during the system retirement and material recycling stage. This assessment, with the proper feedback, is important to ensure that not only are the initially specified system requirements being met, but that any changes in requirements that take place in the user environment are properly reflected back and into the design process (through redesign, reengineering, etc.). In other words, there is a continuous product/process improvement feedback loop, included at the bottom in Figure 1.12, which is critical in the implementation of system engineering.

Experience related to the evaluation and assessment of a system, which is operational and being maintained in the user's environment, must be captured. A baseline configuration (with the appropriate metrics) must be established for the purposes of "benchmarking" and the initiation of possible changes for improvement. This, of course, requires that a good comprehensive data collection, analysis, and evaluation capability be implemented to provide the necessary feedback. It is this knowledge of what really is happening to the system in the user's environment that is critical but often lacking because of the lack of having a good assessment capability in place. Hence, we often end up introducing the same mistakes again and again as we design new systems. Assessment is an inherent part of the system engineering process.

Finally, when changes are being initiated (whether for corrective action or for product/process improvement), the consequences of such changes must be evaluated from a top system-level perspective; that is, assessing the impact of a change on the overall system. The principles of configuration management and change control must be implemented to ensure that the end results are consistent with the basic requirements in terms of both effectiveness and life-cycle cost (i.e., both sides of the spectrum in Figure 1.3). Such changes may be applicable to the prime mission-related elements of the system, the construction/production capability, the maintenance and support infrastructure, and/or the retirement and material recycling capability. The interaction effects, both upward and downward, must be properly addressed in a *systems* context.

It should be noted that, although the system engineering process is applicable in all phases of the life cycle, this is not to imply that any single organizational entity within a given project is responsible for the completion of all of the tasks necessary to accomplish these objectives. The process must be an "inherent" element within any given program structure, and the successful fulfillment of such objectives is dependent on many different organizational groups, working in a cooperative and integrated manner.

1.3 RELATED TERMS AND DEFINITIONS

The preceding framework for the "basics" in describing the principles and concepts associated with system engineering is now extended to include a few additional but related concepts. Figure 1.20 presents the system development process and life-cycle activities in a slightly different context. System design activities, emphasized in Figure

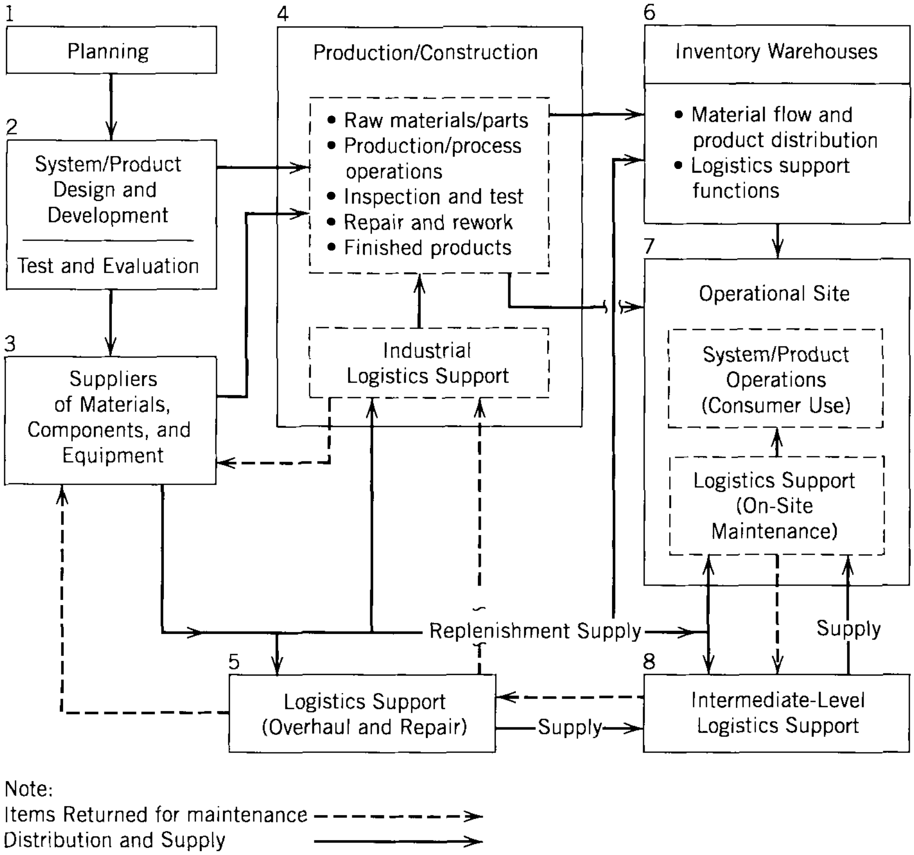

Figure 1.20 System operational and maintenance flow.

1.11 and in the first three columns in Figure 1.12, are addressed in blocks 1, 2, and 3; construction and/or production activities are included in blocks 3 and 4; and then there are the system operational and support activities reflected in blocks 5, 6, 7, and 8.

In Figure 1.20, it should be noted that there is a *forward* flow of activities covering not only the design and development of the system, but also the construction and/or production of the system and its elements, the transportation and distribution of these elements to the various operational sites, and the subsequent installation of the system for sustaining operational use. Throughout this flow, there are production- and logistics-related activities that are essential if the ultimate system is to accomplish its objectives. For instance, the lack of an effective and efficient transportation capability, the absence of a supplier-produced component in a timely manner, or the lack of appropriate information may preclude the successful accomplishment of a mission requirement(s). Thus, having the appropriate "logistics" available where and when needed is critical.

