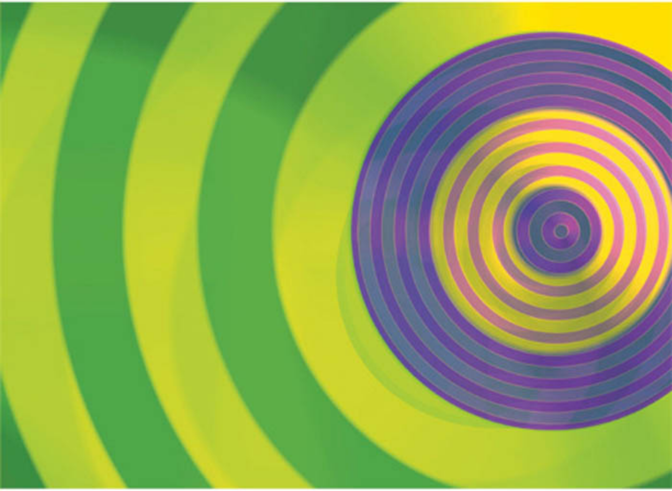
Pearson New International Edition



Logistics Engineering and Management

Benjamin S. Blanchard

Sixth Edition

ALWAYS LEARNING

PEARSON

Pearson New International Edition

Logistics Engineering and Management
Benjamin S. Blanchard
Sixth Edition

Pearson Education Limited
Edinburgh Gate
Harlow
Essex CM20 2JE
England and Associated Companies throughout the world

Visit us on the World Wide Web at: www.pearsoned.co.uk

ISBN 10: 1-292-02713-4
ISBN 13: 978-1-292-02713-5

British Library Cataloguing-in-Publication Data
A catalogue record for this book is available from the British Library

Printed in the United States of America

Table of Contents

This page intentionally left blank

Introduction to Logistics

This text deals with the subject of *logistics* and the design of systems for supportability. Logistics, as defined herein, is approached from a total *system* perspective and includes all the activities associated with the initial design for logistics and supportability; the procurement and acquisition of the elements of support; the supply, materials handling, and physical distribution of components; the transportation and warehousing of products; and the maintenance and support of systems throughout their planned period of utilization. Logistics, to include the various aspects of supply chain management and the follow-on maintenance and support of systems, is addressed from a total *life-cycle* view and must be considered in all phases of a program; that is, logistics must be considered as an inherent element in the system design process, as it constitutes a major activity in the construction and/or production of a system and its components. A logistics and support capability must be in place and effective throughout the period when the system is in operational use, and logistics includes a necessary element of support when the system is retired and its various components are processed for either recycling or disposal. The emphasis throughout this text is on logistics in the context of the system design process; that is, the phase of the life cycle when system requirements are defined and when one can significantly influence the activities that will be required later on when the system is operational, as well as the overall cost-effectiveness of the system itself.

The objective of this chapter is to address the subject of logistics in general, to include some terms and definitions, and to describe the need for logistics in the context of the current international and global environment. The requirements for logistics are addressed from a system perspective, the elements of logistics are discussed, an integrated logistics approach is emphasized, and the need for considering logistics in the system design process is highlighted.

From Chapter 1 of *Logistics Engineering and Management*, Sixth Edition. Benjamin S. Blanchard.

1 THE CURRENT ENVIRONMENT

Having a good understanding of the overall environment is certainly a prerequisite to determining logistics and related requirements, and for successfully implementing the principles and concepts discussed throughout this text. Although individual perceptions will differ depending on personal experiences and observations, there are a number of trends that appear to be significant from our perspective. These trends, shown in Figure 1, are all interrelated and need to be addressed as an integrated set when determining the requirements for systems and for the logistics and maintenance infrastructure necessary to support those systems.

1. *Constantly changing requirements*. The requirements for new systems are constantly changing owing to the dynamic conditions worldwide, to changes in mission thrusts and priorities, and to the introduction and evolution of new technologies. Thus, there is a need for a highly flexible (agile) logistics and maintenance support capability.
2. *More emphasis on systems*. There is a greater emphasis on total *systems* versus the *components* of a system. The system needs to be addressed in total, and throughout its entire life cycle, to ensure that the necessary functions are being accomplished in an effective and efficient manner. Thus, a logistics and maintenance support infrastructure must be considered as a major element of the system, must be in place and reliable, and must be available to support the prime mission-related elements of the system when needed.
3. *Increasing system complexities*. It appears that the structures of many systems are becoming more complex as new technologies are introduced and evolve. An *open-architecture* approach in design is necessary, as systems must be designed

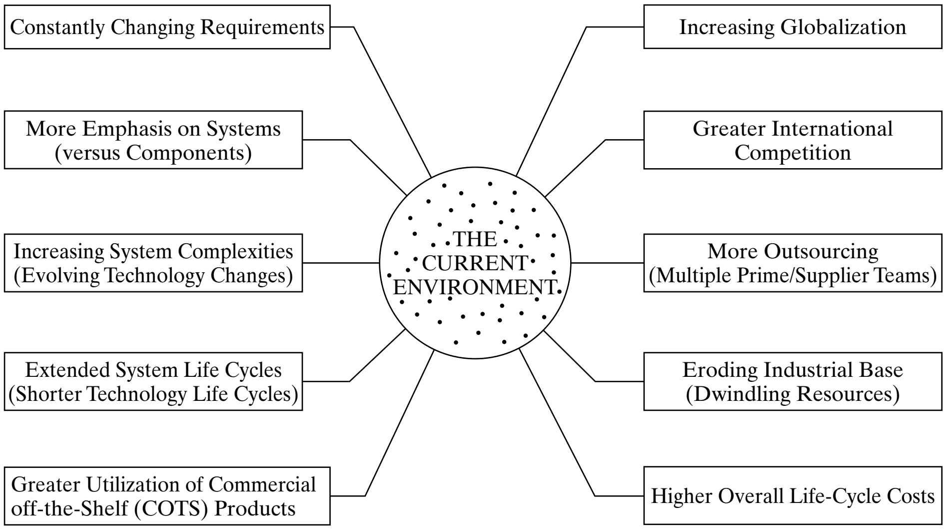


Figure 1 The current environment.

such that changes can be incorporated quickly, efficiently, and without significantly affecting the overall configuration of the system. Given these constraints, the logistics and maintenance support infrastructure must be designed to support the added complexities.

4. *Extended system life cycles—shorter technology life cycles*. The life cycles of many current systems are being extended for one reason or another while at the same time the life cycles of most technologies are becoming relatively shorter (due to obsolescence). As in the situation mentioned in item 3, it is necessary to design systems such that a new technology can be incorporated easily and efficiently. At the same time, the logistics and maintenance support infrastructure must be designed to be responsive, and the duration of the support capability is thus likely to be greater due to the extended system life cycles.
5. *Greater utilization of commercial off-the-shelf (COTS) products*. With current goals pertaining to lower initial costs and shorter and more efficient procurement and acquisition cycles, there has been more emphasis on the utilization of best commercial practices, standard processes, and commercial off-the-shelf (COTS) equipment and software. As a result, there is a greater need for a good definition of requirements at the outset, and there is greater emphasis on the design of systems (and their major subsystems) versus the design of components. Further, much of the required logistics and maintenance support activity has shifted from the major producer to one or more suppliers. This shift, in turn, has increased the complexity of the overall logistics and support network, with more organizations participating, as well as added some challenges in determining the detailed support requirements for many of the COTS items being utilized in the system design configuration.
6. *Increasing globalization*. The world is shrinking and there is more trading with and dependency on different nationalities (and manufacturers) throughout the world thanks to the introduction of rapid and improved communications practices, the availability of quicker and more efficient packaging and transportation methods, the application of electronic commerce (EC) methods for expediting the accomplishment of procurement and related processes, and related reasons. At the same time, the logistics and support configuration must be responsive to the many challenges pertaining to rapid and reliable communications, short transportation times and safe/secure transportation routes, and quick turnaround times in support of maintenance requirements.
7. *More outsourcing*. There is more outsourcing and procurement of COTS items (equipment, software, processes) from external sources of supply than ever before. Thus, there are more suppliers associated with almost any given program. Consequently, there must be a greater emphasis on the early definition and allocation of system-level requirements, the development of a good and complete set of specifications, and a closely coordinated and integrated level of activity throughout the system development and acquisition process. At the same time, a closely and well-integrated logistics and maintenance support capability must be developed and operational when required.
8. *Greater international competition*. Along with the noted trends toward increasing globalization and more outsourcing, there is more international competition than

ever before, owing not only to improvements in communications and transportation methods but to the greater utilization of COTS items and the establishment of effective partnerships worldwide. A major goal is, of course, to deliver in a short time frame a product or service that is reliable and of high quality, cost-effective, and with customer satisfaction in mind. This goal requires a highly responsive, effective, and efficient logistics and maintenance support infrastructure.

9. *Higher overall life-cycle costs*. In general, experience has indicated that the life-cycle costs of many current systems are increasing. Whereas much emphasis has been placed on minimizing the costs associated with the procurement and acquisition of systems, little attention has been dedicated to the costs of system operation and support. In designing systems, one needs to view all decisions in the context of *total cost* to properly assess the risks associated with the decision(s) in question. As the logistics and maintenance support infrastructure is a major element of the system, the various alternative approaches in the design of such must be justified on the basis of life-cycle cost.

Although some of the foregoing and related trends have evolved over time, the tendency is to ignore the changes that have taken place and continue with a business-as-usual approach by implementing some past practices, many of which tend to inhibit innovation and growth. Because the operating environment has undergone a major transition in recent years, the requirements for logistics and system support have also undergone significant changes, and it is anticipated that such changes will continue to evolve. It is thus essential that the logistics discipline continue to grow and evolve as well.

2 THE SCOPE OF LOGISTICS

Historically, the principles and concepts of logistics stem from specific facets of activity within both the commercial and defense sectors of management. According to the *American Heritage Dictionary*, logistics is defined as "*the aspect of military operations that deals with the procurement, distribution, maintenance, and replacement of materiel and personnel.*"[1] *Webster* defines it as "*the aspect of military science dealing with the procurement, maintenance, and transportation of military materiel, facilities, and personnel.*"[2] In the *New Oxford American Dictionary*, logistics is "*the detailed coordination of complex operations involving many people, facilities, and supplies.*"[3]

In the *commercial* sector, where the emphasis is on the business-oriented activities associated primarily with the distribution of relatively small products (e.g., consumables), logistics can be defined as "*that part of the supply chain process that plans, implements, and controls the efficient, effective forward and reverse flow and storage of goods, services, and related information between the point of origin and the point of consumption in order to meet customers' requirements*."[4] In this context, logistics activities

---

[1] *American Heritage Dictionary,* 4th ed., Houghton Mifflin Co., Boston, MA, 2002.

[2] *Merriam-Webster's Collegiate Dictionary,* 10th ed., Merriam-Webster, Inc., Springfield, MA, 1998.

[3] *The New Oxford American Dictionary,* Oxford University Press, 2001.

[4] This definition was developed by the Council of Logistics Management (CLM), 2805 Butterfield Road, Oak Brook, IL. Refer to the CLM web site www.clm1.org, "Glossary of Terms," dated October 1, 2002.

include (1) the identification and management of suppliers, procurement and order processing, and physical supply of materials/services from the sources of supply to the manufacturer or producer; (2) the materials handling and inventory management of materials/services during and throughout the manufacturing process; and (3) the subsequent transportation and physical distribution of products from the manufacturer to the ultimate consumer (i.e., customer). These activities are illustrated in Figure 2, which reflects only the *forward flow*. Additionally, there is a *reverse flow*, which includes those activities that are required when materials and products are retired, recycled/disposed of, and phased out of the inventory; that is, the flow of items from the consumer back to the point of disposal. This reverse flow is known as *reverse logistics*.

Logistics in the commercial sector has traditionally been oriented toward managing the physical flow of materials and products among organizations. Activities such as transportation and warehousing have been available to ensure that the movement of products has been continuous and reliable. Purchasing departments have been responsible for the procurement and acquisition of materials, and marketing groups have been responsible for providing information to the customers both before and after each transaction. In essence, the spectrum of logistics has (in many instances) included a number of different organizational elements, working toward a given objective yet operating somewhat independently.

