7

ORGANIZATION FOR SYSTEM ENGINEERING

The initial planning for system engineering commences during the early stages of conceptual design and evolves through the development of the System Engineering Management Plan (SEMP) described in Chapter 6. To implement this plan successfully requires an organizational structure that will promote, support, and generally enhance the application of system engineering principles and concepts. The proper organizational *environment* must be created that will allow for the accomplishment of system engineering requirements in an effective and efficient manner—that is, the implementation of a top-down, life-cycle-oriented, integrated approach in system design and development. In addition, the organization must be *dynamic* in response to the many changes that are taking place worldwide.

Figure 6.1 shows two sides of the spectrum; that is, the *technology* issues that can be applied to enhance and facilitate the implementation of the system engineering process and the *management* issues that are necessary to meet the objectives in this area. Inherent in this overall spectrum is the *organizational* element. "Organization" is the combining of resources in such a manner as to fulfill a certain need. Organizations constitute groups of individuals of varying levels of expertise, combined in a social structure of some form to accomplish one or more functions. Organizational structures vary with the functions to be performed, and the results will depend on the established goals and objectives, the resources available, the communications and working relationships between the individual participants, the motivation of personnel, and many other factors. The ultimate objective is to achieve the most effective and efficient utilization of human, material, and monetary resources through the establishment of communications and decision-making processes designed to accomplish specific objectives.

This chapter begins with a discussion of different types of organizational structures (their advantages and disadvantages from a generic perspective) and then emphasizes the system engineering organization, its functions, organizational interfaces, and the staffing needed to meet the objectives described throughout this text. Among the structures addressed are the *functional, product line, project, matrix, combined functional-project* approaches, and the implementation of the *integrated product and process development* (IPPD) configuration. Customer (consumer), producer (contractor), and supplier relationships are covered, along with their respective functions/ tasks. Finally, the chapter discusses human resource requirements: the selection of personnel, the skill levels required, organizational leadership characteristics, personal motivational factors, and so on. The material presented herein is directly supportive of the planning process described in Chapter 6.[1]

7.1 DEVELOPING THE ORGANIZATIONAL STRUCTURE

When dealing with "organizations," one must address a number of issues, including *structure, processes, culture, environment,* and various combinations of these. As an initial step, it is logical to consider "structure" first. Processes, culture, and the organizational environment are discussed later.

In the development of any type of an organizational structure, one must start by determining the goals and objectives for the overall company/agency/institution involved, along with the functions and tasks that must be accomplished. Depending on the complexity and size of a program, the structure may assume a pure *functional* model, a *project* or *product line* orientation, a *matrix* approach, or combinations thereof. Further, the structure may change in context as the system development evolves from the conceptual design phase through detail design and development, production, and so on. The ultimate goal, of course, is to achieve the most effective utilization of human, material, and monetary resources in accomplishing the functions that are required at the time.

In regard to system engineering, a prime objective during the early stages of conceptual design is to ensure the proper development of system-level requirements; that is, the needs analysis, feasibility analysis, operational requirements, maintenance concept, identification of technical performance measures (TPMs), and the preparation of the System Specification (Type "A"). These activities are highly *customer/ user* focused and directed toward the *system* as an entity, and their accomplishment does not require a large organization per se. On the other hand, the selection of a few key personnel with the appropriate skills, backgrounds, and experience levels is essential.

[1]The level (depth) of discussion of organizational concepts in this chapter is very cursory and is intended to provide the reader with an overview of some of the key points in respect to system engineering. Three good references for additional material are (1) J. L. Gibson, J. H. Donnelly, J. M. Ivancevich, and R. Konopaske, *Organizations: Behavior, Structure, Processes*, 11th ed. (New York: McGraw-Hill/Irwin, 2003); (2) H. Kerzner, *Project Management: A Systems Approach to Planning, Scheduling, and Controlling*, 7th ed. (New York: John Wiley & Sons, Inc., 2000); and (3) A. P. Sage, *Systems Management for Information Technology and Software Engineering* (New York: John Wiley & Sons, Inc., 1995). Also check Appendix A for additional references.

As the program evolves into the preliminary and detail design and development phases, the number of assigned personnel may increase as the design requirements at the subsystem level (and below) may dictate the necessity for including the expertise of various design disciplines—for example, reliability, maintainability, human factors, safety, and logistics. In this context, the organizational structure may change from a pure *project* configuration to a mixed *functional-project* or *matrix* approach. As the system and its components enter the production phase, the organizational structure may shift once again.[2]

In addressing the organizational issue overall, the emphasis herein is intended to stress the many and varied tasks, described in Section 6.2.2 (Figure 6.6), that must be accomplished, regardless of which organizational element (department or group of personnel) performs the work. Experience indicates that there are organizational departments/groups located within industrial firms and/or government agencies that have been designated as "System Engineering" and assigned the appropriate responsibilities, but are not performing the tasks required. Conversely, there are organizational elements with different identities that are, in actuality, performing the desired functions. Further, for small projects, where a single individual must assume many different roles, the system engineering responsibilities may be accomplished by an electrical engineer, a mechanical engineer, or someone with equivalent background and experience. For instance, the chief engineer or project manager may serve as the "system engineer," or there may be a designated group performing the required tasks.

Whereas there may be variations in approach, Sections 7.2 through 7.5 provide a more in-depth discussion on the various types of organizational structures, the advantages and disadvantages of each, personnel staffing issues, and so on.

7.2 CUSTOMER, PRODUCER, AND SUPPLIER RELATIONSHIPS

To properly address the subject of "organization for system engineering," one needs to view this in the context of the total flow of activities, evolving from the customer and down to the producer (prime contractor) and suppliers. Although this top-down flow may vary in detail, depending on the size of the project and the stage of design and development, this discussion is primarily directed to a large project activity, applicable in the acquisition of many large-scale systems. By addressing large projects, it is hoped that a better understanding of the role of system engineering in a somewhat complex environment will be provided. The reader must then adapt and structure an approach for his or her own program requirements.