At the same time, there is a *reverse* (or backward) flow of activities that deal with the maintenance and support of the system throughout its life cycle, which may be necessary in the event of a system failure. An unreliable system that is nonoperational when needed will obviously not be able to perform its designated mission, and there must be an effective and efficient infrastructure that is readily available and in place that can respond to problems, with the objective of repairing the system and returning it to full operational status in a timely manner. The lack of a needed spare part, an available transportation capability, a necessary item of test equipment, required maintenance software, an appropriate repair facility, or the right data, may prevent the system from performing its intended function(s). Thus, there are a variety of logistics and maintenance support functions needed, which are inherent within this reverse flow of activities (as illustrated in blocks 3, 4, 5, 7, 8, and the dotted lines in Figure 1.20).

These activities, associated with both the *forward* and *reverse* flows in Figure 1.20, are characteristic and applicable for any system. However, they are usually addressed downstream and "after the fact" in the life cycle (constituting one of the problems highlighted in Section 1.1). In the past, there has been little emphasis on *the design for reliability and maintainability, the design for producibility, the design for packaging, the design for transportation and handling, the design for supportability and serviceability, the design for disposability and recyclability,* and so on. Yet these factors should be considered as critical system-level parameters, along with *the design for performance,* and emphasized in the early phases of the system engineering process illustrated in Figure 1.11.

Given this background information, a number of terms and definitions discussed with the objective of strengthening the understanding of system engineering before addressing the process described in Chapter 2.

1.3.1 Concurrent/Simultaneous Engineering

In the mid-1980s the term *concurrent engineering* became popular, with the objective of placing additional emphasis on "concurrency" as it applies to the design and development of the prime mission-related elements of a system, the construction and/or production capability, the maintenance and support infrastructure, and the retirement and material recycling capability. In Figure 1.10, the various life cycles should be viewed on a concurrent basis, which is directly supportive of system engineering objectives.

One of the first formal definitions resulted from a Department of Defense study, in which "concurrent engineering" is defined as "a systematic approach to the integrated, concurrent design of products and their related processes, including manufacture and support. This approach is intended to cause the developers, from the outset, to consider all elements of the product life cycle from conception through disposal, including quality, cost, schedule, and user requirements."[22] As such, concurrent engineering should be included within the system engineering process.

[22]R. I. Winner, J. P. Pennell, H. E. Bertrand, and M. M. G. Slusarczuk, *The Role of Concurrent Engineering in Weapons Systems Acquisition.* Report R-338. (Alexandria, VA: Institute of Defense Analysis, 1988). Additional references are included in Appendix A.

1.3.2 Integrated Product and Process Development (IPPD)

In the early 1990s, the Department of Defense initiated the integrated product and process development (IPPD) concept, which can be defined as a

> management technique that simultaneously integrates all program activities throughout the life cycle, including systems management, development, manufacturing, testing, deployment, operations, support, training, and eventual disposal. Using IPPD, multidisciplined Integrated Product/Process Teams (IPTs) shall simultaneously optimize the product, product manufacturing, and supportability to meet system cost and performance objectives.[23]

Inherent within the IPPD structure are a select number of integrated product/process teams (IPTs), which are composed of representatives from all appropriate functional disciplines working together to design a specified element of the system where unusual complexities exist and/or to solve a given design problem. Such teams, which may be assigned on a short-term basis, may include representation from marketing, engineering, manufacturing, logistics, customer service, and the consumer (user). Chapter 7 includes additional discussion of the IPPD/IPT approach. Once again, these objectives are inherent within the system engineering process and its management.

1.3.3 Logistics and Supply Chain Management

The term *logistics* can be defined variously, depending on the application (e.g., "commercial" versus "defense"), the companies and organizations involved, and one's personal background and experience. In the commercial sector, *logistics* is often defined as "the process of planning, implementing, and controlling the efficient, cost-effective flow and storage of raw materials, in-process inventory, finished goods, and related information from point of origin to point of consumption for the purposes of conforming to customer requirements." This definition was developed by the Council of Logistics Management (CLM) and addresses primarily the flow of materials from the initial sources of supply through materials handling in manufacturing, involving the distribution of products to the ultimate consumer—that is, the activities reflected in the *forward* flow and related to blocks 3, 4, 6, and 7 in Figure 1.20.[24] More specifically, the activities associated with "logistics" in this context are often centered on the commercial manufacturer and can be categorized under the terms *physical supply, manufacturing,* and *physical distribution,* as shown in Figure 1.21.

By projecting Figure 1.21 in the context of Figure 1.20, it can be seen that the functional elements of logistics include logistics planning, purchasing, materials han-

[23]Department of Defense Regulation 5000.2R, "Mandatory Procedures for Major Defense Acquisition Programs (MDAPS) and Major Automated Information System (MAIS) Acquisition Programs," Chapter 5, Paragraph C5.1, April 5, 2002.

[24]The Council of Logistics Management (CLM) is a nonprofit professional business organization of individuals (representing commercial manufacturers, small businesses, and academia), dedicated to the development and enhancement of the logistics profession (visit web site http://www.clm1.org).