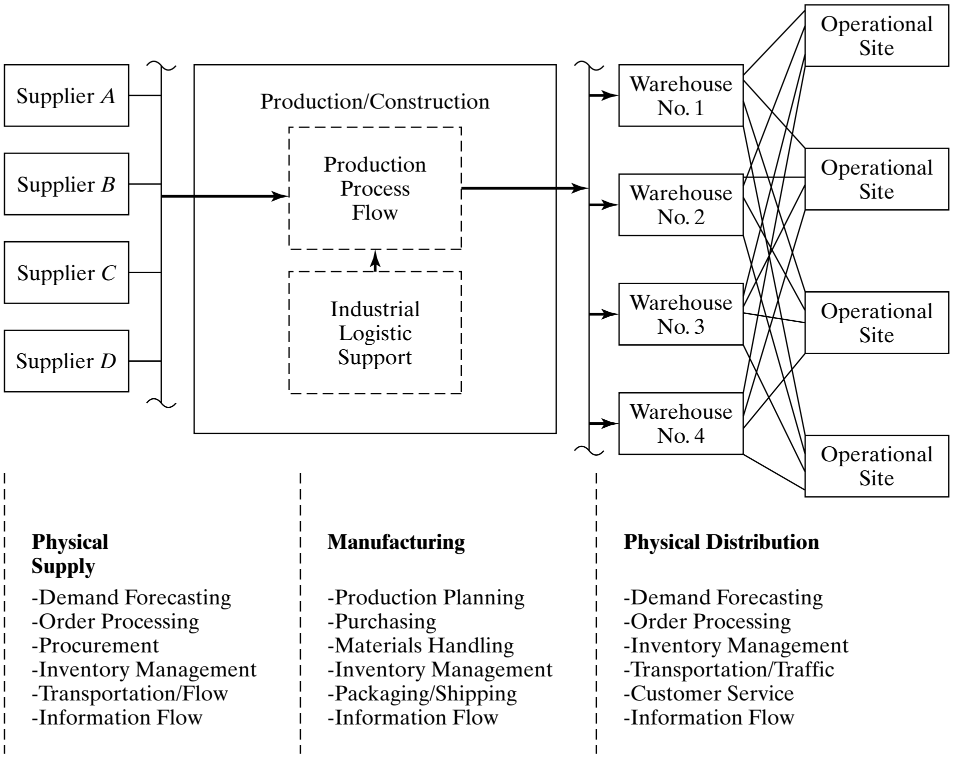


Figure 2 Logistics activities in the production process.

With the advent of electronic commerce (EC) methods and advances in information technology, the role of logistics has assumed some additional responsibilities. The development of bar coding methods, radio frequency identifications (RFID) tags, global positioning systems (GPS), and electronic data interchange (EDI) has enabled the rapid and efficient transfer of information on product/material flows. The role of logistics has taken on a more comprehensive and integrated approach and has grown to include such activities as information technology, marketing and sales, and finance; that is, the economic, finance, and business issues in support of the physical flow of materials and products.[5] At the same time, the current trends toward more outsourcing, increased globalization, and greater international competition have created a need for the establishment of partnerships and coalitions, and for the further expansion of the scope of logistics. These various developments have more recently evolved into the concepts associated with the *supply chain (SC)* and *supply chain management (SCM)*.

The principles and concepts of SC and SCM are not unique and have been applied (using different terminology) to varying degrees for a number of years; however, the current environment with its associated challenges (primarily owing to increased globalization and greater international competition) has focused attention on this area, particularly during the past few years, and has produced some slight variations in definition, as presented in the literature.

In the late 1990s a group of researchers from MIT offered the following definition for SCM: "*a process-oriented, integrated approach to procuring, producing, and delivering end-products and services to customers. It includes sub-suppliers, suppliers, internal operations, trade customers, and end users. It covers the management of materials, information, and funds flow*."[6]

J. T. Mentzer identified and categorized six slightly different definitions from the perspectives of different authors in the field.[7] A consensus set of definitions was then developed to include the following:

1. *Supply chain (SC)*—a set of three or more entities (organizations or individuals) directly involved in the upstream and downstream flow of products, services, finances, and/or information flow from a source to a customer.
2. *Supply chain management (SCM)*—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 purposes of improving the long-term performance of the individual companies and the supply chain as a whole.[8] CLM has adopted this definition of SCM.

---

[5] Coyle, J. J., E. J. Bardi, and R. A. Novak, *Transportation*, 5th ed., South-Western College Publishing, St. Paul, MN, 2000, chap. 1, pp. 9–10.

[6] P. J. Metz, "Demystifying Supply Chain Management," *Supply Chain Management Review*, winter, Reed Elsevier, New York, NY, 1998.

[7] J. T. Mentzer (University of Tennessee), W. DeWitt (University of Maryland), J. S. Keebler (St. Cloud State University), Soonhong Min (Georgia Southern University), N. W. Nix (Texas Christian University), C. D. Smith (University of San Diego), and Z. G. Zacharia (Texas Christian University), "Defining Supply Chain Management," *Journal of Business Logistics* (vol. 22, no. 2, 2001), CLM, Oak Brook, IL.

[8] CLM, Oak Brook, IL. Refer to the CLM web site www.clm1.org, "Glossary of Terms," dated October 1, 2002.

Thus, the SC basically includes all those activities associated with *inbound logistics* (the flow of materials and services from the supplier to the producer/manufacturer), the *material flows* within the factory, and the *outbound logistics* (flow of materials, products, and services from the factory to the customer/consumer). The SC may include many different categories of suppliers located throughout the world, one or more producers or manufacturers of products, and customers operating globally. The formalization of a supply chain is realized through the establishment of *partnerships or coalitions*, who work together to service the customer in the best way possible.

SCM pertains to the *management* of the supply chain, or a group of supply chains, with the objective of providing the required customer services, both effectively and efficiently. It requires a highly integrated approach, employing the appropriate resources (e.g., transportation, warehousing, inventory control, information) and implementing the necessary business processes to ensure complete customer satisfaction. The objective is to accomplish the activities shown in Figure 2, with a total *business* perspective in mind.[9]

In the defense sector, logistics has evolved through the concept of *integrated logistics support (ILS)*, which was formally developed in the mid-1960s. At that time, ILS was defined as

> *a composite of all support considerations necessary to assure the effective and economical support of a system or equipment at all levels of maintenance for its programmed life cycle. It is an integral part of all other aspects of system acquisition and operation.*[10]

ILS, as initially envisioned, included a "life-cycle approach to the planning, development, acquisition, and operation of systems and equipment to maximize readiness and optimize costs." The principal elements of ILS included the system design/support interface, reliability and maintainability, maintenance planning, support and test equipment, supply support, transportation and handling, technical data, facilities, personnel and training, logistic support resource funds, logistic support management information, and contractor support services. The emphasis here is on logistics as it pertains to systems (versus the supply and distribution of smaller components and consumables) and on the effective and efficient support of these systems throughout their planned life cycles. It includes not only the maintenance and sustaining support of these systems during their period of utilization but the design of these systems for *reliability, maintainability*, and *supportability*.

The principles and concepts of ILS were developed further throughout the 1970s, 1980s, and 1990s, and the definition of ILS was expanded to constitute 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*

---

[9] With the objective of gaining the advantage in a competitive environment, it may be appropriate for several different supply chains to establish a formal relationship (or partnership) and join together in forming one overall larger supply chain.

[10] 4100.35G, *Integrated Logistics Support Planning Guide for DoD Systems and Equipment*, Department of Defense, Washington, DC, 1967.

> *each other; (3) acquire the required support; and (4) provide the required support during the operational phase at minimum cost.*[11]

The emphasis here is on the development and implementation of an effective and efficient maintenance and support infrastructure and all the activities related thereto. As illustrated in Figure 3, the required support for an operational system may be provided at different levels depending on the overall system mission requirements, the complexity of the system, its reliability and effectiveness, available resources, cost, and so on.

Inherent within this definition is the current requirement dealing with the *design for supportability*. This requirement pertains to the degree to which a system can be effectively supported, both in terms of the built-in design characteristics of the prime mission-related elements of the system and the characteristics of the overall maintenance and support infrastructure shown in Figure 3 (e.g., personnel, supply support and related inventories, test equipment, maintenance facilities). Such characteristics should include standardization (the utilization of standard components), functional packaging, interchangeability, accessibility, self-test and diagnostics, and compatibility among the various elements of support and the prime mission-related elements of the system. The emphasis here is on system *design*, the first two items in the preceding definition.

More recently, there has been an increased emphasis on logistics (and the design for supportability) early in the system design and development process through the introduction of the concept of *acquisition logistics*, which is

> *a multi-functional technical management discipline associated with the design, development, test, production, fielding, sustainment, and improvement modifications of cost-effective systems that achieve the user's peacetime and wartime readiness requirements. The principal objectives of acquisition logistics are to ensure that support considerations are an integral part of the system's design requirements, that the system can be cost-effectively supported throughout its life cycle, and that the infrastructure elements necessary to the initial fielding and operational support of the system are identified and developed and acquired.*[13]

The emphasis on addressing logistics in the design process is based on the fact that (through past experience) a significant portion of a system's life-cycle cost can be attributed directly to the operation and support of the system in the field, and that much of this cost is based on design and management decisions made during the early stages of system development. In other words, early design decisions can have a large impact on the cost of those downstream activities associated with system operation and maintenance. Thus, it is essential that logistics (and the design for supportability) be addressed from the beginning.

---

[11] DSMC, *Integrated Logistics Support Guide*, Defense Systems Management College, Fort Belvoir, VA, 1994 (DSMC is currently recognized as a major element within the Defense Acquisition University).

[13] MIL-HDBK-502, *Department of Defense Handbook on Acquisition Logistics*, Department of Defense, Washington, DC, May 1997.

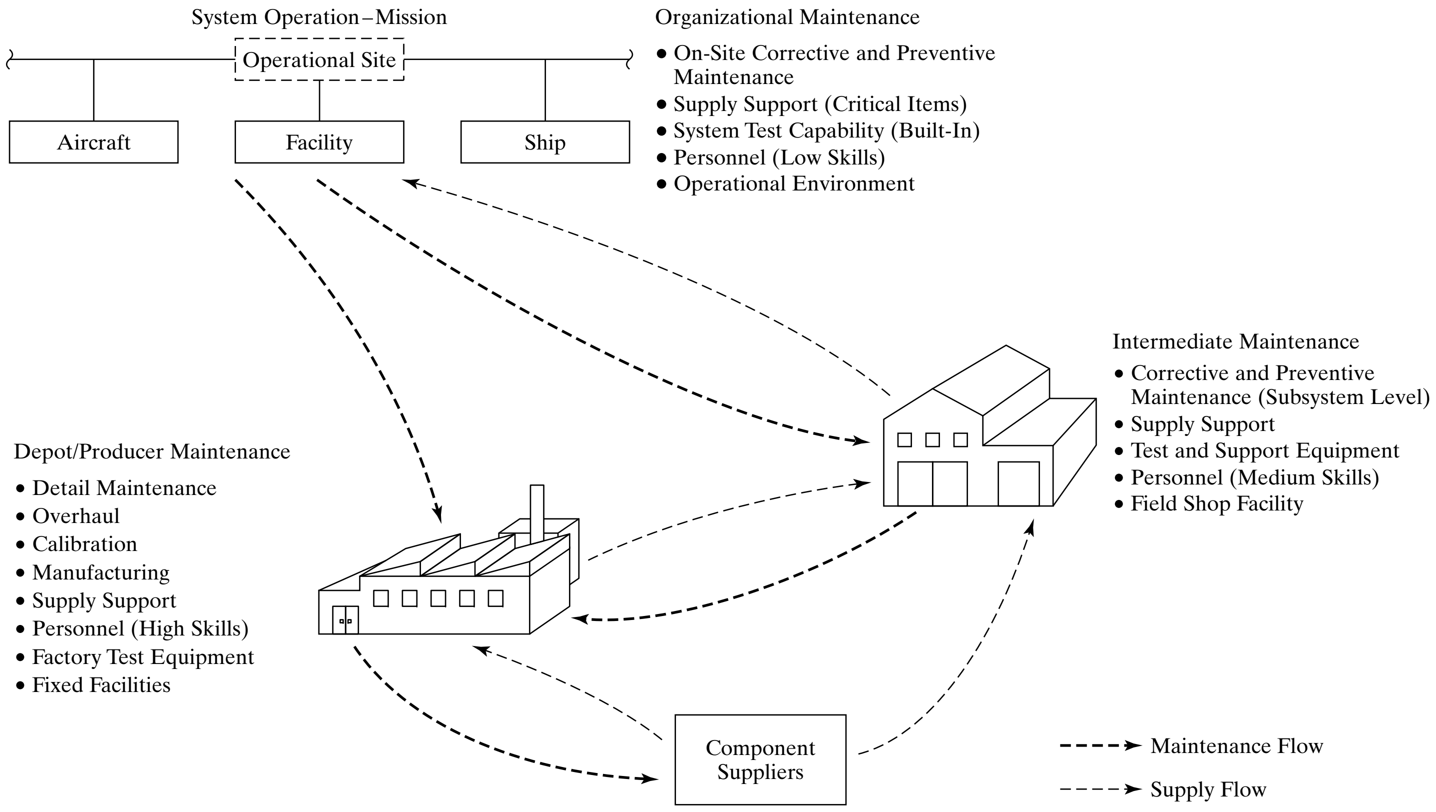


Figure 3 System support infrastructure.