For a relatively large project, the system engineering function may appear at several levels, as shown in Figure 7.1. The requirements for system engineering and the responsibility for implementing the tasks described in Chapter 6 lie with the customer. The customer may establish a system engineering organization to accomplish

[2]It should be noted that, from time to time, a shift in organizational structure may occur as a result of "outside" or "external" influences; for example, resulting from changes in technology applications, changes in supplier requirements, changes in political and economic conditions, and the like.

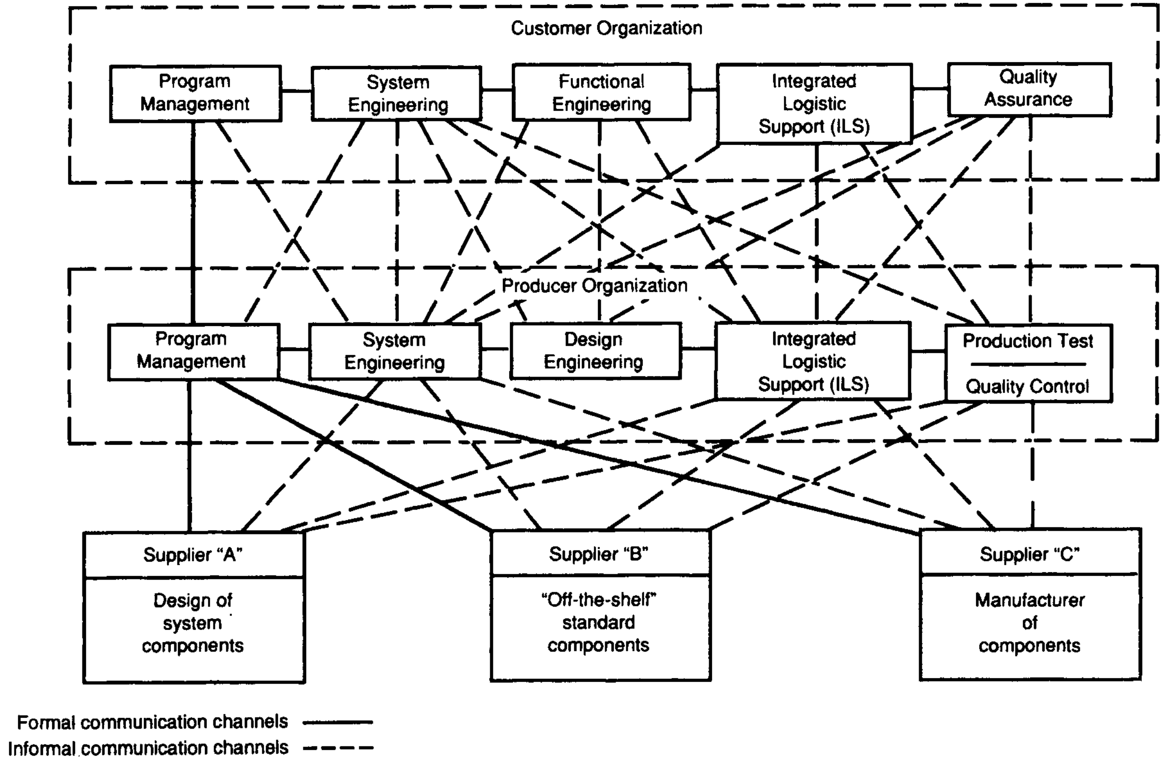

Figure 7.1 Consumer/producer/supplier interfaces.

the required tasks, or these tasks may be relegated (in part or in total) to the producer through some form of contractual arrangement. In any event, the responsibility, along with the authority, for accomplishing system engineering functions must be clearly defined from the beginning.

In some instances, the customer may assume full responsibility for the overall design and development, production, and installation of the system and its elements for operational use. The needs analysis, feasibility studies, definition of operational requirements and the maintenance concept, identification and prioritization of TPMs, preparation of the System Specification (Type "A"), and preparation of the System Engineering Management Plan (SEMP) are accomplished by the customer. Top-level functions are defined and specific program requirements are allocated to individual producers, subcontractors, and suppliers.

In other cases, whereas the customer provides the overall guidance in terms of issuing a general Statement of Work (SOW) or a contractual document of an equivalent nature, the producer (or *prime contractor*) is held responsible for the entire system design and development effort and for completing the tasks described in Chapter 6. In other words, although both the customer and the producer have established system engineering organizations, the basic responsibility for fulfilling the objectives described throughout this text lies with the producer's organization, with supporting tasks being accomplished by individual suppliers as required. To accomplish this, the customer must delegate the appropriate level of *responsibility* for completing the functions specified, and the necessary *authority* as well. Further, the customer must make available all of the input data necessary for the producer to successfully complete the conceptual design tasks noted earlier.[3]

In Figure 7.1, it should be noted that there is an extensive amount of communication required, not only within each of the customer and producer organizations, but also between the various customer, producer, and supplier organizations. Although the solid lines pertain primarily to the more formal program management direction of contractual nature, there are many informal channels of communication that must exist to ensure that the proper dialogue is established between the numerous and varied entities involved in the system development effort. The successful implementation of a *teaming* or *partnership* approach, along with the fostering of concurrent engineering principles, is heavily dependent on good communications (both downward and upward) from the beginning.

7.3 CUSTOMER ORGANIZATION AND FUNCTIONS

The customer/consumer organization may vary, ranging from one or a small group of individuals to an industrial firm, a commercial business, an academic institution, a government laboratory, the Department of Defense, or a military service. The cus-

[3]It is not uncommon for the customer to perform a requirements analysis, prepare a report describing the requirements for a new system, place it in a file somewhere, and then fail to pass on the necessary information later to the responsible producer. Thus, the producer has to generate a new set of requirements that may, or may not, be consistent with those initially developed by the customer.

tomer may be the ultimate "user" of the system or may be the procuring agency for a user. An example of the latter is found within the defense sector, where the Air Force, Army, and Navy each have acquisition agencies that are responsible for the contracting and procurement of systems, and the "user" is the operating command in the field/fleet responsible for the utilization and sustaining maintenance and support of the system throughout its planned life cycle.