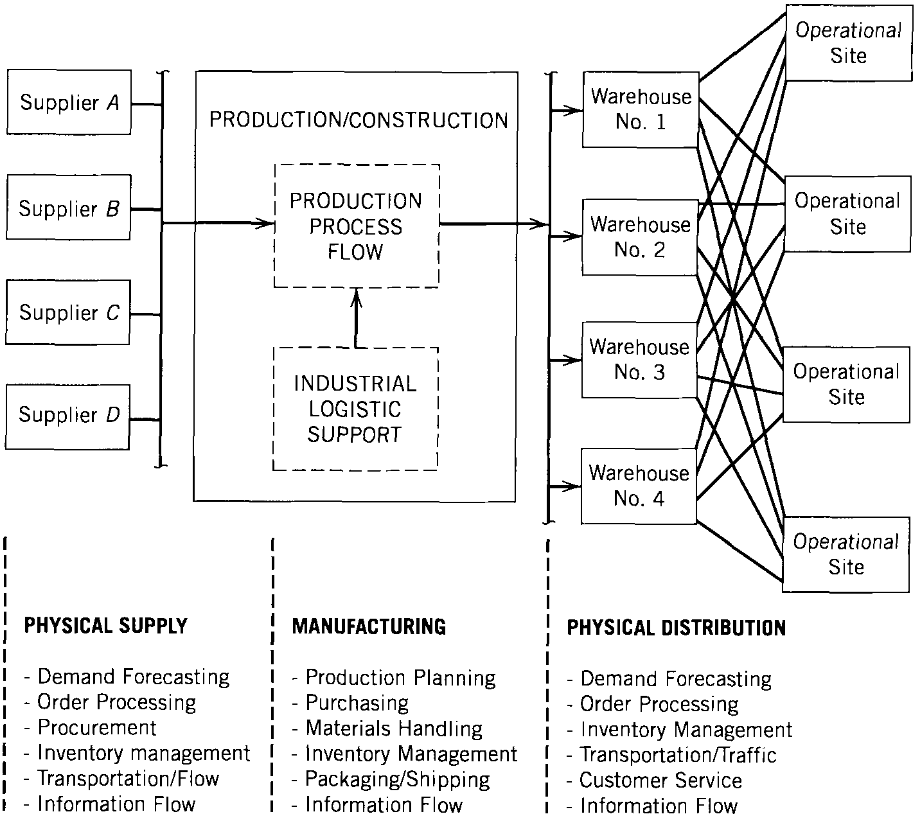

Figure 1.21 *Logistics activities in the production process.*

dling and inventory control, packaging and shipping, transportation, warehousing, information flow, customer service, and logistics management. It should be noted that this definition (by itself) is not life-cycle complete, as it does not address "systems" and the issues of product design and maintenance and support. Nevertheless, these activities are an essential part of the overall flow depicted in Figure 1.20 and must be considered in the context of the system engineering process.

During the past few years, there has been a major advance in the field with the development of a broader approach known as *supply chain management* (SCM). In many companies, the "logistics" organization has traditionally been responsible for managing the physical flow of materials and products among organizations (including the functional elements noted earlier). Marketing and sales have been responsible for providing information to potential customers before and after a transaction. The relatively recent advent of information technology has enabled the development and application of information flow among organizations. The development of bar coding, radio frequency identification (RFID) tags, global positioning system (GPS) technology, and electronic data interchange (EDI) methods has assisted organizations in the "tracking" of and providing information on product flows, each step along the way, as the product progresses from the source of supply to the consumer (user). Although each of these activities has (in the past) been considered somewhat independently, they are now being integrated (along with all supporting business and financial management practices) within the concept of SCM. In other words, the concept of SCM is broader and more encompassing than what was known as "commercial logistics" in the past.

According to J. J. Coyle, SCM "integrates *product, information,* and *cash flows* among organizations from the point of origin to the point of consumption with the goal of maximizing consumption satisfaction and minimizing organizational costs."[25] This includes the integration of those activities identified in Figure 1.21, along with strategic planning, marketing and sales, information technology, and financial management. In a recent article, "Defining Supply Chain Management," in the *Journal of Business Logistics,* there are six slightly different definitions of SCM noted. However, after some consensus, the following definition for SCM is offered: "The systemic, strategic coordination of the traditional business functions and the tactics across these business functions within a particular company and across businesses within the supply chain, for the purpose of improving the long-term performance of the individual companies and the supply chain as a whole." The supply chain (SC) in this case is defined as "a set of three or more entities (organizations and individuals) directly involved in the upstream and downstream flows of products, services, finances, and/or information from a source to a customer."[26]

In any event, no matter how one may wish to define it, the SCM concept is certainly growing in recognition and importance. With current trends toward outsourcing, more suppliers involved in a given program, greater international competition, and increasing globalization (refer to Figure 1.1), there is likely to be even greater dependence on this area of activity as it affects the design and development, production, and utilization of systems in the future. For example, many companies have been forced to work within the framework of formal partnerships in order to survive (versus acting as independent contractors), and these partnerships then become an inherent part of the flow process illustrated in Figure 1.20. Again, logistics and supply chain management must be addressed within the context of the system engineering process.[27]

[25] J. J. Coyle, E. J. Bardi, and R. A. Novack, *Transportation,* 5th ed. (St. Paul, MI: South Western Publishing, 2000). Emphasis added.

[26] J. T. Mentzer, W. DeWitt, J. S. Keebler, S. Min, N. W. Nix, and Z. G. Zacharia, "Defining Supply Chain Management," *Journal of Business Logistics* Vol. 22, no. 2: pp. 1–25. Published by the Council of Logistics Management, Oak Brook, IL, 2001.

[27] It should be noted that the material presented thus far emphasizes logistics in the commercial sector and not the entire spectrum of logistics as practiced in the defense sector. Historically, logistics as it applies for defense systems, has been covered within the context of *integrated logistic support* (ILS), which, in turn, has included not only what is described in Section 1.3.3 but the maintenance and support infrastructure that is discussed further in Section 1.3.4. Recently, the term *acquisition logistics* has become popular within the Department of Defense (DOD) and includes the principles and concepts of SCM and maintenance and support, as applicable in each phase of the system life cycle.