To further stress the requirement for dealing with logistics in the system design process, the Department of Defense recently introduced the concept of *performance-based logistics (PBL)*.[14] The objective is to emphasize the importance of and need for the maintenance and support infrastructure (refer to Figure 3) by establishing some specific metrics and to include these as quantitative *design-to* performance requirements in the appropriate specifications. Such requirements may be covered within the spectrum of system-level requirements (e.g., operational availability, system effectiveness, life-cycle cost, level of sustainability) and/or to a specific element of the maintenance and support infrastructure (e.g., personnel effectiveness, quantitative goals for transportation times and cost, supply support effectiveness, facility utilization and throughput, information access and process time, test equipment reliability). These logistics-related performance factors must be integrated with (and supportive of) the higher-level system performance factors as they pertain to the overall mission of the system.[15]

In covering the scope of logistics, one needs to consider the entire spectrum of activity in this area, including both the commercial and the defense approaches discussed earlier. Accordingly, it would be appropriate to start with a good understanding of the total flow of activities, from system inception to utilization and back. Referring to Figure 4, we see that there is an *outward* flow commencing with the definition of requirements and initial planning (block 1), to system design and development (block 2), manufacturing and production (blocks 3 and 4), and the distribution of products to warehouses and operational sites (blocks 6 and 7). There are system design activities, SC and associated SCM activities, and there are sustaining system maintenance and support activities. The activities described and emphasized for both the commercial and defense sectors must be integrated and addressed within the context of this overall process.

At the same time, there is a *reverse* flow beginning at the customer's/user's operational site (block 7), and back to the various levels of maintenance (blocks 5, 7, and 8), the original producer (blocks 3 and 4), a third-party maintenance provider (block 3), and so on. There are logistics activities associated with the sustaining maintenance and support of the system throughout its planned life cycle, and for the retirement of system components (and the subsequent recycling and/or disposal of materials). These include both the activities associated with *reverse logistics* (as practiced in the commercial sector) and the various *maintenance* requirements included within the spectrum of logistics in the defense sector.

In essence, we should be addressing *all* these activities and requirements on an integrated life-cycle basis and from a total system perspective. The interrelationships are many and, if we are to be competitive in today's environment, we need to do a better job of integrating both the commercial and defense aspects of logistics into a single

---

[14] DoD 50002.2-R, *Mandatory Procedures for Major Defense Acquisition Programs (MDAPS) and Major Automated Information System (MAIS) Acquisition Programs*, Department of Defense, Washington, DC, April 5, 2002.

[15] MIL-HDBK-502, "How to Develop Measurable and Testable Supportability Requirements," Section 6, *Department of Defense Handbook on Acquisition Logistics*, Department of Defense, Washington, DC, May 1997.

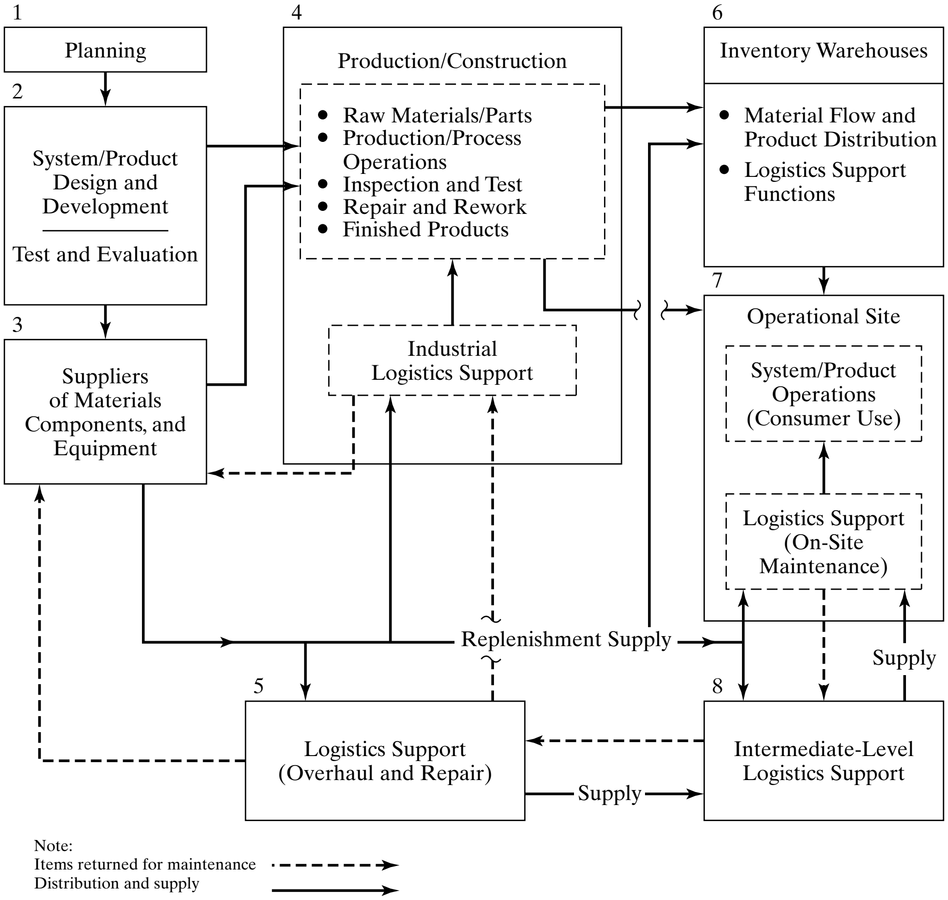


Figure 4 System operational and maintenance flow.

entity. Further, we need to consider the logistics and maintenance infrastructure as being a major element of a system, not a separate and after-the-fact requirement.

3 THE ELEMENTS OF LOGISTICS

In Section 2. the objective was to define logistics (in a broad context) and to relate the various activities to the flow process illustrated in Figure 4. In determining the resource requirements for the implementation of these activities, it can be seen that there are needs for personnel, transportation, spares/repair parts and related inventories, test and support equipment, facilities, data/documentation, computer resources, and various combinations thereof. In the planning, design, and implementation of logistics, one needs to ensure that these resources are fully integrated, as conveyed in Figure 5, as the interactions among these various elements are many. A brief description of each of the elements in the figure is presented next.

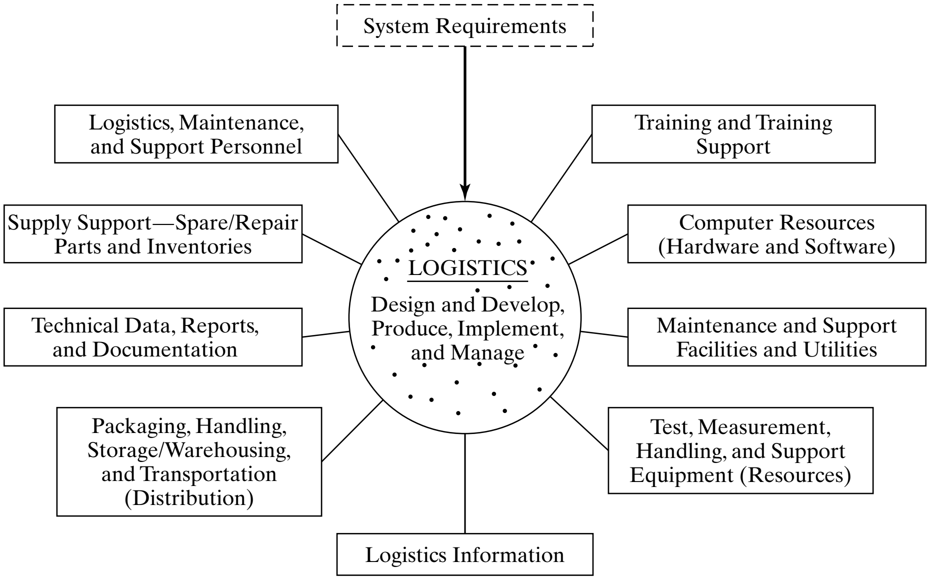


Figure 5 The basic elements of logistics (functional).

1. *Logistics and maintenance support planning*. Inherent within the circle in Figure 5 are those ongoing and iterative planning, organization, and management activities necessary to ensure that the logistics requirements for any given program are properly coordinated and implemented. Initial planning and analyses lead to the establishment of requirements for logistics and the overall support of the system throughout its life cycle. A model can be developed to identify all the logistics activities, such as those described and related to the forward flow in Figure 4. Maintenance planning for those activities related to the reverse flow commences with the definition of the maintenance concept (in the conceptual design phase) and continues through supportability analyses (in the preliminary system and detail design and development phases) to the ultimate development of a maintenance plan. Maintenance planning should result in the integration of the various elements of support (shown in Figure 5) with the prime mission-related elements of the system and should lead to the definition and development of the infrastructure illustrated in Figure 3. A comprehensive logistics plan needs to be implemented through the establishment of an organizational structure, along with the necessary management and control functions to ensure that the plan is properly carried out. The key objective here is to integrate the elements (shown in Figure 5) with the activities shown in Figures 3 and 4.
2. *Logistics, maintenance, and support personnel*. Personnel required to perform unique logistics and system maintenance activities are included in this category. Such activities include the initial provisioning and procurement of items of support, production-related logistics functions, the installation and checkout of the system and its elements at the user's operational site, customer service functions

(field service), the sustaining support of the system (prime mission-related elements and elements of the maintenance and support infrastructure) throughout its planned period of use, and those functions required for the retirement and recycling/disposal of material. Personnel at all levels of maintenance (see Figure 3), mobile teams, and operators/maintainers at special test facilities and calibration laboratories are included. In the evaluation of a particular system, it is important to include only those who can be directly attributed to the support of that system.

3. *Training and training support*. This category includes all personnel, equipment, facilities, data/documentation, and associated resources necessary for the training of operational and maintenance personnel, to include both *initial* and *replenishment (replacement)* training. Training equipment (e.g., simulators, mockups, special devices), training manuals, and computer resources (software) are developed and utilized as necessary to support the day-to-day on-site training, distance education (training via the Internet), and education of a more formal nature.
4. *Supply support—spares/repair parts and associated inventories*. This element includes all spares (repairable units, assemblies, modules, etc.), repair parts (nonrepairable components), consumables (liquids, lubricants, gases, disposable items), special supplies, and related inventories needed to maintain the prime mission-related equipment, computers and software, test and support equipment, transportation and handling equipment, training equipment, communications equipment, and facilities/utilities. Spares/repair parts are required throughout the system operational (utilization) phase and in support of the retirement and recycling/disposal of system components.
5. *Computer resources (hardware and software)*. This category covers all computers, associated software, connecting components, networks, and interfaces necessary to support the day-to-day flow of information for all logistics functions, scheduled and unscheduled maintenance activities, and special monitoring and reporting requirements such as those pertaining to access to CAD/CAM/CAS data, the implementation of condition monitoring programs, and in support of system diagnostic capabilities.
6. *Technical data, reports, and documentation*. Technical data may include system installation and checkout procedures, operating and maintenance instructions, inspection and calibration procedures, overhaul instructions, facilities data, system modification instructions, engineering design data (specifications, drawings, materials and parts lists, CAD/CAM/CAS data, special reports), logistics provisioning and procurement data, supplier data, system operational and maintenance data, and supporting databases. Included in this category is the ongoing and iterative process of data collection, analysis, and reporting covering the system throughout its life cycle (i.e., the maintenance data collection and assessment capability).
7. *Maintenance and support facilities and utilities*. This category includes all special facilities that are unique and are required to support logistics activities, to include storage buildings and warehouses and maintenance facilities at all levels (see Figures 3 and 4). Physical plant, portable buildings, mobile vans, personnel

housing structures, intermediate-level maintenance shops, calibration laboratories, and special repair shops (depot, overhaul, material suppliers) must be considered. Capital equipment and utilities (heat, power, energy requirements, environmental controls, communications, safety and security provisions, etc.) are generally included as part of facilities.

8. *Packaging, handling, storage/warehousing, and transportation (distribution).* This category of logistics includes all materials, equipment, special provisions, containers (reusable and disposable), and supplies necessary to support the packaging, safety and preservation, storage, handling, and/or transportation of the prime mission-related elements of the system, personnel, spares and repair parts, test and support equipment, technical data, computer resources, and mobile facilities. Included are all the initial and sustaining transportation requirements for the distribution of materials and for the maintenance and support activities throughout the system life cycle (i.e., the forward and reverse flows illustrated in Figure 4). The primary modes of transportation (air, highway, pipeline, railway, and waterway) and intermodal (truck–rail, truck–water, rail–water, truck–air, rail–air, etc.) requirements must be addressed.
9. *Test, measurement, handling, and support equipment.* This category includes all tools, condition monitoring equipment, diagnostic and checkout equipment, special test equipment, metrology and calibration equipment, maintenance fixtures and stands, and special handling equipment required to support operational and maintenance functions throughout the forward and reverse flows illustrated in Figure 4. Test and support equipment requirements at each level of maintenance (see Figure 3) must be addressed, as well as the overall *traceability* of test requirements (measures) to a secondary standard, a transfer standard, and ultimately to a primary standard.
10. *Logistics information.* This item refers to the resources necessary to ensure that an effective and efficient logistics information flow is provided throughout and to the organizations responsible for all the activities reflected in Figure 4. This flow includes the necessary communication links among the customer, producer (prime contractor), subcontractors, suppliers, and supporting maintenance organizations. It is essential that the proper type and amount of information be provided to the appropriate organizational elements, in the proper format, and in a reliable and timely manner, with the necessary security provisions included. Inherent within this category is the utilization of the latest EC methods, EDI capabilities, e-mail, and the Internet. This capability not only tends to facilitate the integration of the organizations participating in a given project but aids in the integration of SC and maintenance activities and of the various logistics elements identified in Figure 5.