In Figure 7.1, the acquisition agency may be represented by the top block, with a chain of industrial firms, small businesses, and component suppliers providing the materials and services necessary for the development of the system and its elements. In such instances, it is incumbent on the procuring agency to ensure that the early contracting and acquisition process will result in satisfying the needs of the ultimate "user," not just to respond to the short-term desires of the procuring agency. In this case, the procuring agency must be responsive to the "user" organization (as the customer), the producer or industrial firm (in Figure 7.1) must be responsive to the acquisition agency (as the customer), and the suppliers must be responsive to the producer (as the customer). The question is, Who is the *ultimate customer*, who is *your customer*, and do the requirements associated with the latter support the objectives specified for the first? It is essential that this overall "chain" of organizational entities be addressed in the planning and development of systems.

There are a variety of approaches and associated organizational relationships involved in the design and development of new systems. The objective is to identify the overall "program manager" and to pinpoint the responsibility for *system engineering management*. In the past, there have been numerous instances in which the procuring agency (e.g., the "customer" in Figure 7.1) has initiated a contract with an industrial firm (e.g., the "producer") for the design and development, and/or reengineering, of a large system, but has not delegated the complete responsibility (or corresponding *authority*) for system engineering management. The industrial firm has been held responsible for the design, development, production, and delivery of a system in response to certain specified requirements. However, the customer has not always provided the producer with the necessary data and/or controls to allow the development effort to proceed in accordance with good system engineering practices. At the same time, the customer has not performed the necessary functions of system engineering management. The net result has been the development of systems without the consideration of many of the characteristics discussed throughout Chapter 3; that is, systems that are unreliable, not maintainable, not supportable, not cost-effective, and not responsive to the needs of the ultimate users.

The fulfillment of system engineering objectives is highly dependent on a *commitment* from the top down. These objectives must be recognized from the beginning by the customer, and an organizational entity needs to be established to ensure that these objectives are met. The program manager must first "understand" and "believe in" the concepts and principles of system engineering, and then must create the appropriate environment and take the lead by initiating either of the following courses of action:

1. Accomplish the system engineering functions within the customer's organizational structure (see Figure 7.1). This may include completing the basic activities reflected in Figure 1.12 and described in Figure 6.6; that is, the needs

analysis and feasibility studies, development of operational requirements and the maintenance concept, the identification and prioritization of TPMs, functional analysis and allocation, synthesis, design optimization, and so on. In other words, the customer (or procuring agency) will prepare the System Specification (Type "A"), will perform all of the tasks required at the *system level*, and will delegate requirements for the subsystem level and below.

2. Accomplish the system engineering functions within the industrial firm or the producer's organizational structure (shown in Figure 7.1). These may include the completion of the system engineering tasks reflected in Figure 1.12 and described in Figure 6.6; that is, development of operational requirements and the maintenance concept, functional analysis and allocation, synthesis, design optimization, and so on. Although the customer will define the program requirements in the form of a Statement of Work (SOW), all of the system engineering tasks and associated management functions will be delegated to and be accomplished by the producer.

Although these two options represent the extremes, there may be any combination of models in which the responsibilities for accomplishing system engineering management functions have been split. In such cases, it is essential that the responsibility for system engineering be established from the beginning. The customer must clarify system objectives and program functions, and the requirements for system engineering must be well defined. It is critical that the process described in Chapter 2 be implemented properly, independent of organizational splits, the sharing of responsibilities, or any other conditions.

In the event that the system engineering responsibility is delegated to the producer (i.e., the preceding second option), the customer must completely support this decision by providing the necessary top-down guidance and managerial backing. Responsibilities must be properly delineated, system-level data generated through earlier customer activities and studies made available to the producer (e.g., the results of feasibility analyses, the documentation of operational requirements), and the producer must be given the necessary leeway relative to making decisions at the system level. The challenge for the customer is to prepare a good, comprehensive, well-written, and clear Statement of Work to be implemented by the producer. The emphasis should be on the issues of producer *performance,* specifying *what* needs to be accomplished and *when,* versus telling the producer *how* to perform the job. In addition, the various lines of communication between the customer and producer shown in Figure 7.1 must support a unified and consistent approach throughout.

7.4 PRODUCER ORGANIZATION AND FUNCTIONS (THE "CONTRACTOR")

For the purposes of discussion, it is assumed that the producer (or contractor) in Figure 7.1 will undertake the bulk of the system engineering activities associated with the design and development of a large-scale system. The customer will specify the necessary system-level and program requirements through the preparation of a *Re-*

quest for Proposal (RFP) or an *Invitation for Bid* (IFB), and various industrial firms will respond by submitting a formal proposal. The response may represent the results of a *teaming* arrangement involving a designated number of industrial firms and component suppliers. As there may be a number of responding proposals, a formal competition is initiated, individual proposals are reviewed and evaluated, contractual negotiations are consummated, and a selection is made. The successful contractor (i.e., producer) will then proceed with the proposed level of effort.

In addressing program requirements, it is essential that the successful contractor have access to all information and data leading to the requirements specified in the technical portions of the RFP/IFB. In some instances, the RFP will include a system specification covering the technical aspects of system development, along with a Statement of Work (SOW) directed toward project tasks and the management aspects of a program. The preparation of the specification will result from the completion of those activities described in Sections 2.1 through 2.7. In other words, by the time that the contractor gets involved in this case, the customer will have completed the first three tasks shown in Figure 6.6. The main objective here is to ensure continuity in the transition from the activities accomplished by the customer to those to be performed by the contractor.

This transition process is one of the most critical points in a program. First, the process described in Chapter 2 must be maintained, and a thorough understanding of this process by both customer and contractor personnel is essential. Second, the specification and Statement of Work prepared by the customer must be complete and easily understandable; they must "talk to each other," and they must jointly *promote* the system engineering process. Often, in attempting to meet a schedule, specifications and Statements of Work are hurriedly put together without the benefit of a complete review and the proper level of integration. The results are usually diasterous, and the follow-on activities reflect inconsistencies and the lack of the proper integration of those activities described in Chapter 3. Finally, given a good specification and Statement of Work, the key system engineering activities must not be *negotiated out* in the development of a contractual agreement between the customer and the contractor (i.e., the development of a contract work breakdown structure; refer to Section 6.2.4). Sometimes there is a tendency to eliminate system engineering tasks to save money, which reflects a lack of understanding of the process and its objectives. This must not be allowed to happen.