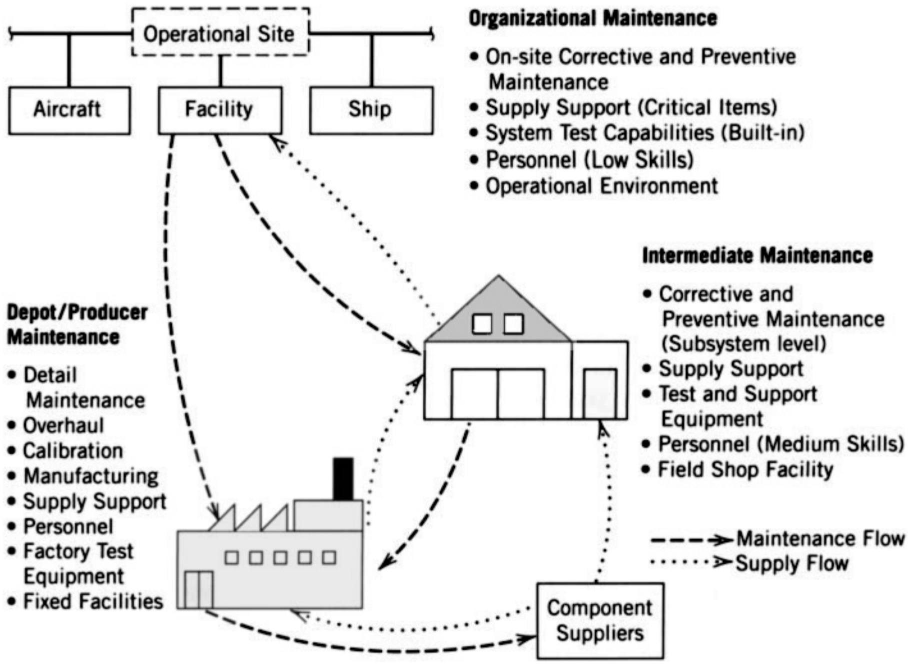

Figure 1.22 System maintenance and support infrastructure.

1.3.4 Integrated System Maintenance and Support

In Figure 1.20, there is also a *reverse* flow relating to some of the activities in blocks 3, 4, 5, 7, 8, the dotted lines indicating a "path" whereby faulty items are sent for maintenance and repair as necessary. Figure 1.22 shows an expansion of this, presented in the form of a maintenance and support infrastructure network.

Figure 1.22 shows an example of a basic "three-levels-of-maintenance approach": organizational maintenance, intermediate-level maintenance, and depot/producer/supplier maintenance. Depending on the type of system, the mission to be accomplished, the system's complexity and reliability, geographical location where utilized, customer desires, and so on, there may be some variation in repair policies and the infrastructure may include only two levels of maintenance. Further, there may be one or more third-party maintenance contractors involved in the network. In any event, there must be some form of a maintenance and support infrastructure, in place and readily available, to ensure that the system will continue to be "operational" when required.[28] Referring to the network in Figure 1.22, it can be seen that the functional elements of support include maintenance and support planning, maintenance personnel, training, spares/repair parts and associated inventories, test and support equip-

[28]The system maintenance concept and repair policies are discussed further in Chapter 2.

ment, maintenance facilities, packaging and shipping, transportation, warehousing, computer resources, technical data, and management. These various elements must be closely integrated, with an effective information technology (IT) capability facilitating the necessary integration, as illustrated in Figure 1.23.

Traditionally, the subject of maintenance has been addressed after the fact and downstream in the system life cycle, and the maintenance and support infrastructure has not been considered as an element of a system but rather as a separate and somewhat unrelated entity. Through the years, the results of such a practice have been rather costly, with a large portion of the total life-cycle cost for many systems being attributed to maintenance activities accomplished downstream (refer to Figures 1.3 and 1.4). In response, there have been some efforts leading to the recognition of the maintenance and support infrastructure early in the system life cycle and as an inherent element of a system (refer to Figure 1.5).

In the defense sector, the DOD initiated the concept of *integrated logistic support* (ILS) in the mid-1960s. ILS is a management function that provides the initial planning, funding, and controls that help to ensure that the ultimate consumer (or user) will receive a system that will not only meet performance requirements, but can be supported expeditiously and economically throughout its programmed life cycle. More specifically, ILS can be defined as "a disciplined, unified, and iterative approach to the management and technical activities necessary to (1) integrate support considerations into system and equipment design; (2) develop support requirements that are related consistently to readiness objectives, to design, and to each other; (3) acquire the required support; and (4) provide the required support during the operational phase at minimum cost." A major ILS objective is to ensure the proper and timely integration of the elements of support, as shown in Figure 1.23.[29]

More recently, in the interest of economy, the DOD has been emphasizing (1) increased reliance on the utilization of best commercial logistics and supply chain practices in meeting the support requirements for defense systems and (2) an increased emphasis on the *design for supportability/sustainability* and consideration of the maintenance and support infrastructure within the context of the systems engineering process. Relative to the first area, there has been a great deal of growth in adopting many of the principles of supply chain management in the defense sector, particularly in view of the growth in information technology (IT) and electronic commerce (EC) methods. In regard to the second area of emphasis, the concept of *acquisition logistics* has become popular, and its focus is segmented into three interrelated parts: (1) designing the system for support, (2) designing the support system, and (3) acquiring the support elements.[30] In essence, logistics in the defense sector has become an integrated mix of the activities depicted in Figures 1.21 and 1.22.

[29]This definition initially evolved from Department of Defense Instruction 5000.2, "Defense Acquisition Management Policies and Procedures," Part 7, 1991. It should be noted that this definition is the result of an evolving set of definitions stemming from the original *ILS Planning Guide for DOD Systems and Equipment*, 4100.35, 1967.