The objective is to provide the right *balance* of resources applied throughout the system support infrastructure illustrated in Figures 3 and 4. A cost-effective approach must be reached that requires the proper mix of best commercial practices, supplemented by new developmental items where necessary and when justified. As new technologies are introduced and current processes are improved, the specific resource requirements at each level may shift somewhat. For example, the need for large spares/repair parts inventories may not be required as transportation times and costs decline. The availability of overnight express, combined with good communication processes, can help solve the high-cost large-inventory problem. The need for large data packages (e.g., technical manuals, drawings) at each maintenance location is reduced with the advent of new EDI data formats and processes. The development of computer-based information systems provides for faster and more accurate information and greater visibility about the type and location of various assets at a given point in time. The decision-making and communications processes may be enhanced accordingly. Through the supportability analysis, numerous trade-off studies are conducted involving various mixes and combinations of the logistics elements identified herein which, hopefully, will lead to the design and development of an effective support infrastructure.

4 LOGISTICS IN THE SYSTEM LIFE CYCLE

Logistics, as viewed from a total system perspective, includes activities throughout each phase of the system life cycle. Initially, early planning functions lead to the definition of logistics requirements. Subsequently, through synthesis, analysis, and design trade-off studies, the logistics and maintenance support infrastructure is defined. Next is the acquisition of the elements of logistics, and the follow-on implementation requirements in support of production/construction activities, system operation/utilization in the field, and the final retirement and processing of items for recycling and/or disposal.

Logistics requirements are applicable in each of the phases of the life cycle of systems identified in Figure 6. Further, there is an overlap and it is essential that these requirements be addressed concurrently, as illustrated in Figure 7. When there is a need for a new system (in response to a new customer requirement), one must evolve through the design and development of the prime mission-related elements of the system, the production of multiple quantities of these items (or the construction of a single entity), the distribution and installation of the system and its components at designated user sites, utilization and the sustaining maintenance and support of the system throughout its planned life cycle, and system retirement and the recycling and/or disposal of its components. As the prime elements of the system are being developed (referring to the top life cycle in Figure 7), consideration must be given to ensuring that the appropriate reliability, maintainability, supportability, producibility, and disposability characteristics are included in the design. This, in turn, leads to the design of

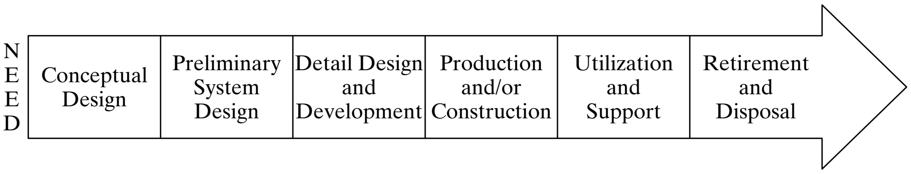


Figure 6 The system life-cycle phases.

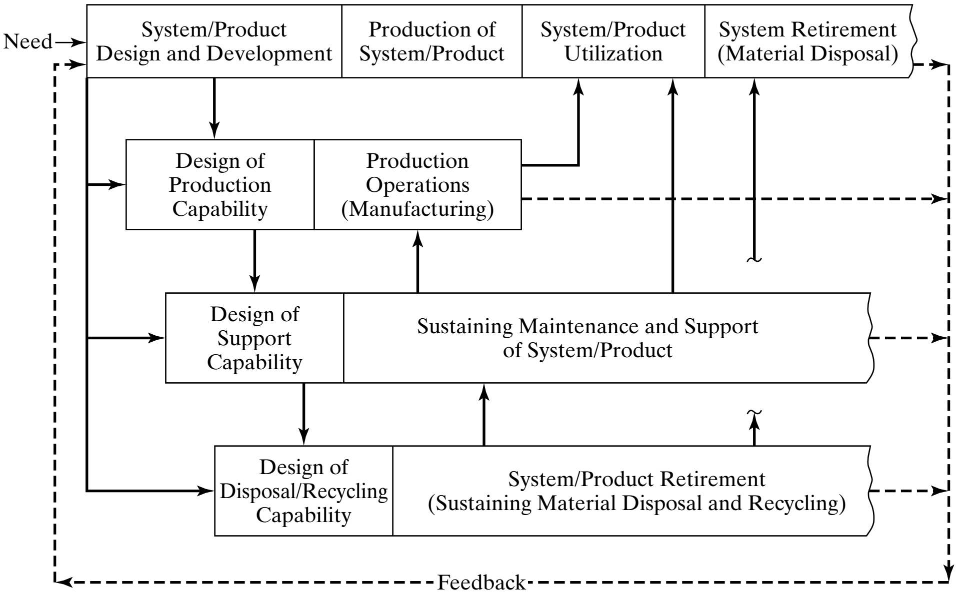


Figure 7 The interrelationships of the life-cycle phases in system development. (Source: Blanchard, B. S., and W. J. Fabrycky, *Systems Engineering and Analysis*, 3rd ed., Prentice Hall, Upper Saddle River, NJ, 1998).

the production capability (the second life cycle), the design of the maintenance and support infrastructure (the third life cycle), and the design of material recycling and disposal capability (the fourth life cycle). In designing these functions, one must ensure that the characteristics built into the design complement and support those characteristics that are inherent within the top-level system configuration. Further, there are *feedback* effects, as the results of the design of the second, third, and fourth life cycles can have a detrimental (or positive) impact on the activities in the top life cycle.[16]

With reference to Figure 7, the requirements for logistics are initially determined during the early stages of the top life cycle, and the design of the prime mission-related elements of the system must reflect the design for logistics and supportability. As one determines the production/construction requirements (second life cycle), the ultimate design configuration must include the requirements pertaining to SCM and the activities presented in Figure 2. In the development of the maintenance and support infrastructure (third life cycle), the results need to reflect a network similar to that presented in Figure 3. Additionally, there should be an equivalent flow covering the activities associated with the processing of system components for recycling and/or disposal (to include the activities dealing with reverse logistics in the fourth life cycle).

[16] The activities within and the interrelationships between these life cycles are discussed extensively in Blanchard, B. S., and W. J. Fabrycky, *Systems Engineering and Analysis*, 3rd ed., Prentice Hall, Inc., Upper Saddle River, NJ, 1998. Additionally, the principles of *concurrent engineering* must be applied in order to meet the objectives inherent in *good* system design.

This is an integrated "back-and-forth" process of evolutionary development, with the necessary feedback provisions for continuous process improvement.

In the interest of simplification, the steps shown in Figure 8 are included as an expansion of the design and development activities included in each of the life-cycle phases in Figure 6 (and represented by block 2 in Figure 4). Further, Figure 9 provides an example of some of the major interface relationships that often exist between the mainstream system design activities and the major logistics functions. The basic steps in Figure 9 are discussed next.

1. Given a specific need, the system operational characteristics, mission profiles, deployment, utilization, effectiveness figures of merit, maintenance constraints, and environmental requirements are defined. Effectiveness figures of merit may include factors for cost-effectiveness, availability, dependability, reliability, maintainability, supportability, and so on. From this information, the system maintenance concept is defined, and a system-level specification is developed. Operational requirements and the maintenance concept are the basic determinants of logistic support resources (Figure 9, blocks 1 and 2).
2. Major operational, test, production, and support functions are identified, and qualitative and quantitative requirements for the system are allocated as design criteria (or constraints) for significant indenture levels of the prime mission-related elements as well as applicable elements of support (i.e., test and support equipment, facilities, etc.). Those requirements that include logistics factors also form boundaries for the design (Figure 9, blocks 3 and 4).
3. Within the boundaries established by the design criteria, alternative prime element and support configurations are evaluated through trade-off studies, and a preferred approach is selected. For each alternative, a preliminary supportability analysis is conducted to determine the anticipated required resources associated with that alternative. Through numerous trade study iterations, a chosen prime system architecture and support policy are identified (Figure 9, blocks 5 and 6).
4. The chosen prime system configuration is evaluated through a supportability analysis that leads to the gross identification of logistics resources. The system configuration (prime mission equipment and support elements) is reviewed in terms of its expected overall effectiveness and compliance with the initially specified qualitative and quantitative requirements (i.e., its capability to cost-effectively satisfy the statement of need). The ultimate output leads to the generation of subsystem specifications (and lower-level specifications) forming the basis for detail design (Figure 9, blocks 7 and 8).
5. During the design process, direct assistance is provided to design engineering personnel. These tasks include the interpretation of criteria; performance of special studies; participation in the selection of equipment and suppliers; making predictions (reliability and maintainability); participation in progressive formal and informal design reviews; and participation in the test and evaluation of engineering models and prototype equipment. An in-depth supportability analysis, based on released design data, results in the identification of specific support requirements for tools, test and support equipment, spare/repair parts, personnel

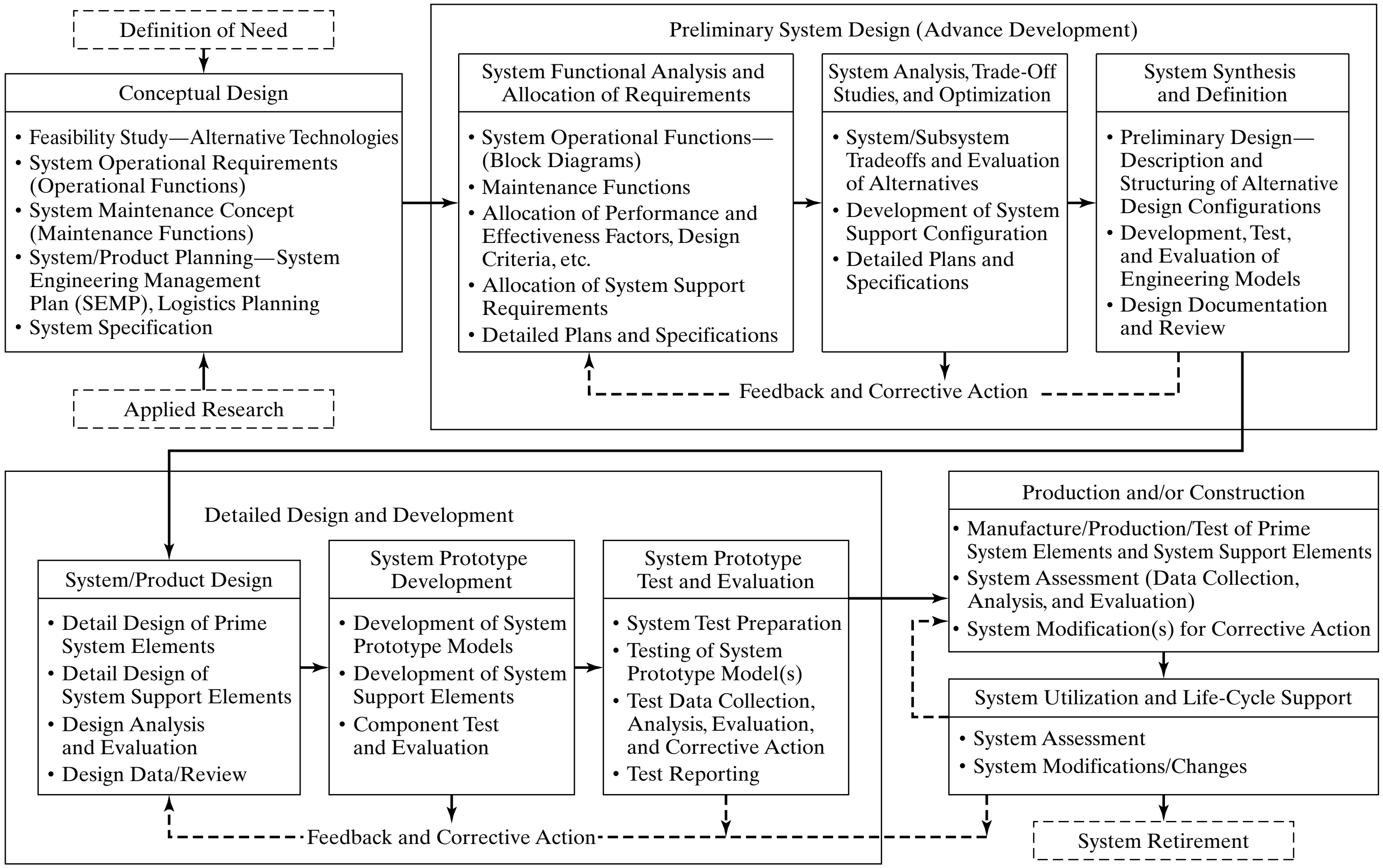


Figure 8 The major steps in system design and development.