Given that system-level requirements have been properly defined and that a prime contractor has been selected to accomplish the design and development effort, the next step is to address the subject of system engineering in the context of the contractor's organizational structure. Organizational structures vary from the pure *functional,* to the *project,* the combined *project-functional,* the *matrix,* and so on. These organizational patterns are discussed in the sections to follow, as they relate to the objectives of system engineering.

7.4.1 Functional Organization Structure

The primary building block for most organizational patterns is the *functional structure* reflected in Figure 7.2. This approach, sometimes referred to as the "classical" or "traditional" approach, involves the grouping of specialties or disciplines into separately

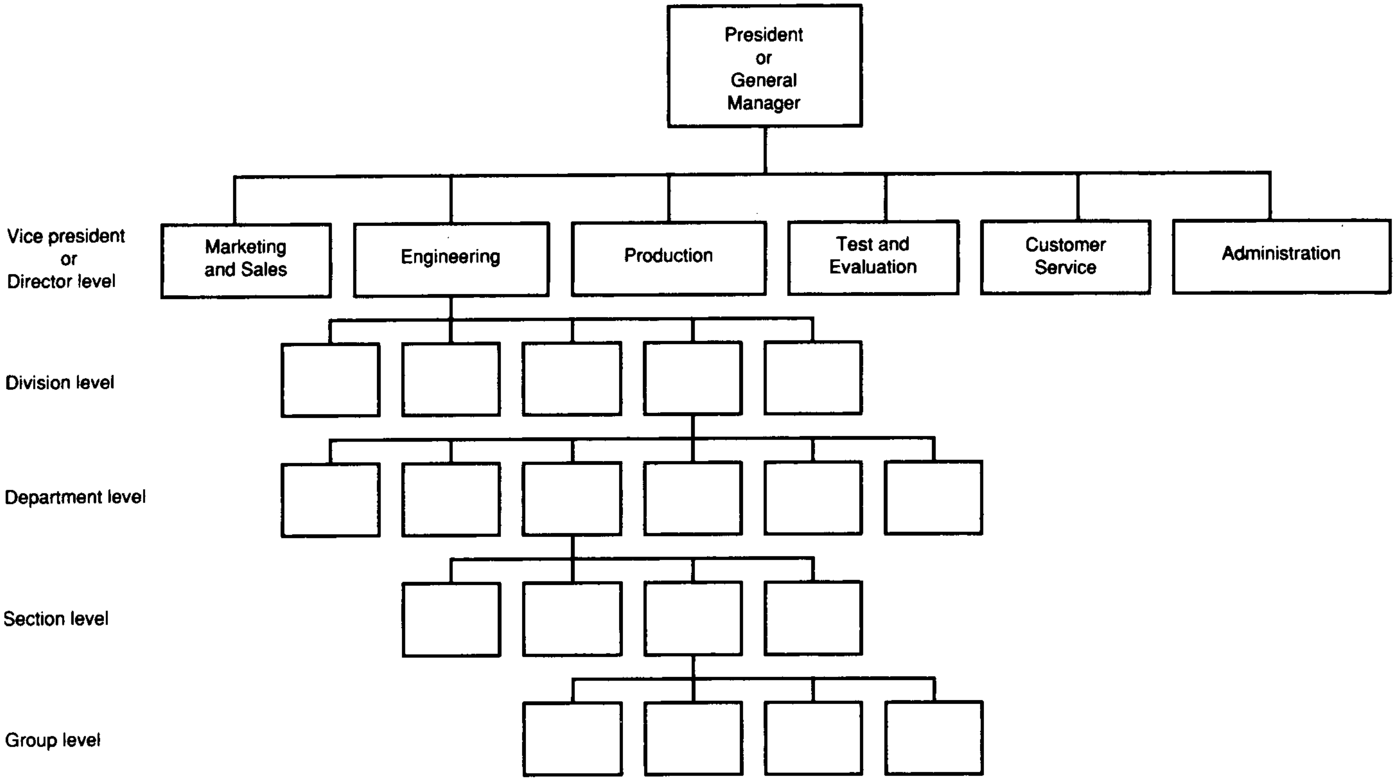

Figure 7.2 Producer organization (traditional functionally oriented structure).

identifiable entities. The intent is to perform similar activities within one organizational component. For example, all engineering work would be the responsibility of one executive, all production or manufacturing work would be the responsibility of another executive, and so on. Figure 7.3 shows a further breakout of engineering activities for illustrative purposes.

As shown in the figures, the depth of the individual elements of the organization will vary with the type of project and level of emphasis required. For projects involving the conceptual and/or preliminary design of new systems, there will be a