[30]MIL-HDBK-502, *Acquisition Logistics*. (Washington, DC: Department of Defense, May 1997). It should be noted that this document includes a major section on systems engineering.

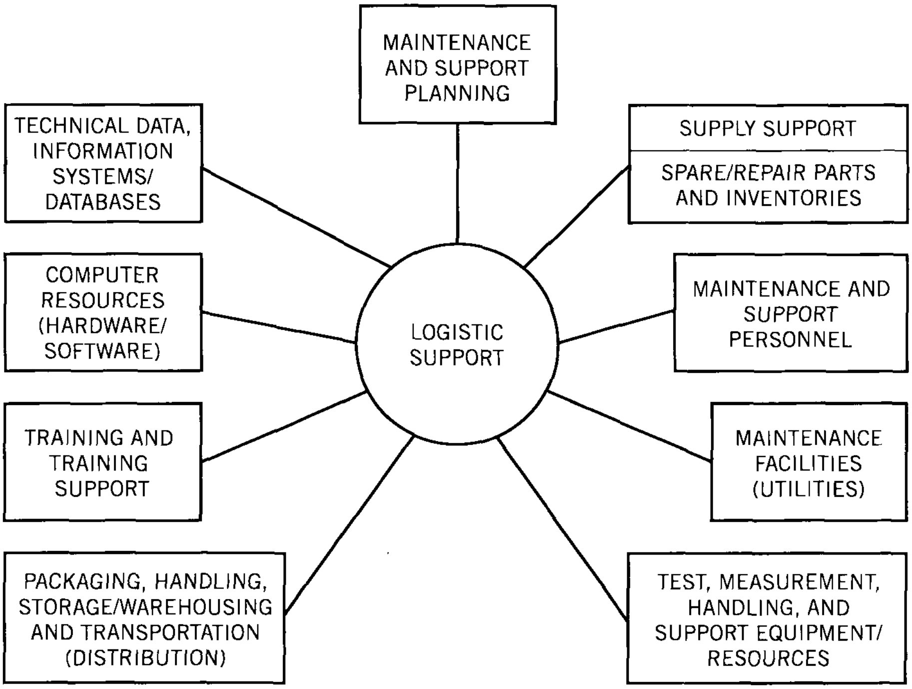

Figure 1.23 Functional elements of logistics.

In the commercial sector, the maintenance and support issue has been addressed more recently through the concept of *total productive maintenance* (TPM). TPM, a concept originally developed by the Japanese, constitutes an integrated, top-down, system-oriented, life-cycle approach to maintenance, with the objective of maximizing productivity. TPM, directed primarily to the commercial manufacturing environment:

1. Promotes the overall effectiveness and efficiency of equipment in a factory. It includes *maintenance prevention* (MP) and *maintainability improvement* (MI), which consider the appropriate incorporation of reliability and maintainability characteristics in design.
2. Establishes a complete preventive maintenance program for factory equipment based on life-cycle criteria (similar to the reliability-centered maintenance approach used in establishing preventive maintenance requirements).
3. Is implemented on a "team" basis, involving various departments to include engineering, production operations, and maintenance.
4. Involves every employee in the company, from the top management to the workers on the shop floor. Even equipment operators are responsible for the care and maintenance of the equipment they operate.

5. Is based on the promotion of preventive maintenance through "motivational management" (the establishment of autonomous small-group activities for the maintenance and support of equipment).

Total productive maintenance, often defined as "productive maintenance" implemented by all employees, is based on the principle that equipment improvement must involve everyone in the organization, from line operators to top management. The objective is to eliminate equipment breakdowns, speed losses, minor stoppages, and so on. It promotes defect-free production, just-in-time (JIT) production, and automation. The concept of TPM promotes continuous improvement in maintenance.[31]

Related to TPM is the concept of *total asset management* (TAM), which is being addressed by those industries and government agencies that are faced with budgetary constraints, limited available resources, and greater international competition. TAM is directed toward systems in which there are significant capital assets and in which there is a need to adopt a total life-cycle approach to resource management.

1.3.5 Configuration Management (CM)

Configuration management (CM) is a management approach that includes identifying, documenting, and auditing the functional and physical characteristics of an item, recording the configuration of the item, and controlling the changes to the item and its documentation. The purpose is to provide a complete audit trail of design decisions and system modifications. CM is a concept of *baseline* management, which includes the definition of the *functional* baseline for a system, the *allocated* baseline, and the *product* baseline identified in Figure 1.12. Successful fulfillment of system engineering requirements is heavily dependent on a good disciplined approach to baseline management. This is particularly true in considering the current trends toward evolutionary design and the introduction of new technologies into a system configuration on a continuing basis.[32]

1.3.6 Total Quality Management (TQM)

Total quality management (TQM) can be described as a totally integrated management approach that addresses system/product quality during all phases of the life cycle and at each level in the overall system hierarchy. It provides a before-the-fact orientation to quality, and it focuses on system design and development activities as well as manufacturing and production, maintenance and support, and related func-

[31]The concept of TPM was initiated in Japan, through the Japan Institute for Plant Maintenance (JIPM), in 1971. A good initial reference is S. Nakajima (Ed.), *Total Productive Maintenance (TPM) Development Program*. (Portland, OR: Productivity Press, English trans., 1989). TPM has grown significantly in terms of implementation throughout the world. See Appendix A for additional references.

[32]Department of Defense Regulation 5000.2R, "Mandatory Procedures for Major Defense Acquisition Programs (MDAPS) and Major Automated Information System (MAIS) Acquisition Programs," Chapter 5, Paragraph C5.2.3.4.5, April 5, 2002.

tions. TQM is a unification mechanism linking human capabilities to engineering, production, and support processes. The emphasis is on total customer satisfaction, the iterative practice of "continuous improvement," and a total integrated organizational approach. As part of the initial system design and development effort, consideration must be given to (1) the design of the processes that will be used to manufacture and produce the components of the system and (2) the design of the support infrastructure that will provide the necessary ongoing maintenance of that system throughout its planned life cycle. In this regard, the principles of TQM must be inherent within the system engineering process.