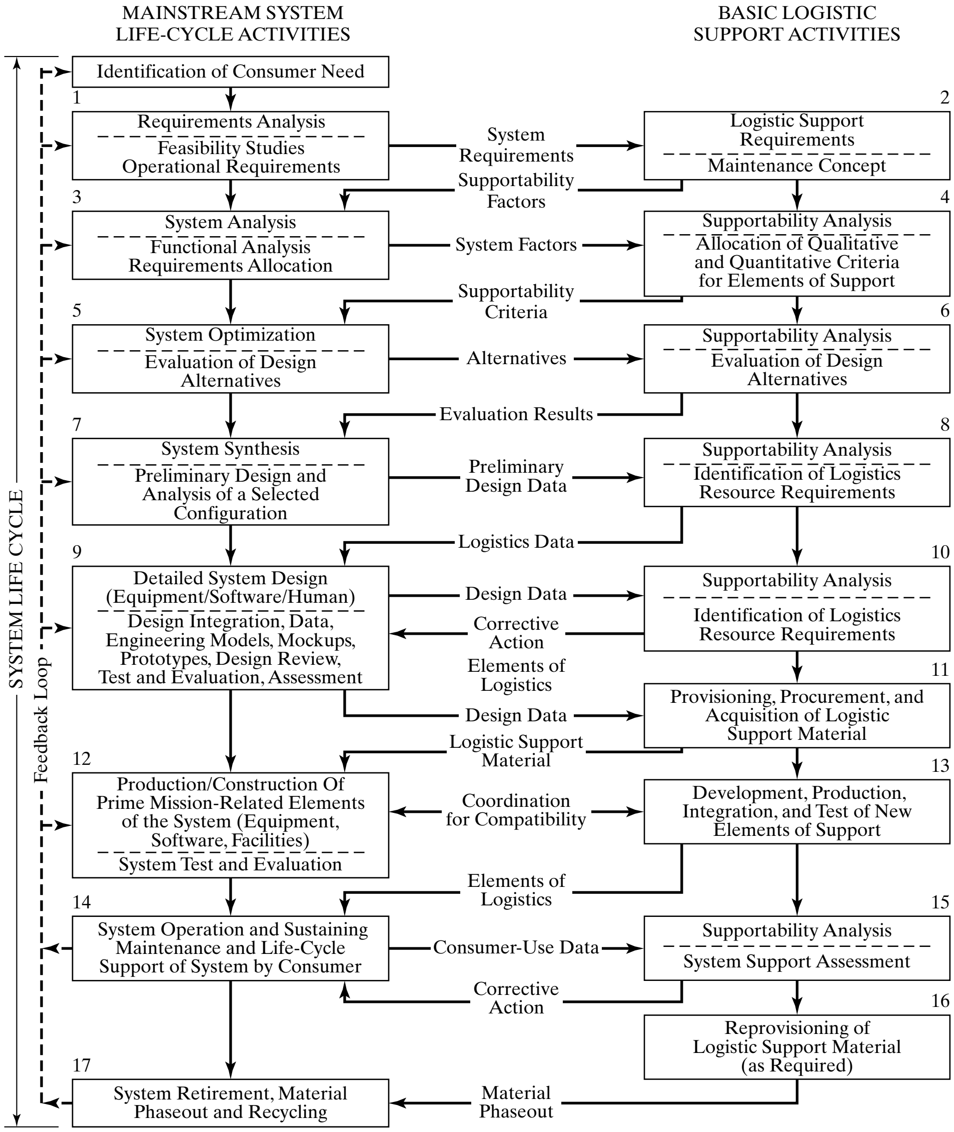


Figure 9 The interface relationships between basic design and logistics functions.

quantities and skills, training requirements, technical data, facilities, transportation, packaging, and handling requirements. The supportability analysis at this stage provides (a) an assessment of the system design for supportability and potential cost/system effectiveness, and (b) a basis for the provisioning and acquisition of specific support items (Figure 9, blocks 9 to 11).[17]

6. The prime mission-related elements of the system are produced and/or constructed, tested, and distributed or phased into full-scale operational use. Logistic support elements are acquired, tested, and phased into operation on an as-needed basis. Throughout the operational life cycle of the system, logistics data are collected to provide (a) an assessment of system/cost effectiveness and an early identification of operating or maintenance problems and (b) a basis for the reprovisioning of support items at selected times during the life cycle (Figure 9, blocks 12 to 16).
7. As elements of the system become obsolete and are retired, and material items are phased out of the inventory, the appropriate processes must be in place for recycling such material items for other uses or disposing of them in such a way as not to degrade the environment. The supportability analysis is updated to cover the support resources that are necessary for system retirement and material phaseout (Figure 9, block 17).

Consideration of the basic steps in Figure 9 is essential in the development of any system; however, the extent and level of activity within each block are tailored to the specific requirement (e.g., type of system, extent of development, associated risks, mission and operational needs). Figure 9 represents a thought process in which logistic support considerations are presented in the context of system engineering requirements.

As one proceeds through the system life cycle, which is based on the need to perform a designated function over time, there may be additional logistics requirements associated with design changes and the modification of a system for one reason or another. As seen in Figure 10, the projected life cycle for selected technologies may be of limited duration and shorter than the life cycle of the system overall. Thus, the system will require modification with the insertion of replacement Technologies *A* to *C* at the points indicated. Depending on the system architecture (and whether an open-architecture approach has been incorporated into the design), the modification process may be relatively simple or highly complex. In any event, the supportability analysis must be updated to reflect any system modifications.[18]

---

[17] Provisioning and acquisition refers to the process of source coding, identification of potential suppliers, preparing the procurement package and establishing a contractual arrangement, receiving and inspection of materials, and the ultimate distribution of items to the desired locations.

[18] It is not uncommon in today's environment to extend the life of a system and to accomplish the necessary reengineering, upgrading, modification, and the like, by replacing obsolete technologies as necessary. The system life cycle may be extended over a 15- to 30-year period; yet, many of the technologies initially selected in the design process may have life cycles of only 3 to 5 years (if that long). Thus, it is important to be able to plan for future growth. In any event, the requirements for logistics throughout the system life cycle are continuous, and the posture is highly dynamic.

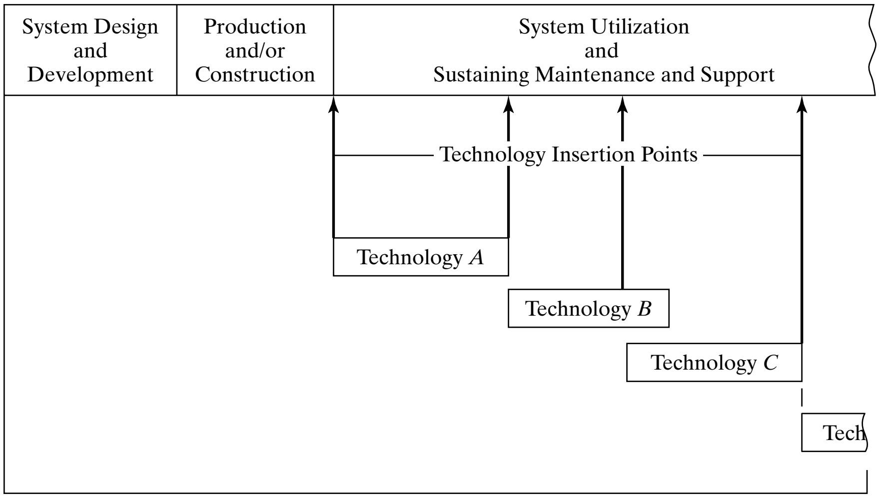


Figure 10 System life cycle with new technology insertions.

5 PERFORMANCE-BASED LOGISTICS (PBL)

Essential for the development of any system is a good and complete definition of the requirements for that system at the outset. Such requirements, stated in quantitative and measurable terms, stem from the initial definition of need for the system and evolve through the development of system operational requirements (i.e., mission scenarios, the functions that the system must perform, etc.), the maintenance concept, and the identification and prioritization of technical performance measures (TPMs). The objective is to establish some key metrics for the system and to develop the appropriate criteria as an *input* to design. To ensure that the requirements for the system are realized, one must first specify the appropriate measurable goals, design to these goals, and subsequently verify that these goals have been met. Further, these goals (as designated performance factors) must be related directly to the mission scenarios that the system will be expected to accomplish. In other words, the emphasis here is on the specification of requirements before the fact, versus after the fact, which may turn out to be inadequate and nonresponsive to the needs of the customer.

The early specification of performance factors has, in many cases, been a practice in the past. For example, such parameters as speed, range, accuracy, thrust, throughput, power output, size, weight, and volume have been applied as design-to goals; however, requirements such as these are applicable only to equipment, software, or other elements of the system and do not take into consideration the performance objectives for the system as a whole. Given that the logistics and maintenance support infrastructure is to be considered as an element of the system, then it would be appropriate to mesh logistics and supportability requirements with other system operational requirements at the outset.

Once again, whatever requirements are specified at the system level must be related and directly traceable to the mission(s) that the system is expected to accomplish. A few examples follow:

1. The operational availability (Ao) for the system shall be greater that 98%.
2. The system mean time between maintenance (MTBM) shall be 1000 hours, or greater.
3. The mean maintenance downtime (MDT) for the system shall be 4 hours, or less.
4. The manufacturing process shall be capable of producing *x* products, in *y* time, and at a *z* unit cost, with a defect rate not to exceed 1%.
5. The response time for the logistics and maintenance support infrastructure shall not exceed 4 hours.
6. The process time for removing an obsolete item from the operational inventory shall not exceed 12 hours, the cost per item processed shall be *x* dollars or less, and the resulting environmental degradation shall be zero.
7. The unit life-cycle cost for the system shall not exceed *x* dollars, based on a 10-year planned life cycle.

Although these performance factors apply primarily to the system (as an entity), inherent within each is a dependency on one or more elements of the system. For example, the specification of *operational availability* (A_o) obviously depends on the maintenance and support infrastructure to minimize downtime. A specification of process requirements for manufacturing depends on logistics and the activities involved in the supply chain. A specification of response time for logistics depends on the database access time, the speed and reliability of communications, the transportation time, the acquisition times for spares and repair parts, the reliability of test equipment, and so on.

After the appropriate performance requirements have been specified for the system, these requirements may then be allocated to the various elements of the system as appropriate: equipment, software, people, facilities, data, elements of support, and so forth. In other words, given the requirements for the system, it will be necessary to establish the appropriate design-to requirements for various elements of logistics (see Figure 5). An example of the top-down allocation process is illustrated in Figure 11. It should be noted that all specified requirements must be tailored to the program, must be measurable, and must be traceable back to the system-level requirement.