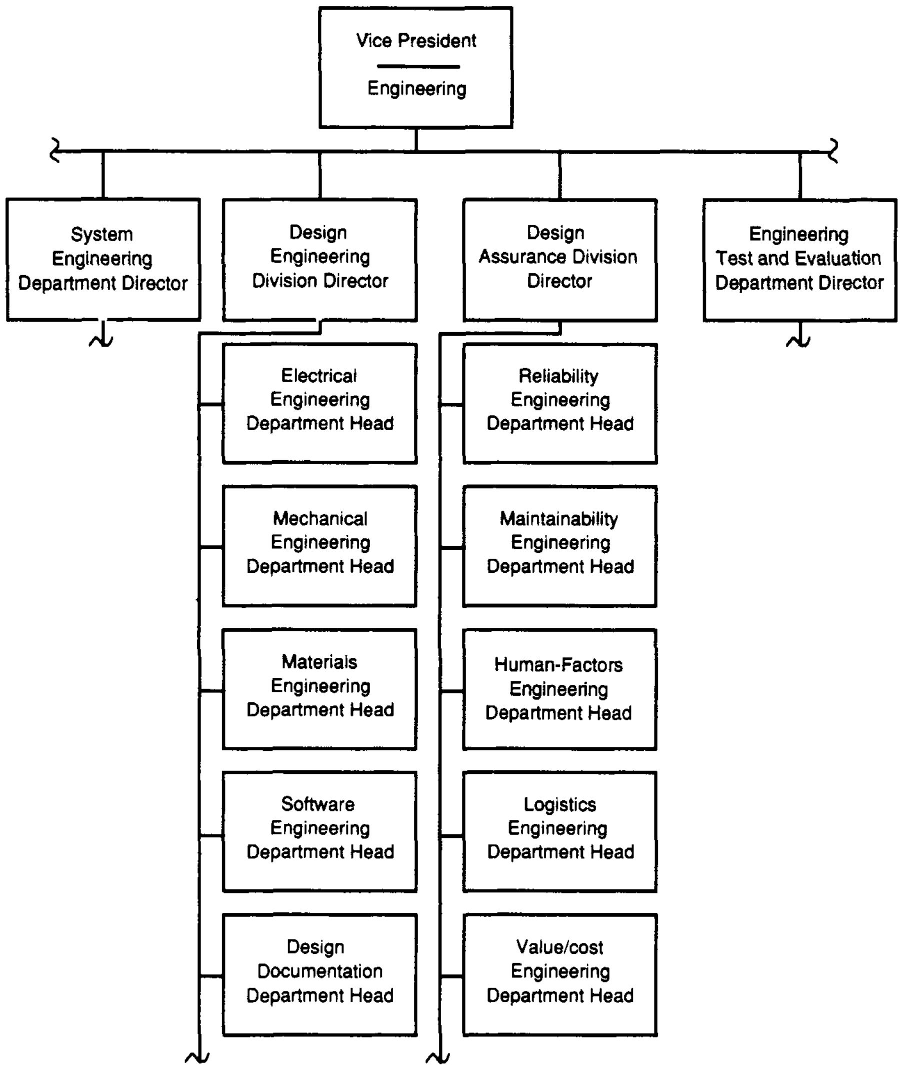

Figure 7.3 Breakout of engineering organizational activities.

great deal of emphasis on marketing and engineering. Within engineering, the system engineering organization should be highly influential in the design decision-making process, as compared with some of the individual design disciplines. Later, as the development process phases into detail design, the individual design disciplines will assume a greater degree of importance, and the interest in production and manufacturing increases.

As with any organizational structure, there are advantages and disadvantages. Figure 7.4 identifies some of the pros and cons associated with the pure functional approach illustrated in Figure 7.2. As shown, the president (or general manager) controls all the functional entities necessary to design and develop, produce, deliver, and support a system. Each department maintains a strong concentration of technical expertise, and thus a project can benefit from the most advanced technology in the field.

Advantages

1. Enables the development of a better technical capability for the organization. Specialists can be grouped to share knowledge. Experiences from one project can be transferred to other projects through personnel exchange. Cross-training is relatively easy.

2. The organization can respond more quickly to a specific requirement through the careful assignment (or reassignment) of personnel. There are a larger number of personnel in the organization with the required skills in a given area. The manager has a greater degree of flexibility in the use of personnel and a broader manpower base with which to work. Greater technical control can be maintained.

3. Budgeting and cost control are easier because of the centralization of areas of expertise. Common tasks for different projects are integrated, and it is easier not only to estimate costs but also to monitor and control costs.

4. The channels of communication are well established. The reporting structure is vertical, and there is no question as to who is the "boss."

Disadvantages

1. It is difficult to maintain an identity with a specific project. No single individual is responsible for the total project or the integration of its activities. It is hard to pinpoint specific project responsibilities.

2. Concepts and techniques tend to be functionally oriented with little regard for project requirements. The "tailoring" of technical requirements to a particular project is discouraged.

3. There is little customer orientation or focal point. Response to specific customer needs is slow. Decisions are made on the basis of the strongest functional area of activity.

4. Because of the group orientation relative to specific areas of expertise, there is less personal motivation to excel and innovation concerning the generation of new ideas is lacking.

Figure 7.4 A functional organization–advantages and disadvantages.

In addition, levels of authority and responsibility are clearly defined, communication channels are well structured, and the necessary controls over budgets and costs can be easily established. In general, this organizational structure is well suited for a single project operation, large or small.

On the other hand, the pure functional organization may not be as appropriate for large multiproduct firms or agencies. Where there are a large number of different projects, each competing for special attention and the appropriate resources, there are some disadvantages. The main problem is that there is no strong central authority or individual responsible for the total project. As a result, the integration of activities that cross functional lines becomes difficult. Conflicts occur as each functional activity struggles for power and resources, and decisions are often made on the basis of what is best for a functional group rather than what is best for the project. Further, the decision-making processes are sometimes slow and tedious because all communications must be channeled through upper-level management. Basically, projects may fall behind and suffer in the classical functional organization structure.

7.4.2 Product-Line/Project Organization Structure

As industrial firms grow and there are more products being developed, it is often convenient to classify these products into common groups and to develop a product-line organization structure, as shown in Figure 7.5. A company may become involved in the development of communication systems, transportation systems, and electronic test and support equipment. Where there is functional commonality, it may be appropriate to organize the company into three divisions, one for each product line. In such instances, each division will be self-sufficient relative to system design and support. Further, these divisions may be geographically separated, and each may serve as a functional entity with operations similar to those described in Section 7.4.1.

In divisions in which large systems are being developed, the product-line responsibilities may be subdivided into projects, as illustrated in Figure 7.6. In such cases, the project will be the lowest independent entity.

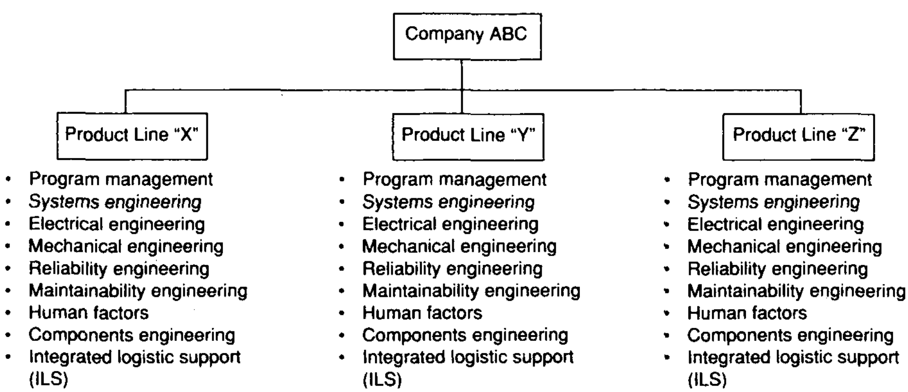

Figure 7.5 Traditional project/product-line organization.