1.3.7 Total System Value and Life-Cycle Cost (LCC)

A system should be measured in terms of its total value to the consumer. For the purposes of discussion, it is necessary to consider both sides of the balance, as illustrated in Figure 1.24; that is, the *technical factors* and the *economic factors*. Of particular interest within the domain of system engineering is the issue of *life-cycle cost* (LCC). LCC includes all costs associated with the system life cycle, which can be broken down as follows:

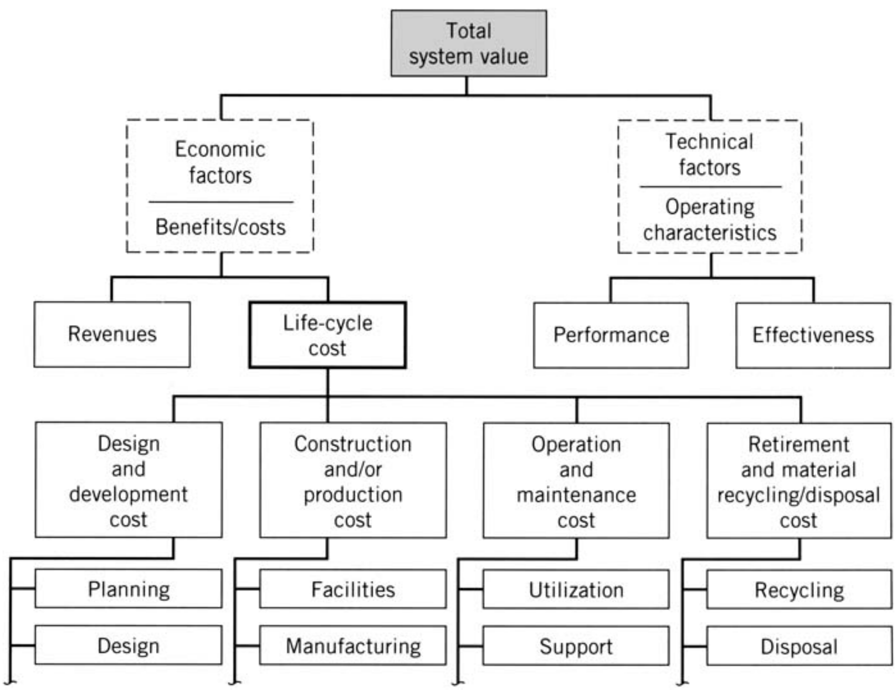

Figure 1.24 Total system value.

1. *Research and development (R&D) cost:* the cost of feasibility studies; developing operational and maintenance requirements; system analyses; detail design and development; fabrication, assembly, and test of engineering models; initial system test and evaluation; and associated documentation
2. *Production and construction cost:* the cost of fabrication, assembly, and test of operating systems (production models); operation and the sustaining maintenance and support of the manufacturing capability; facility construction; and the acquisition of an *initial* system support capability (e.g., test and support equipment, spare/repair parts, and technical documentation)
3. *Operation and maintenance cost:* the cost of system operation and the sustaining maintenance and support of the system through its planned life cycle (e.g., manpower and personnel, spare/repair parts and related inventories, test and support equipment, transportation and handling, facilities, software, modifications, and technical data)
4. *System retirement and phase-out cost:* the cost of phasing the system and its components out of the inventory because of obsolescence or wearing out; recycling of items for further use; condemnation and the disposal of materials.

Life-cycle costs can be categorized many different ways, depending on the type of system and the sensitivities desired in cost-effectiveness measurement. The objective is to ensure *total cost visibility* (see Figure 1.4). This is necessary if one is to be able to properly assess the risks associated with each of the major design and management decisions made throughout the life cycle. Life-cycle cost (LCC) is a major theme throughout this text, and the process for conducting a life-cycle cost analysis is highlighted in Appendix C.

1.4 SYSTEM ENGINEERING MANAGEMENT

The successful implementation of system engineering principles and concepts is dependent not only on the *technology* issues and the process, but on *management* issues as well. As illustrated in Figure 1.25, there are two sides of the spectrum, each dependent on the other. The best tools/models may be available to implement the process shown in Figure 1.12; however, there is no guarantee for success unless the proper organizational environment has been created and an effective management structure is in place. Top management must first believe in and then provide the necessary support to enable the application of system engineering methods to in-house projects. Specific objectives must be defined, policies and procedures must be developed and properly implemented, and an effective reward structure must be supportive. The challenge is *proper implementation.*

Although there are variations from one program to the next, Figure 1.26 presents a baseline for discussion. The major program phases and milestones are noted, along with a few selected activities and events that are significant from a system engineer-

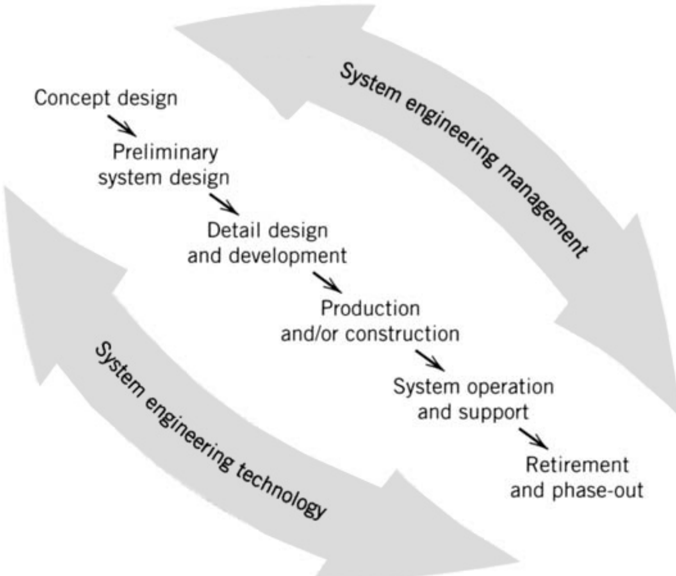

Figure 1.25 Management and technology application to the system engineering process.