The objective is to specify these requirements early, as an input to system design, and not downstream in the life cycle. This approach, to specify performance-based logistics (PBL) requirements early in the system life cycle, is currently being emphasized in the defense sector. As MIL-HDBK-502 states: "*supportability factors are integral elements of program performance specifications. However, support requirements are not to be stated as distinct logistics elements, but instead as performance requirements that*

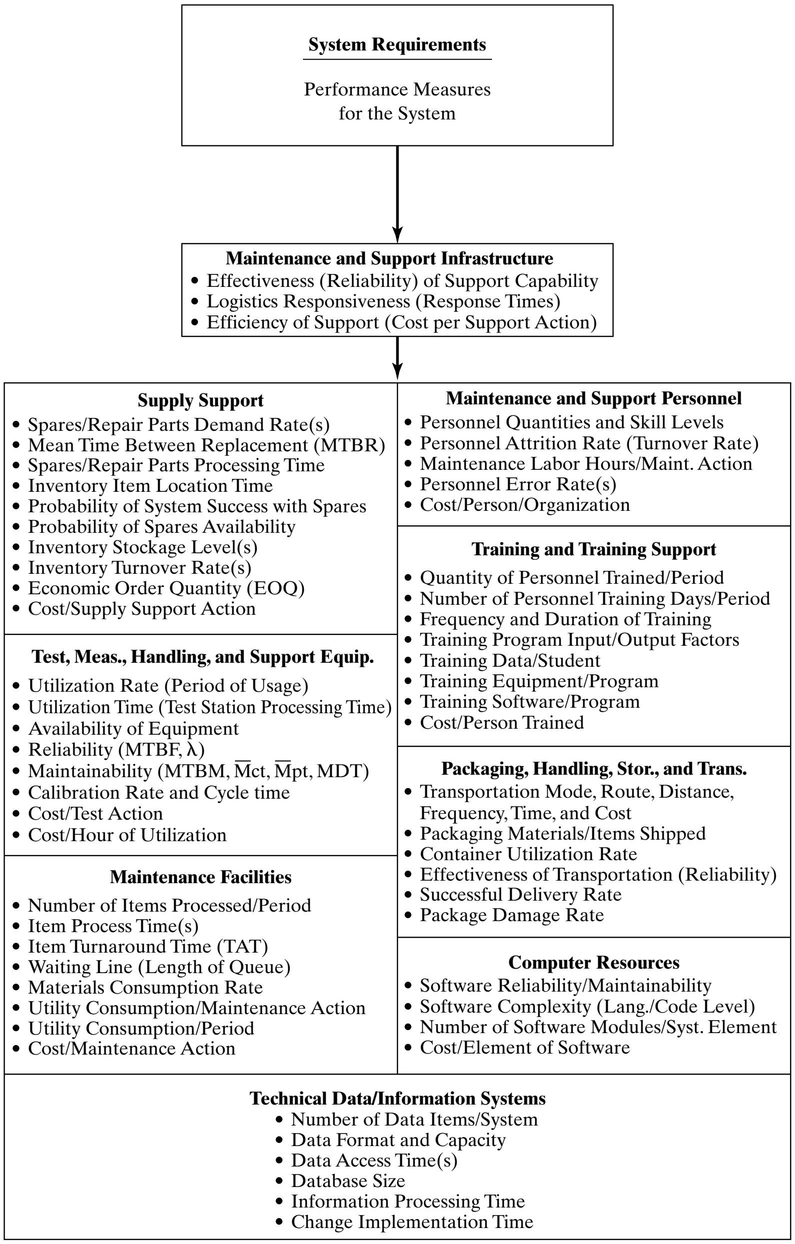


Figure 11 Selected technical performance measures for the support infrastructure.

relate to a system's operational effectiveness, operational suitability, and life-cycle cost reduction."[20] Thus, in reference to Figure 11, each of the allocated factors as they are applied to the various elements of logistics must be traceable back to some operational requirement at the system level.

6 THE NEED FOR LOGISTICS ENGINEERING

Experience in recent years has indicated that the complexity and the costs of systems, in general, have been increasing. A combination of the introduction of new technologies in response to a constantly changing set of performance requirements, the increased external social and political pressures associated with environmental issues, the requirements to reduce the time that it takes to develop and deliver a new system to the customer, and the requirement to extend the life cycle of systems already in operation constitutes a major challenge. Further, many of the systems currently in use today are not adequately responding to the needs of the user, nor are they cost-effective in terms of their operation and support, at a time when available resources are dwindling and international competition is increasing worldwide.

In addressing the issue of cost-effectiveness, one often finds a lack of *total cost visibility*, as illustrated by the "iceberg" in Figure 12. For many systems, the costs associated with design and development, construction, initial procurement and installation of capital equipment, production, and so forth, are relatively well known. We deal with, and make decisions based on, these costs on a regular basis; however, the costs associated with utilization and the maintenance and support of the system throughout its planned life cycle are somewhat hidden. This has been particularly true through the past decade or so when systems have been modified to include the "latest and greatest technology" without consideration of the cost impact downstream. In essence, we have been relatively successful in addressing the short-term aspects of cost but have not been very responsive to the long-term effects.

At the same time, it has been indicated that a large percentage of the total life-cycle cost for a given system is attributed to operating and maintenance activities (e.g., up to 75% for some systems). When addressing cause-and-effect relationships, one often finds that a significant portion of this cost stems from the consequences of decisions made during the early phases of planning and conceptual design. Decisions pertaining to the selection of technologies and of materials, the design of a manufacturing process, equipment packaging schemes and diagnostic routines, the performance of functions manually versus using automation, the design of maintenance and support equipment, and so forth have a great impact on the downstream costs and, hence, life-cycle cost. Additionally, the ultimate maintenance and support infrastructure selected for a system throughout its period of utilization can significantly affect the overall cost-effectiveness of that system. Thus, including life-cycle considerations in the decision-making process from the beginning is critical. As illustrated in Figure 13, although improvements to reduce cost can be initiated at any stage, it can be seen that the greatest impact on life-cycle cost (and hence, maintenance and support costs) can be realized

---

[20] MIL-HDBK-502, *Department of Defense Handbook—Acquisition Logistics*, Department of Defense, Washington, DC, May 1997, Sections 5.1 and 6.

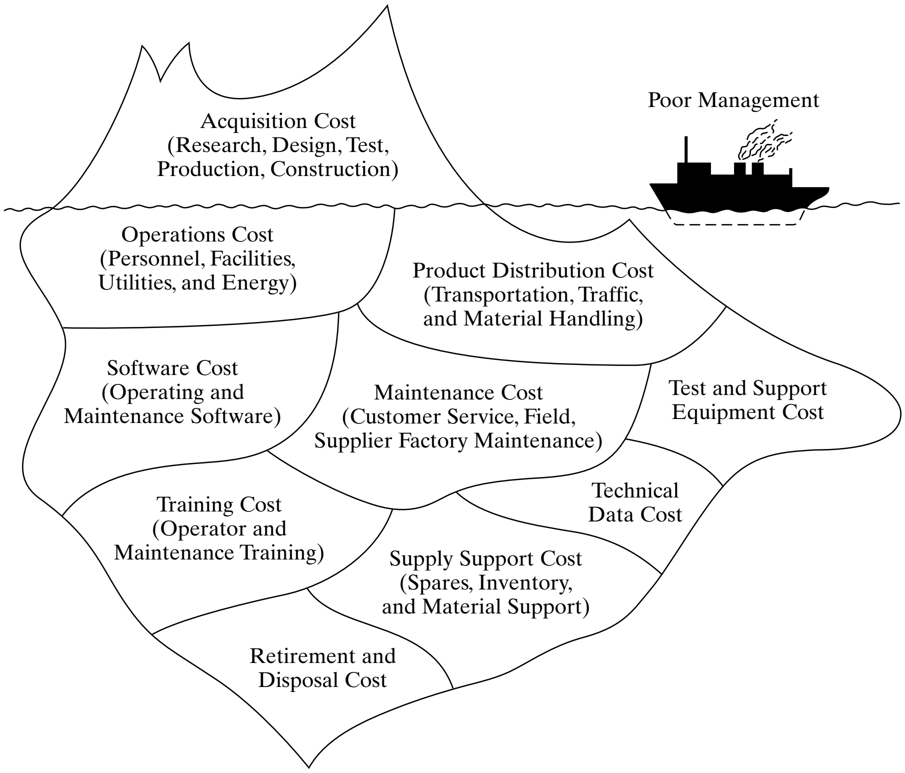


Figure 12 Total cost visibility.

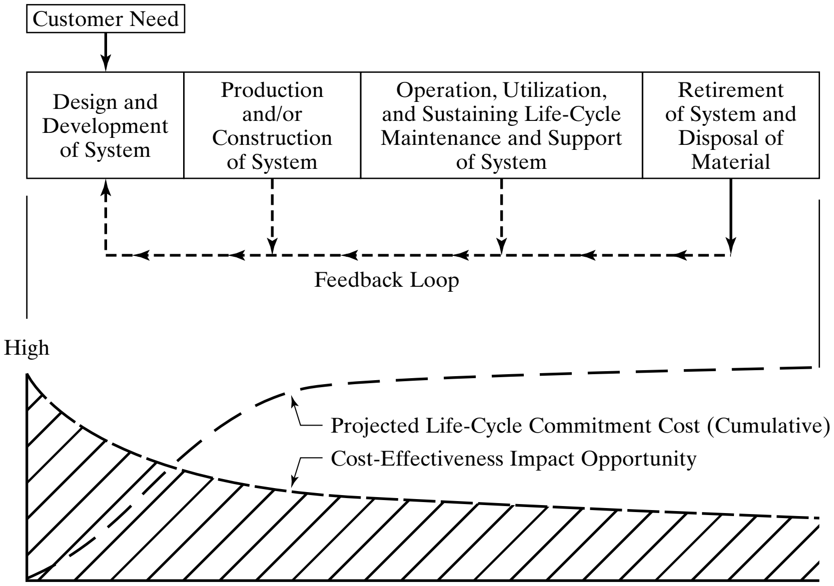


Figure 13 Opportunity for affecting logistics and system cost-effectiveness.

during the early phases of system design and development. In other words, logistics and the design for supportability must be inherent within early system design and development process if the results are to be cost-effective.

Historically, logistics has been considered after the fact, and the activities associated with logistics have not been very popular, have been implemented downstream in the system life cycle, and have not received the appropriate level of management attention. Experience has indicated that these prevailing practices have been detrimental in many instances, and the results have been costly, as conveyed in Figure 12. Although much has recently been accomplished in considering logistics in the design process, such coverage is still occurring rather late. Figure 14 provides a rough comparison showing the effects of early life-cycle planning versus addressing supportability issues later on. Hence, it is imperative that future system design and development (and/or re-engineering) efforts emphasize (1) improving methods for defining system requirements as related to *true* customer needs early in the conceptual design phase, and addressing performance, effectiveness, and *all* essential characteristics of the system on an integrated basis (to include the specific requirements for logistics); (2) addressing the *total* system, its prime mission-oriented components and its elements of support from a life-cycle perspective; (3) organizing and integrating the appropriate and necessary logistics-related activities into the mainstream system design effort, concurrently and in a timely manner; and (4) establishing a *disciplined* approach, with the necessary review, evaluation, and feedback provisions to ensure that logistics (and the design for supportability) is adequately considered in the overall system acquisition process.

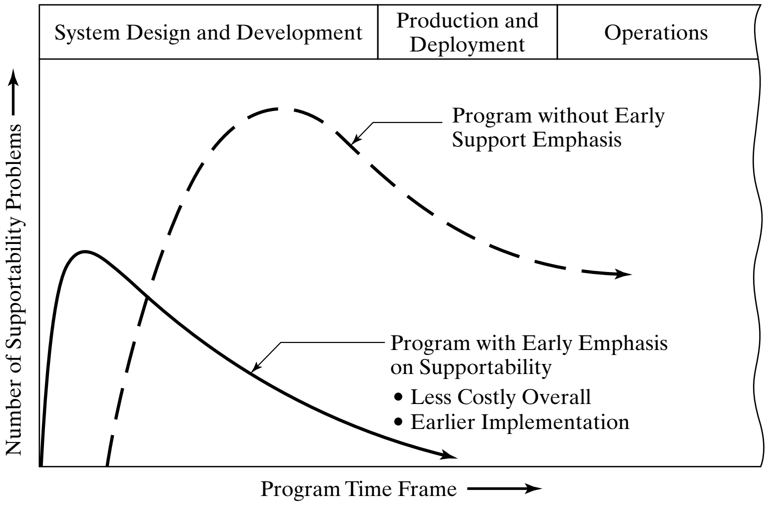


Figure 14 The consequences of not addressing supportability from the beginning.

In summary, logistics must be considered as an integral part of the engineering process. More specifically, *logistics engineering* may include the following activities:

1. The initial definition of system support requirements (as part of the requirements analysis task in systems engineering).
2. The development of criteria as an input to the design of not only those mission-related elements of the system but the support infrastructure as well (input to design and procurement specifications).
3. The ongoing evaluation of alternative design configurations through trade-off studies, design optimization, and formal design review (i.e., the day-to-day design integration tasks pertaining to system supportability).
4. The determination of the resource requirements for support based on a given design configuration (i.e., personnel quantities and skill levels, spares and repair parts, test and support equipment, facilities, transportation, data, and computer resources).
5. The ongoing assessment of the overall support infrastructure with the objective of continuous improvement through iterative process of measurement, evaluation, and recommendations for enhancement (i.e., the data collection, evaluation, and process improvement capability).

Although the overall spectrum of logistics includes many additional functions (e.g., procurement, materials flow, transportation, distribution), the emphasis here is on the design for supportability, or the first two blocks in Figure 15.