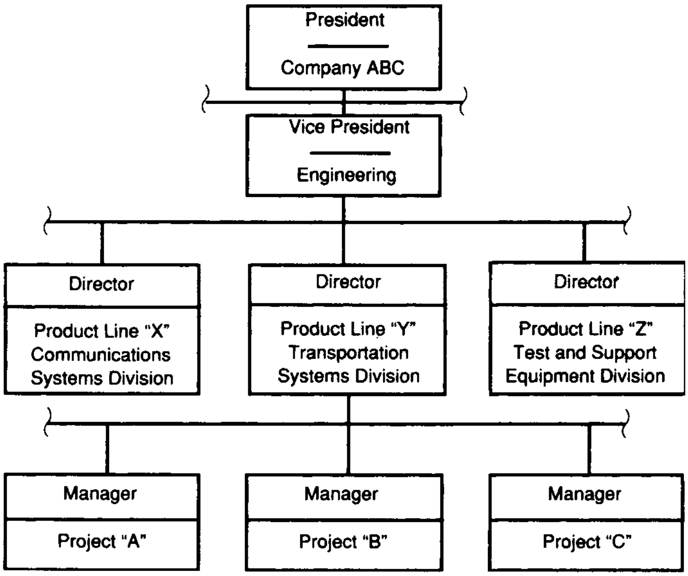

Figure 7.6 Product-line organization with project subunits.

A project organization is one that is solely responsible for the planning, design and development, production, and support of a single system or a large product. It is time-limited, directly oriented to the life cycle of the system, and the commitment of personnel and material is purely for the purposes of accomplishing tasks peculiar to that system. Each project will contain its own management structure, its own engineering function, its own production capability, its own support function, and so on. The project manager has the authority and the responsibility for all aspects of the project, whether it is a success or a failure.

In the case of both product-line and project structures, the activities are organized as presented in Figure 7.5. The lines of authority and responsibility for a given project are clearly defined, and there is no question as to priorities. On the other hand, there is potential for the duplication of activities within a firm, which can be quite costly. The emphasis is on individual projects in this structure, as compared with the overall functional approach illustrated in Figure 7.2. Some of the advantages and disadvantages of product-line/project structures are presented in Figure 7.7.

7.4.3 Matrix Organization Structure

The matrix organizational structure is an attempt to combine the advantages of the pure functional organization and the pure project organization. In the functional organization, technology is emphasized and project-oriented tasks, schedules, and time constraints are often sacrificed. In the pure project structure, technology tends to suffer, because there is no single group responsible for its planning and development of such! Matrix management is an attempt to acquire the greatest amount of technology,

Advantages
1. The lines of authority and responsibility for a given project are clearly defined. Project participants work directly for the project manager, communication channels within the project are strong, and there is no question as to priorities. A good project orientation is provided.
2. There is a strong customer orientation, a company focal point is readily identified, and the communication processes between the customer and the contractor are relatively easy to maintain. A rapid response to customer needs is realized.
3. Personnel assigned to the project generally exhibit a high degree of loyalty to the project, there is strong motivation, and personal morale is usually better with product identification and affiliation.
4. The required personnel expertise can be assigned and retained exclusively on the project without the time sharing that is often required in the functional approach.
5. There is greater visibility relative to all project activities. Cost, schedule, and performance progress can be easily monitored, and potential problem areas (with the appropriate follow-on corrective action) can be identified earlier.

Disadvantages
1. The application of new technologies tends to suffer without strong functional groups and the opportunities for technical interchange between projects. As projects go on and on, those technologies that are applicable at project inception continue to be applied on a repetitive basis. There is no perpetuation of technology, and the introduction of new methods and procedures is discouraged.
2. In contractor organizations where there are many different projects, there is usually a duplication of effort, personnel, and the use of facilities and equipment. The overall operation is inefficient and the results can be quite costly. There are times when a completely decentralized approach is not as efficient as centralization.
3. From a managerial perspective, it is difficult to effectively utilize personnel in the transfer from one project to another. Good qualified workers assigned to projects are retained by project managers for as long as possible (whether they are being effectively utilized or not), and the reassignment of such personnel usually requires approval from a higher level of authority, which can be quite time-consuming. The shifting of personnel in response to short-term needs is essentially impossible.
4. The continuity of an individual's career, growth potential, and opportunities for promotion are often not as good when he or she is assigned to a project for an extended period of time. Project personnel are limited in terms of opportunities to be innovative relative to the application of new technologies. The repetitiousness of tasks sometimes results in stagnation.

Figure 7.7 A project/product-line organization–advantages and disadvantages.

consistent with project schedules, time and cost constraints, and related customer requirements. Figure 7.8 presents a typical matrix organization structure.

Each project manager reports to a vice president, has the overall responsibility, and is accountable for project success. At the same time, the functional departments are responsible for maintaining technical excellence and for ensuring that all available technical information is exchanged between projects. The functional managers, who also report to a vice president, are responsible for ensuring that their personnel are knowledgeable of the latest accomplishments in their respective fields.