ing perspective. These phases, which are discussed further in detail in subsequent chapters, can be summarized as follows:

1. During the early stages of conceptual design, it is essential that good communications between the producer and the consumer(s) be established from the beginning. Defining the true need, conducting feasibility analyses, developing operational requirements and the maintenance concept, and identifying specific quantitative and qualitative requirements at the system level are critical. These requirements must be properly conveyed through a well-prepared System Specification (Type "A"). This top-level system specification constitutes the most important *technical* document, from which all lower-level specifications evolve. Without a good foundation from the beginning, all subsequent lower-level requirements may be questionable (refer to Chapter 3).

2. During the latter stages of conceptual design, a comprehensive System Engineering Management Plan (SEMP) must be developed to ensure the implementation of a program that will lead to a well-coordinated and integrated product output. The SEMP, which evolves from the top-level Program Management Plan (PMP), integrates all lower-level planning documents. It includes the design-related tasks necessary to enhance the day-to-day system development effort, the implementation of concurrent engineering methods, and the integration of the appropriate organizational entities into a "team" approach. The SEMP must directly support the requirements in the System Specification (Type "A") from a *management* perspective, and

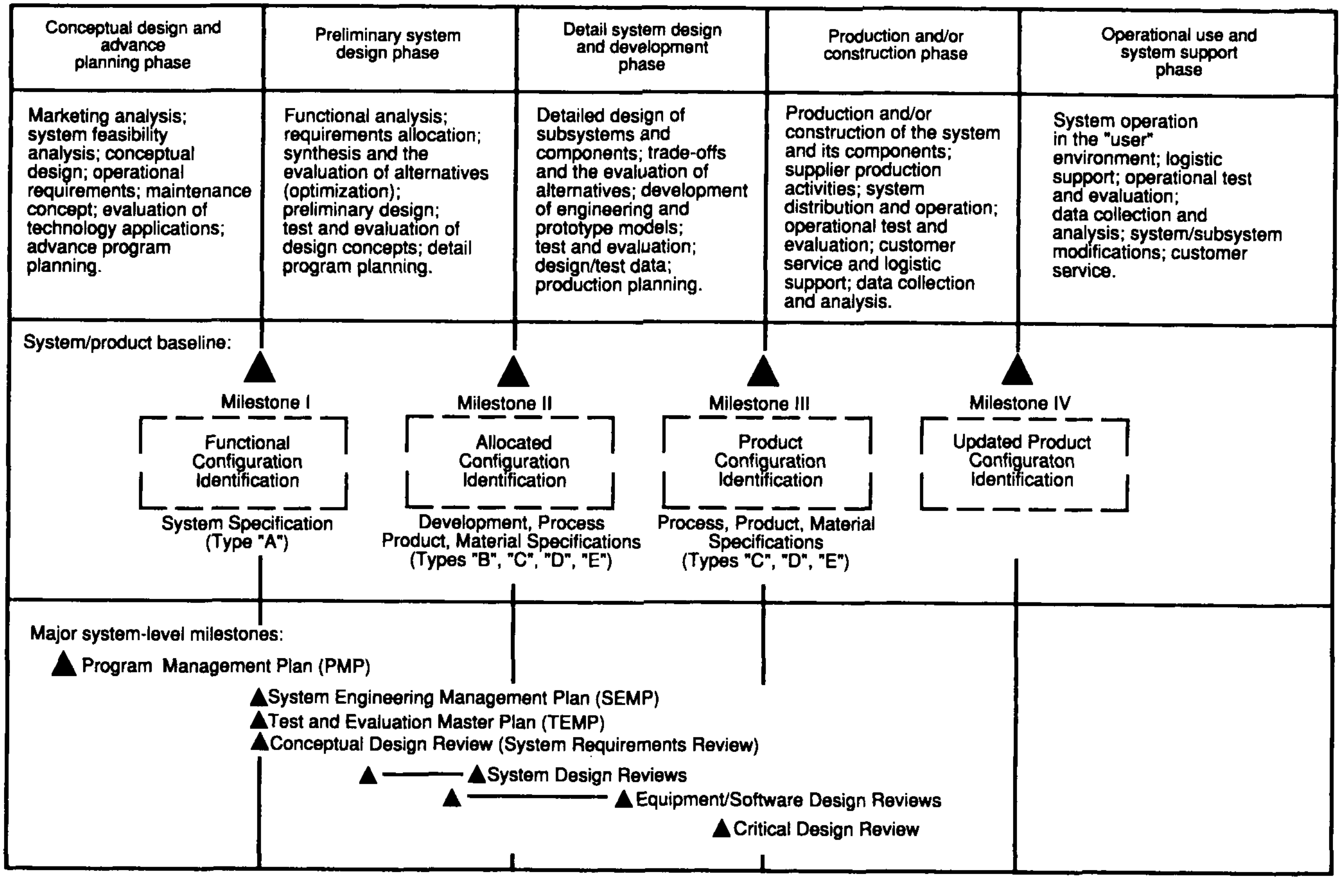

Figure 1.26 The system acquisition process and major milestones. *Source:* SYSTEMS ENGINEERING AND ANALYSIS 2/E by Blanchard/Fabrycky, © Reprinted by permission of Pearson Education, Inc., Upper Saddle River, NJ.

the two documents must "talk to each other." The SEMP is addressed in detail in Chapter 6.