7 RELATED TERMS AND DEFINITIONS

With the objective of further clarifying the field of logistics and its many interfaces, it seems appropriate to direct some attention to its language. A few terms and definitions

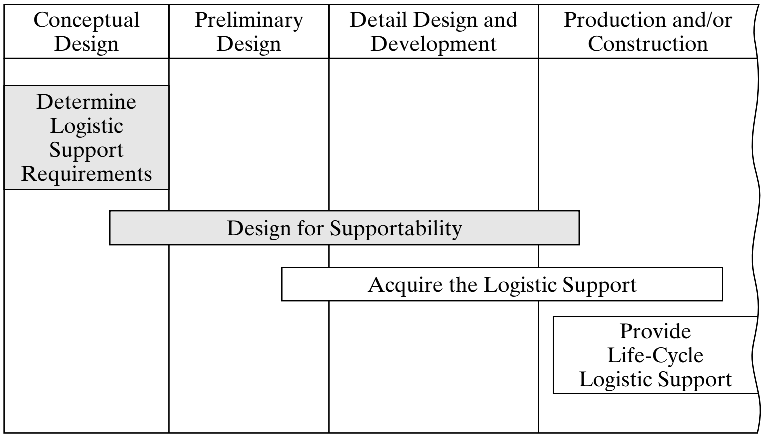


Figure 15 Logistics activities in the system life cycle.

are discussed to provide the reader with the fundamentals necessary to better understand the material presented in this text.

7.1 System Engineering

System engineering may be defined differently depending on one's background and personal experience. The inaugural issue of "Systems Engineering," published by the International Council on Systems Engineering (INCOSE), describes a variety of approaches;[21] however, the basic theme deals with a top-down process that is life-cycle oriented and involves the integration of functions, activities, and organizations.

More recently, the Fellows of INCOSE developed the following consensus definition:

> *System engineering is an engineering discipline whose responsibility is to create and execute an interdisciplinary process to ensure that the customer and stakeholder's needs are satisfied in a high-quality, trustworthy, and cost and schedule efficient manner throughout a system's entire life cycle. This process is usually comprised of the following seven tasks:* **S***tate the problem;* **I***nvestigate alternatives;* **M***odel the system;* **I***ntegrate;* **L***aunch the system;* **A***ssess performance; and* **R***e-evaluate (***SIMILAR***). The systems engineering process is not sequential. The functions are performed in a parallel and iterative manner.*[22]

The Department of Defense (DoD) defines system engineering as "*an approach to translate approved operational needs and requirements into operationally suitable blocks of systems. The approach shall consist of a top-down, iterative process of requirements analysis, functional analysis and allocation, design synthesis and verification, and system analysis and control. Systems engineering shall permeate design, manufacturing, test and evaluation, and support of the product. Systems engineering principles shall influence the balance between performance, risk, cost, and schedule*." More specifically, "the systems engineering process shall:

1. Transform approved operational needs and requirements into an integrated system design solution through concurrent consideration of all life-cycle needs (i.e., development, manufacturing, test and evaluation, deployment, operations, support, training, and disposal; and
2. Ensure the interoperability and integration of all operational, functional, and physical interfaces. Ensure that system definition and design reflect the requirements for all system elements: hardware, software, facilities, people, and data; and
3. Characterize and manage technical risks.

---

[21] Inaugural issue, "Systems Engineering," *Journal of the International Council on Systems Engineering* INCOSE, Seattle, WA. (vol. 1, no. 1, July/September 1994).

[22] "A Guide to the Systems Engineering Body of Knowledge (SEBok)—Introduction," *INSIGHT*, vol. 5, issue 1, INCOSE, Seattle, WA, April 2002.

The key systems engineering activities that shall be performed are *requirements analysis, functional analysis/allocation, design synthesis and verification*, and *system analysis and control*."[23]

A slightly different definition (preferred by the author) is "*the application of scientific and engineering efforts to: (1) transform an operational need into a description of system performance parameters and a system configuration through the use of an iterative process of definition, synthesis, analysis, design, test and evaluation, and validation; (2) integrate related technical parameters and ensure the compatibility of all physical, functional, and program interfaces in a manner that optimizes the total definition and design; and (3) integrate reliability, maintainability, usability (human factors), safety, producibility, supportability (serviceability), disposability, and other such factors into a total engineering effort to meet cost, schedule, and technical performance objectives*."[24]

Basically, system engineering is *good* engineering with certain designated areas of emphasis, a few of which are noted as follows:

1. A top-down approach is required, viewing the system as a *whole*. Although engineering activities in the past have very adequately covered the design of various system components, the necessary *overview* and an understanding of how these components effectively fit together has not always been present.
2. A *life-cycle* orientation is required, addressing all phases to include system design and development, production and/or construction, distribution, operation, sustaining maintenance and support, and retirement and material phaseout. Emphasis in the past has been placed primarily on system design activities, with little (if any) consideration toward their impact on production, operations, support, and disposal.
3. A better and more complete effort is required relative to the initial *identification of system requirements*, relating these requirements to specific design goals, the development of appropriate design criteria, and the follow-on analysis effort to ensure the effectiveness of early decision making in the design process. In the past, the early front-end analysis effort, as applied to many new systems, has been minimal. Consequently, greater individual design efforts have been required downstream in the life cycle, many of which were not well integrated with other design activities and required modification later on.
4. An *interdisciplinary* effort (or team approach) is required throughout the system design and development process to ensure that all design objectives are met in an effective manner. This necessitates a complete understanding of the many different design disciplines and their interrelationships, particularly for large projects.

When referring to the system life cycle, one should view not only the prime mission-oriented elements of the system (e.g., a radar set, a communications network) but the

---

[23] Department of Defense Regulation 5000.2R, "Mandatory Procedures for Major Defense Acquisition Programs (MDAPS) and Major Automated Information System (MAIS) Acquisition Programs," Department of Defense, Washington, DC, chap. 5, par. C5.2, April 5, 2002.

[24] This is a slightly modified version of the definition of systems engineering that was included in the original version of MIL-STD-499, "Systems Engineering," Department of Defense, Washington, DC, July 1969.

applicable production process, the support infrastructure, and the retirement and material disposal process as well. Basically, the four life cycles presented in Figure 7 must be addressed concurrently, as the interactions among the four categories of activity are numerous. As the prime equipment design materializes, the key questions are the following: Is the design configuration producible? Is it supportable? Is it disposable? Is the approach economically feasible?

In summary, system engineering per se is not to be considered as being an engineering discipline in the same context as electrical engineering, mechanical engineering, reliability engineering, or any other design specialty area. Actually, system engineering involves the integrated and coordinated efforts of many different design and related disciplines, applied as part of a top-down/bottom-up process, evolving from the point when a consumer need is first identified, through development, construction and/or production, distribution, utilization and support, and the ultimate system retirement. Figure 16 provides an illustration of the system development process, and the shaded area is where logistics engineering can play a major role.[25]

7.2 System Analysis

Inherent within the system engineering process is an ongoing analytical effort. In a somewhat puristic sense, *analysis* refers to a separation of the whole into its component parts, an examination of these parts and their interrelationships, and a follow-on decision relative to a future course of action.

More specifically, throughout system design and development there are many different alternatives (or trade-offs) requiring some form of evaluation. For instance, there are alternative system operational scenarios, alternative maintenance and support concepts, alternative equipment packaging schemes, alternative diagnostic routines, and alternative manual versus automation applications. The process of investigating these alternatives, and the evaluation of each in terms of some criteria, constitutes an ongoing analytical effort.

To accomplish this activity in an effective manner, the engineer (or analyst) relies on the use of available analytical techniques/tools to include operations research methods such as simulation, linear and dynamic programming, integer programming, optimization (constrained and unconstrained), and queuing theory to help solve problems. Further, mathematical models are used to help facilitate the quantitative analysis process.

7.3 Supportability Analysis (SA)

The *supportability analysis* (SA) is an iterative analytical process by which the logistic support necessary for a new (or modified) system is identified and evaluated. The SA constitutes the application of selected quantitative methods to (1) aid in the initial determination and establishment of supportability criteria as an input to design; (2) aid in the evaluation of various design alternatives; (3) aid in the identification, provisioning,

---

[25] It is within the system engineering process that logistics engineering activities play a major role, with the design for supportability being a prime objective. Also, refer to Blanchard, B. S., *System Engineering Management*, 3rd ed., John Wiley & Sons, Hoboken, NJ, 2004.

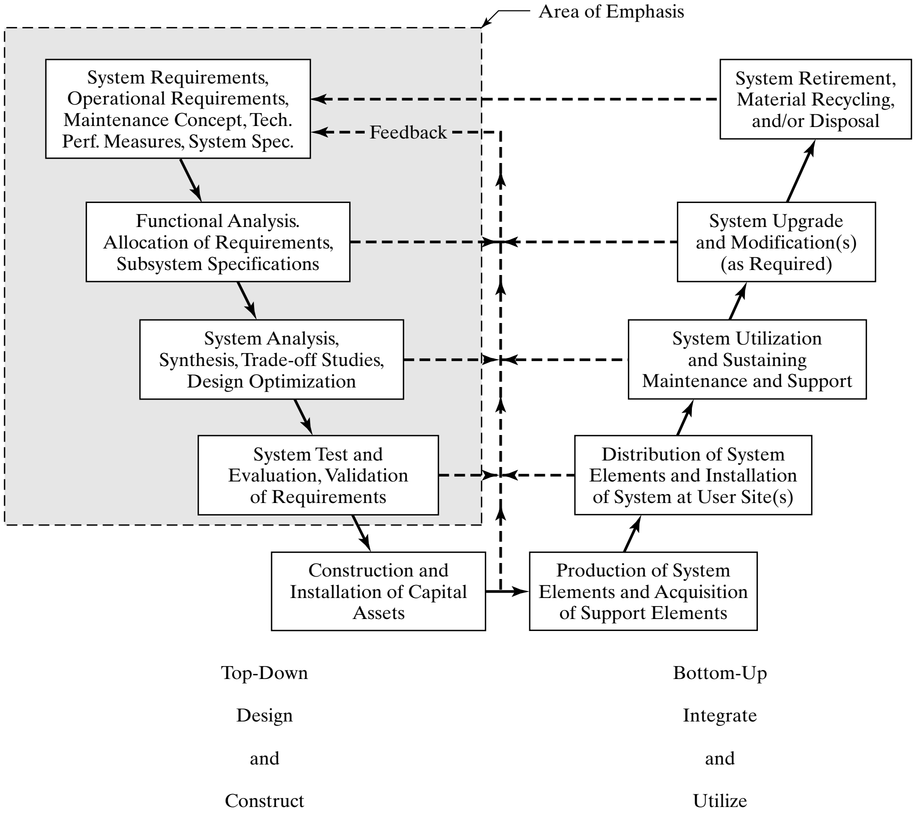


Figure 16 Top-down/bottom-up system development process.

and procurement of the various elements of maintenance and support; and (4) aid in the final assessment of the system support infrastructure throughout the utilization phase. The SA constitutes a design analysis process that is part of the overall system engineering analysis effort and is applied during the early phases in the life cycle and often includes the maintenance task analysis (MTA), level of repair analysis (LORA), FMECA/FTA, reliability-centered maintenance (RCM) analysis, transportation analysis, life-cycle cost analysis (LCCA), and logistics modeling. An output of the SA is the identification and justification of the logistics resource requirements described in Section 5.

7.4 Concurrent/Simultaneous Engineering

Recognizing the concurrent trends in system acquisition, the Department of Defense introduced the concept of *concurrent engineering*, which 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*."[27]

The objectives of concurrent engineering include (1) improving the quality and effectiveness of systems/products through a better integration of requirements and (2) reducing the system/product development cycle time through a better integration of activities and processes. Consequently, the total life-cycle cost for a given system should be reduced.

From our perspective, the requirements associated with concurrent engineering are inherent within the spectrum of system engineering. The requirements in both instances address the four life cycles illustrated in Figure 7, concurrently and as an integrated whole.

7.5 Software Engineering

Given today's trends and the continuing development of computer technology, software is becoming (if it is not already) a significant element in the configuration of many systems. Current experience indicates that software considerations are inherent in more than 75% of the system design and development efforts. Software may be viewed in three areas:

1. Software that is included as a mission-related component of the system and is required for the operation of that system. From a logistics perspective, there is a requirement to maintain this software throughout its planned life cycle.
2. Software that is required to accomplish maintenance functions on the system (e.g., diagnostic routines, condition monitoring programs). A logistics engineering function includes the initial development and the subsequent maintenance of this software.
3. Software that is required to support program-oriented activities (e.g., the software associated with various computer-based models used for design analyses, the software associated with the preparation and processing of various categories of design data such as required to meet the computer-aided support (CAS) requirements).

The development of software must be properly integrated with the development of the hardware, human, and other elements of the system. Further, these activities, as they

---

[27] IDA Report R-338, *The Role of Concurrent Engineering in Weapons System Acquisition*, Institute of Defense Analysis, Alexandria, VA, 1988. A similar approach has been applied in the commercial sector but identified as *simultaneous engineering*.

apply to system support, must be properly integrated with the activities accomplished in logistics engineering.

7.6 Reliability (*R*)

Reliability can be defined simply as the probability that a system or product will perform in a satisfactory manner for a given period of time when used under specified operating conditions. This definition stresses the elements of probability, satisfactory performance, time, and specified operating conditions. These four elements are extremely important, since each plays a significant role in determining system/product reliability.