The matrix organization, in its simplest form, can be considered as being a two-

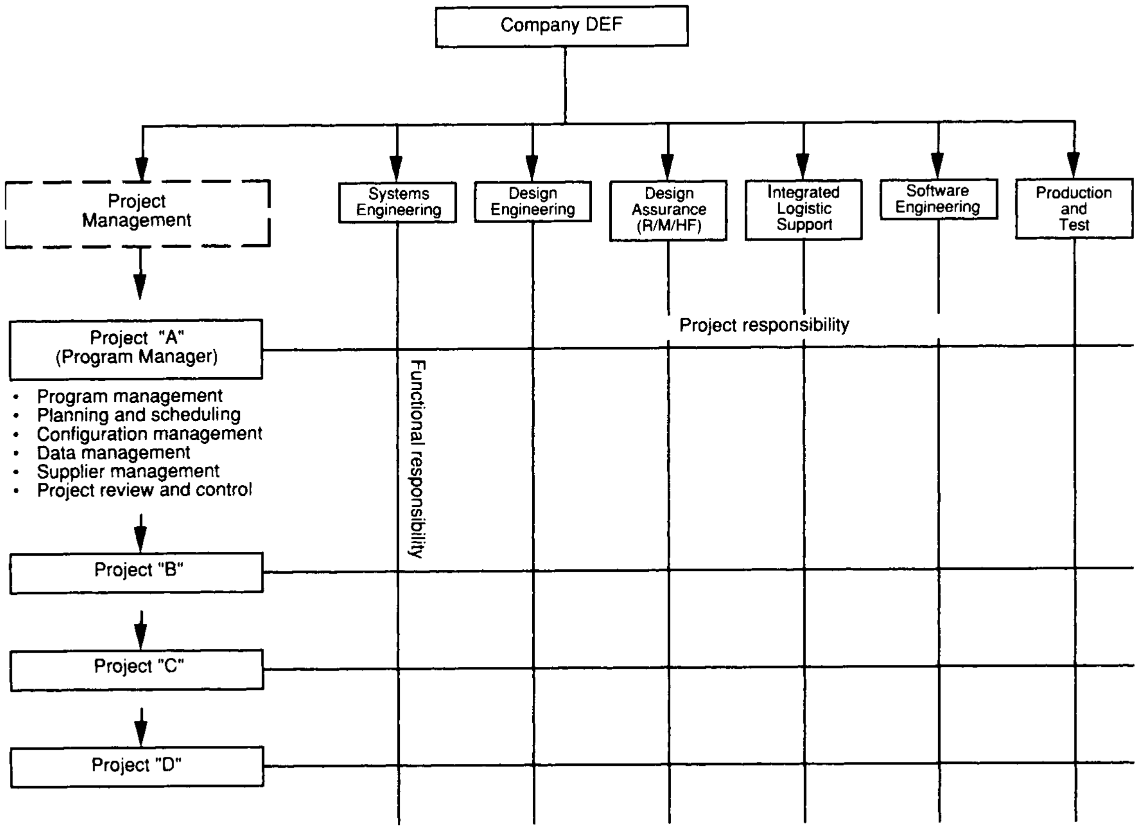

Figure 7.8 Pure matrix organization structure.

dimensional entity, with the projects representing potential profit centers and the functional departments identified as cost centers. For small industrial firms, the two-dimensional structure may be the preferred organizational approach because of the flexibility allowed. The sharing of personnel and the ability to shift back and forth are often inherent characteristics. On the other hand, for large corporations with many product divisions, the matrix becomes a multidimensional structure.

As the number of projects and functional departments increases, the matrix structure can become quite complex. To ensure success in implementing matrix management, a highly cooperative and mutually supportive environment must be created within the company. Managers and workers alike must be committed to the objectives of matrix management. A few key points follow:

1. Good communication channels (vertical and horizontal) must be established to allow for a free and continuing flow of information between projects and the functional departments. Good communications must also be established from project to project.

2. Both project managers and functional department managers should participate in the initial establishment of companywide and program-oriented objectives. Further, each must have an input and become involved in the planning process. The purpose is to help ensure the necessary commitment on both sides. In addition, both project and functional managers must be willing to negotiate for resources.

3. A quick and effective method for conflict resolution must be established, to be used in the event of disagreement. A procedure must be developed with the participation and commitment of both project and functional managers.

4. For personnel representing the technical functions and assigned to a project, the project manager and the functional department manager should agree on the duration of assignment, the tasks to be accomplished, and the basis on which the individual(s) will be evaluated. The individual worker must know what is to be expected of him or her, the criteria for evaluation, and which manager will be conducting the performance review (or how the performance review will be conducted). Otherwise, a "two-boss" situation (each with his or her own objectives) may develop, and the employee will be caught in the middle.

The matrix structure provides the best of several worlds: that is, a composite of the pure project approach and the traditional functional approach. The main advantage pertains to the capability of providing the proper mix of technology and project-related activities. At the same time, a major disadvantage relates to the conflicts that arise on a continuing basis as a result of a power struggle among project and functional managers, changes in priorities, and so on. Further advantages and disadvantages are noted in Figure 7.9.

7.4.4 Integrated Product and Process Development (IPPD)

With the objectives of concurrent engineering in mind, the Department of Defense (DOD) initiated the concept of *Integrated Product and Process Development* (IPPD) in the mid-1990s. IPPD can be defined as "a management technique that simultane-

Advantages
1. The project manager can provide the necessary strong controls for the project while having ready access to the resources from many different function-oriented departments.
2. The functional organizations exist primarily as support for the projects. A strong technical capability can be developed and made available in response to project requirements in an expeditious manner.
3. Technical expertise can be exchanged between projects with a minimum of conflict. Knowledge is available for all projects on an equal basis.
4. Authority and responsibility for project task accomplishment are shared between the project manager and the functional manager. There is mutual commitment in fulfilling project requirements.
5. Key personnel can be shared and assigned to work on a variety of problems. From the company top-management perspective, a more effective utilization of technical personnel can be realized and program costs can be minimized as a result.
Disadvantages
1. Each project organization operates independently. In an attempt to maintain an identity, separate operating procedures are developed, separate personnel requirements are identified, and so on. Extreme care must be taken to guard against possible duplication of efforts.
2. From a company viewpoint, the matrix structure may be more costly in terms of administrative requirements. Both the project and the functional areas of activity require similar administrative controls.
3. The balance of power between the project and the functional organizations must be clearly defined initially and closely monitored thereafter. Depending on the strengths (and weaknesses) of the individual managers, the power and influence can shift to the detriment of the overall company organization.
4. From the perspective of the individual worker, there is often a split in the chain of command for reporting purposes. The individual is sometimes "pulled" between the project boss and the functional boss.