3. During the latter stages of conceptual design, a Test and Evaluation Master Plan (TEMP), or equivalent, must be developed for the purposes of assessment and ultimate validation. As requirements are initially specified in the System Specification (Type "A") and planned through the tasks described in the SEMP, the methods/techniques to be used for measuring and evaluating the system to ensure compliance with these requirements must be described. This plan must address test and evaluation activities on a fully integrated basis, employing the appropriate combination of simulation and other analytical tools, mock-ups, laboratory models, and prototype models. Test and evaluation are covered further in Chapter 2.

4. As system design and development progresses, there is a need to schedule a series of formal design reviews at discrete points where the design configuration evolves from one level of definition to another; that is, conceptual, system, equipment/software, and critical design reviews. The purpose of these reviews is to ensure that the specified requirements are being met prior to entering into a subsequent phase of effort, and to ensure that the necessary communications exist across organizational lines. See Chapter 5 for further discussion of design reviews and evaluation requirements.

5. Toward the latter stages of detail design, throughout the construction/production phase, and during the operational use and maintenance support phase, there is a need to provide ongoing assessment and validation of the system. The objective is to ensure that the consumer requirements are being met and to establish a "baseline" for the purposes of benchmarking and the initiation of a *continuous process improvement* activity. Design changes are initiated as required to correct any noted deficiencies.

The successful implementation of system engineering principles is highly dependent on proper management of the simplified process depicted in Figure 1.27. Inherent in this process is the application of different technologies employed to facilitate the steps of requirements analysis, functional analysis and allocation, synthesis, design optimization, and validation.

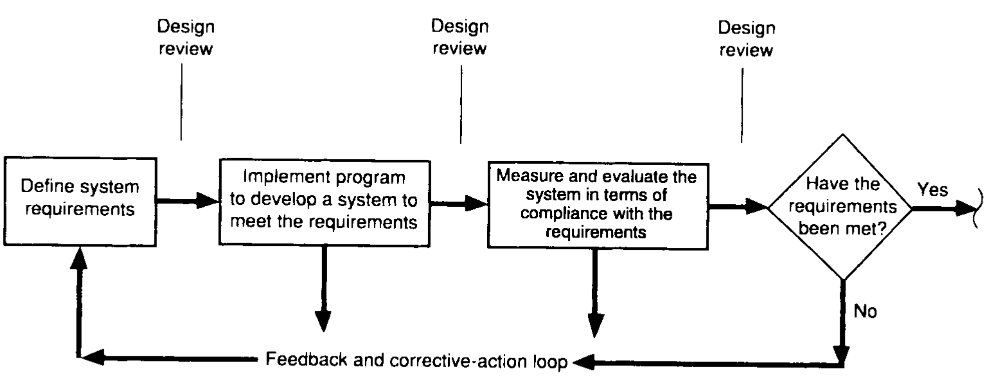

Figure 1.27 The basic system requirements, evaluation, and review process.

1.5 SUMMARY

This chapter provides an abbreviated introduction to some of the key terms and definitions inherent in the discussions throughout subsequent chapters. Although many additional terms are introduced throughout this text, it is hoped that this brief discussion of "systems," "system analysis," "system science," "system engineering," and the "life cycle," will stimulate the thought processes needed for the material to come. The information presented herein, and particularly the concepts illustrated in Figures 1.12, 1.13, and 1.14, are a natural introduction to the system engineering process discussed in Chapter 2.

QUESTIONS AND PROBLEMS

1. Provide, in your own words, a definition of a "system." Include some examples.
2. Select a system of your choice and describe the system life cycle. Construct a detailed flow diagram tailored to your situation.
3. Define *system engineering.* What is included? Why is it important? How does system engineering differ from system science and system analysis?
4. What are the differences (or similarities) between system engineering and some of the more traditional disciplines such as civil engineering, electrical engineering, mechanical engineering, and so on?
5. Refer to Figure 1.10 (Example "A"). Describe the interrelationships between the three illustrated life cycles.
6. Refer to Figure 1.13. What are some of the key system engineering objectives that can be applied?
7. Refer to Figure 1.14. What are some of the key system engineering objectives that can be applied?
8. What is the significance of the feedback process illustrated in Figure 1.15?
9. What are the major system engineering functions in conceptual design? Preliminary design? Detail design and development? System operational use and life-cycle support?
10. Describe the basic differences between the waterfall model, the spiral model, and the Vee model. How do they compare with the model proposed by the author?
11. Refer to Figure 1.20. Briefly highlight the activities that are critical for the successful implementation of the system engineering process. When in the life cycle must these activities be addressed?
12. Refer to Figure 1.21. Describe how these activities might affect/influence system engineering (if at all).

13. Refer to Figure 1.22. Describe how these activities might affect/influence system engineering (if at all).

14. Refer to Figure 1.23. Explain why these elements should be considered (or not considered) as inherent elements of a system.

15. The successful implementation of the system engineering process is dependent on both technological and management issues. Explain why. Provide an example of how one can affect the other.

16. Why is the System Specification (Type "A") important? Develop an outline for a system of your choice.

17. What is the purpose of design reviews?

18. What is *concurrent engineering?* How does it relate to system engineering?

19. What is *configuration management?* Why is it important in system engineering?

20. Why is ILS important? How does it relate to system engineering?

21. What is *life-cycle cost?* What is included? Why is it important to consider such cost in the decision-making process?