Probability, the first element in the reliability definition, is usually stated as a fraction or a percentage signifying the number of times that an event occurs (successes), divided by the total number of trials. For instance, a statement that the probability of survival (P_s) of an item for 80 hours is 0.75 (or 75%) indicates that we can expect that the item will function properly for at least 80 hours, 75 times out of 100 trials.

When there are a number of supposedly identical items operating under similar conditions, it can be expected that failures will occur at different points in time; thus, failures are described in probabilistic terms. In essence, the fundamental definition of reliability is heavily dependent on the concepts derived from probability theory.

Satisfactory performance, the second element in the reliability definition, indicates that specific criteria must be established that describe what is considered to be satisfactory system operation. A combination of qualitative and quantitative factors defining the functions that the system or product is to accomplish, usually presented in the context of a system specification, are required.

The third element, *time*, is one of the most important, since it represents a measure against which the degree of system performance can be related. One must know the time parameter in order to assess the probability of completing a mission or a given function as scheduled. Of particular interest is being able to predict the probability that an item will survive (without failure) for a designated period of time (sometimes designated as *R* or *P*). Also, reliability is frequently defined in terms of mean time between failure (MTBF), mean time to failure (MTTF), or mean time between maintenance (MTBM); thus, the aspect of time is critical in reliability measurement.

The *specified operating conditions* under which a system or product is expected to function constitute the fourth significant element of the basic reliability definition. These conditions include environmental factors such as geographical location where the system is expected to operate, the operational profile, the transportation profile, temperature cycles, humidity, vibration, and shock. Such factors must address not only the conditions for the period when the system or product is operating but also the conditions for the periods when the system (or a portion thereof) is in a storage mode or being transported from one location to another. Experience has indicated that the transportation, handling, and storage modes are sometimes more critical from a reliability standpoint than the conditions experienced during actual system operational use.

The four elements just discussed are critical in determining the reliability of a system or product. System reliability (or unreliability) is a key factor in the frequency of maintenance, and the maintenance frequency obviously has a significant impact on logistic support requirements. Reliability predictions and analyses are required as an input to the supportability analysis.

Reliability is an inherent characteristic of design. As such, it is essential that reliability be adequately considered at program inception and that reliability be addressed throughout the system life cycle.

7.7 Maintainability (*M*)

Maintainability, like reliability, is an inherent characteristic of system or product design. It pertains to the ease, accuracy, safety, and economy in the performance of maintenance actions. A system should be designed such that it can be maintained without large investments of time, cost, or other resources (e.g., personnel, materials, facilities, test equipment) and without adversely affecting the mission of that system. Maintainability is the *ability* of an item to be maintained, whereas *maintenance* constitutes a series of actions to be taken to restore an item or retain it in an effective operational state. Maintainability is a design parameter. Maintenance is a result of design.

Maintainability can also be defined as a characteristic in design that can be expressed in terms of maintenance frequency factors, maintenance times (i.e., elapsed times and labor hours), and maintenance cost. These terms may be presented as different figures of merit; therefore, maintainability may be defined on the basis of a combination of factors, such as the following:

1. A characteristic of design and installation expressed as the probability that an item will be retained in or restored to a specified condition within a given period of time, when maintenance is performed in accordance with prescribed procedures and resources.
2. A characteristic of design and installation expressed as the probability that maintenance will not be required more than x times in a given period, when the system is operated in accordance with prescribed procedures. This may be analogous to reliability when the latter deals with the overall frequency of maintenance.
3. A characteristic of design and installation expressed as the probability that the maintenance cost for a system will not exceed y dollars per designated period of time, when the system is operated and maintained in accordance with prescribed procedures.

Maintainability requires the consideration of many different factors involving all aspects of the system, and the measures of maintainability often include a combination of the following:

1. MTBM: mean time between maintenance, which includes both preventive (scheduled) and corrective (unscheduled) maintenance requirements. It includes consideration of reliability MTBF and MTBR. MTBM may also be considered as a reliability parameter.
2. MTBR: mean time between replacement of an item due to a maintenance action (usually generates a spare-part requirement).
3. $\overline{\text{M}}$: mean active maintenance time (a function of $\overline{\text{M}}\text{ct}$ and $\overline{\text{M}}\text{pt}$).
4. $\overline{\text{M}}\text{ct}$: mean corrective maintenance time. Equivalent to mean time to repair (MTTR).
5. $\overline{\text{M}}\text{pt}$: mean preventive maintenance time.
6. $\widetilde{\text{M}}\text{ct}$: median active corrective maintenance time.
7. $\widetilde{\text{M}}\text{pt}$: median active preventive maintenance time.
8. MTTR_g: geometric mean time to repair.
9. M_{max}: maximum active corrective maintenance time (usually specified at the 90% and 95% confidence levels).
10. MDT: maintenance downtime (total time during which a system is not in condition to perform its intended function). MDT includes active maintenance time ($\overline{\text{M}}$), logistics delay time (LDT), and administrative delay time (ADT).
11. MLH/OH: maintenance labor hours per system operating hour.
12. Cost/OH: maintenance cost per system operating hour.
13. Cost/MA: maintenance cost per maintenance action.
14. Turnaround time (TAT): that element of maintenance time needed to service, repair, and/or check out an item for recommitment. This constitutes the time that it takes an item to go through the complete cycle from operational installation through a maintenance shop and into the spares inventory ready for use.
15. Self-test thoroughness: the scope, depth, and accuracy of testing.
16. Fault isolation accuracy: accuracy of system diagnostic routines in percent.

Maintainability, as an inherent characteristic of design, must be properly considered in the early phases of system development, and maintainability activities are applicable throughout the life cycle.

7.8 Maintenance and Support

1. Maintenance. *Maintenance* includes all actions necessary for retaining a system or product in, or restoring it to, a serviceable condition. Maintenance may be categorized as corrective maintenance or preventive maintenance.

a. *Corrective maintenance* includes all unscheduled maintenance actions performed, as a result of system/product failure, to restore the system to a specified condition. The corrective maintenance cycle includes failure identification, localization and isolation, disassembly, item removal and replacement or repair in place, reassembly, checkout, and condition verification. Also, unscheduled maintenance may occur as a result of a suspected failure, even if further investigation indicates that no actual failure occurred.

b. *Preventive maintenance* includes all scheduled maintenance actions performed to retain a system or product in a specified condition. Scheduled maintenance includes periodic inspections, condition monitoring, critical item replacements, and calibration. In addition, servicing requirements (e.g., lubrication, fueling) may be included under the general category of scheduled maintenance.

2. Maintenance level. Corrective and preventive maintenance may be performed on the system itself (or an element thereof) at the site where the system is used by the customer, in an intermediate shop near the customer's operational site, and/or at a depot, at a supplier, or at a manufacturer's plant facility. *Maintenance level* pertains to the division of functions and tasks for each area where maintenance is performed. Task complexity, personnel skill-level requirements, special facility needs, economic criteria, and so on, dictate to a great extent the specific functions to be accomplished at each level. Maintenance may be classified as *organizational, intermediate*, and *depot*.

3. Maintenance concept. The *maintenance concept* (as defined in this text) constitutes a series of statements and/or illustrations defining criteria covering maintenance levels (e.g., two levels of maintenance, three levels of maintenance), major functions accomplished at each level of maintenance, basic support policies, effectiveness factors (e.g., MTBM, $\overline{\mathrm{M}}\mathrm{ct}$, MLH/OH, cost/MA), and primary logistic support requirements. The maintenance concept is defined at program inception and is a prerequisite to system/product design and development. The maintenance concept is also a required input to the supportability analysis (SA).

4. Maintenance plan. The *maintenance plan* (as compared with the maintenance concept) is a detailed plan specifying the methods and procedures to be followed for system support throughout the life cycle and during the utilization phase. The plan includes the identification and use of the required elements of logistics necessary for the sustaining support of the system. The maintenance plan is developed from the SA data and is usually prepared during the detail design phase.

5. Total productive maintenance (TPM). *Total productive maintenance* (*TPM*) is a Japanese concept involving an integrated, top-down, system life-cycle approach to maintenance, with the objective of maximizing productivity. TPM is directed primarily to the commercial manufacturing environment, utilizing many of the principles inherent within the integrated maintenance and support concept. More specifically, TPM

a. aims to maximize overall equipment effectiveness (to improve overall efficiency).

b. establishes a complete preventive maintenance program for the entire life cycle of equipment.

c. is implemented on a team basis and involves various departments, such as engineering, production operations, and maintenance.

d. involves every employee, from top management to the workers on the floor. Even equipment operators are responsible for maintenance of the equipment they operate.

e. is based on the promotion of preventive maintenance through *motivational management* (autonomous small-group activities).

TPM, 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. TPM includes continuous improvement in maintenance.[31]

7.9 Human Factors (Ergonomics)

Human factors pertain to the human element of the system and the interface(s) between the human being, the machine, facilities, and associated software. The objective is to assure complete compatibility between the system physical and functional design features and the human element in the operation, maintenance, and support of the system. Considerations in design must be given to anthropometric factors (e.g., the physical dimensions of the human being), human sensory factors (e.g., vision, hearing, and feel capabilities), physiological factors (e.g., impacts from environmental forces), psychological factors (e.g., human needs, expectations, attitude, motivation), and their interrelationships. Human factors (such as reliability and maintainability) must be considered early in system development through functional analysis, operator and maintenance task analysis, error analysis, safety analysis, and related design support activities. Operator and maintenance personnel requirements (i.e., personnel quantities and skill levels) and training program needs evolve from the task analysis. Maintenance personnel requirements are also identified in the supportability analysis.[32]

7.10 Safety and Security

Safety is a system design characteristic. The selection of certain materials in the design and construction of a system element could produce harmful toxic effects on the human; the placement and mounting of components could cause injuries to the operator and/or the maintainer; the use of certain fuels, hydraulic fluids, and/or cleansing liquids could result in an explosive environment; the location of certain electronic

---

[31] Refer to Nakajima, S. (Ed.), *TPM Development Program*, Productivity Press, Portland, OR, translated into English in 1989. There have been subsequent numerous additional publications on the subject, also published by Productivity Press. The concept of TPM was first introduced in Japan in the early 1970s and is being implemented throughout industry under the guidance of the Japanese Institute for Plant Maintenance (JIPM). The concept became popular in the United States, and the American Institute of Total Productive Maintenance (AITPM) was established. There are many companies currently applying the principles of TPM in one form or another.

[32] This area of activity may also be included under such general terms as *human engineering, ergonomics*, and *system psychology*.

components close together may cause the generation of an electrical hazard; the performance of a series of strenuous tasks during the operation or maintenance of the system could cause personal injury; and so on.

Safety is important both from the standpoint of the human operator and/or maintainer and from the standpoint of the equipment and other elements of the system. Through faulty design, one can create problems that could result in human injury. Also, problems can be created that result in damage to other elements of the system. In other words, the concerns in design deal with both personal safety and equipment safety.

Although not usually included within the class of the more traditional disciplines associated with engineering and the design of systems, the issue of *security* has certainly assumed a high priority in view of the continuing threats of terrorism and the terrorist acts that are taking place in today's world. Thus, there is an added dimension that needs to be addressed within the overall spectrum of system engineering; that is, the *design for security*. The question at this point is: How does one design a system to preclude the planned introduction of faults/failures that will cause the system (or any portion thereof) to be completely destroyed, resulting in the damage of material, facilities, and/or the loss of life? The objective, of course, is to be able to prevent an individual (or group of individuals) from intentionally sabotaging a system for one reason or another.[34]

Although the intent may be different (i.e., inducing a problem intentionally versus inadvertently), the goal here is similar to the design objectives that are specified within the disciplines of human factors engineering and safety engineering. In human factors engineering, one of the objectives is to design a system to preclude the introduction of faults by the operator (or maintainer) that will cause the system not to be able to perform its mission. In safety engineering, an objective is to design a system such that faults cannot be introduced that will result in system damage and/or personal injury/death. In both cases, the major concern has related to the possibility of inducing problems while in the process of performing system functions during the accomplishment of a mission, in the performance of a maintenance task, and/or in the accomplishment of a support activity. The assumptions in these cases relate to the possibility that such problems may occur through some unintentional act or series of acts.

Going one step further, we need to address the issue of *intent*. The question is: What characteristics should be incorporated in the design of a system that will prevent (or at least deter) one or more individuals from *intentionally* inducing faults that will destroy the system, cause harm to personnel, and/or have an impact that will endanger society and the associated environment? In response, the design should consider the incorporation of an external security alarm capability that will detect an attempt by unauthorized personnel to operate/maintain the system, a condition-based monitoring capability that will enable a continuing check on the status of the system, a built-in

---

[34] Subsequent to the "9/11" incident, there has been a great deal of emphasis on *security* and the *design for security*. In the defense sector, in particular, an added requirement in the development of new (and the modification of existing) systems has been directed to the goal of including the necessary design characteristics to counter the threat of terrorism.