Figure 7.9 A matrix organization–advantages and disadvantages.

ously integrates all essential acquisition activities through the use of multidiscipline teams to optimize the design, manufacturing, and support processes."[4] The concept promotes the communications and integration of the key functional areas as they apply to the various phases of program activity from conceptual design through detail design and development. Although the specific nature of the activities involved

[4]DOD 5000.2-R, *Mandatory Procedures for Major Defense Acquisition Programs (MDAPS) and Major Automated Information System (MAIS) Acquisition Programs*, (Washington DC: Office of the Secretary of Defense).

and the degree of emphasis exerted will change somewhat as system design and development evolves, the concept conveyed in Figure 7.10 is maintained throughout to ensure the appropriate integration. In this regard, the concept of IPPD is directly in line with system engineering objectives; that is, to cause the integration of the various features of design and the organizations involved in the design process.

7.4.5 Integrated Product/Process Teams (IPTs)

Inherent within the IPPD concept is the establishment of *Integrated Product Teams* (IPTs), with the objective of addressing certain designated and well-defined issues.[5] An IPT, constituting a selected team of individuals from the appropriate disciplines, may be established to investigate a specific segment of design, a solution for some outstanding problem, design activities that have a great impact on a high-priority TPM, and so on. The objective is to create a *team* of qualified individuals that can effectively work together to solve some problem in response to a given requirement. Further, there may be a number of different teams established to address issues at different levels in the overall system hierarchical structure; that is, issues at the system level, subsystem level, and/or component level. As shown in Figure 7.10, an IPT may be established to concentrate on those activities that significantly impact selected *performance* factors, *cost of ownership,* and *configuration management.* There may be another IPT assigned to "track" the *integrated data* environment issue. The objective is to provide the necessary emphasis in critical areas and to reap the benefits of a *team* approach in arriving the best solution possible.

IPTs are often established by the program manager or by some designated high-level authority in the organization. The representative team members must be well qualified in their respective areas of expertise, empowered to make on-the-spot decisions when necessary, proactive relative to team participation, success-oriented, and resolved to addressing the problem assigned. The program manager must clearly define the objectives for the team, the expectations in terms of results, and the team members must maintain a continuous "up-the-line" communications channel. The longevity of an IPT will depend on the nature of the problem and the effectiveness of the team in progressing toward meeting its objective. Care must be taken to avoid the establishment of too many teams, as the communication processes and interfaces become too complex when there are many teams in place. In addition, there often are conflicts when it comes to issues of importance, and a critical issue may be "traded off" as a result. Further, as the team ceases to be effective in accomplishing its objectives, it should be disbanded accordingly. An established team that has outlived its usefulness can be counterproductive.

7.4.6 System Engineering Organization

Sections 7.4.1 through 7.4.5 provide an overview of the major characteristics of the functional, project, and matrix organization structures. Some of the advantages and

[5] "IPT" is also used as a designator for *Integrated Process Team.* Another term used in a similar context is *Process Action Team* (PAT).

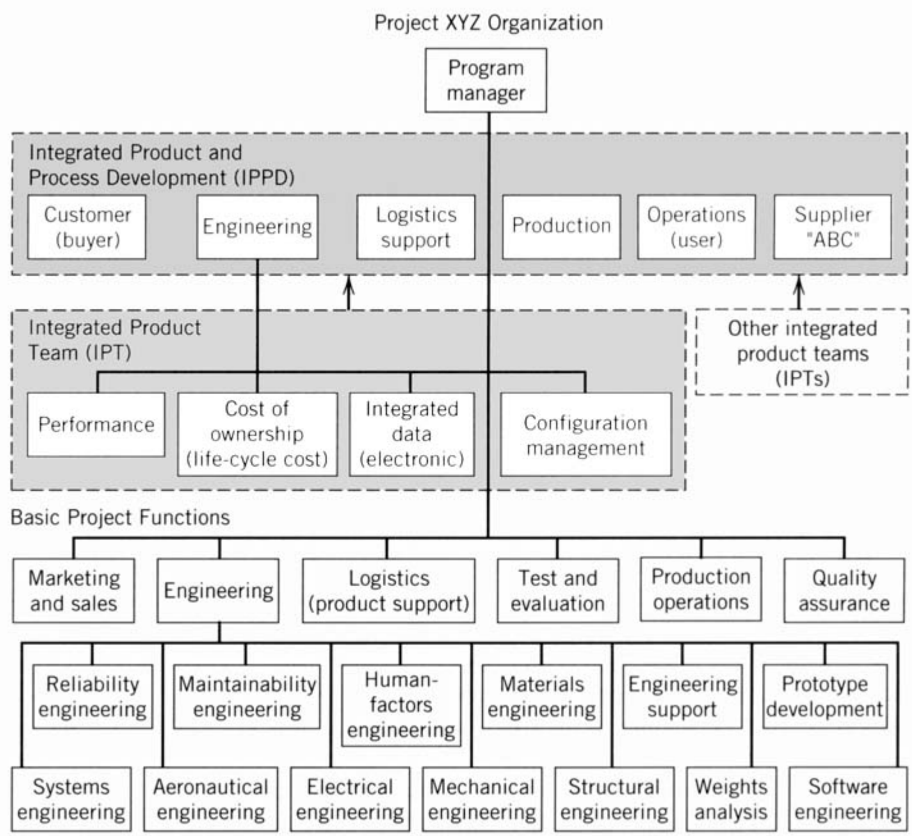

Figure 7.10 Functional organization structure showing IPPD/IPTs.

disadvantages of each are identified. It is important to thoroughly understand and have these characteristics in mind in developing an organizational approach involving system engineering. More specifically, in considering system engineering objectives, the following points should be noted:

1. The function of system engineering must be oriented to the objective of bringing a system into being in an effective and efficient manner. In this regard, there is a natural close association with the project type of organizational structure. System engineering is heavily involved in the initial establishment of requirements and in the follow-on integration of design engineering and supporting activities throughout system development, production, and operational use. System engineering influences design to a significant degree, and this is best accomplished through a project organizational structure.

2. The nature of the system engineering function, its objectives in terms of design integration, its many interfaces with other program activities, and so on, require the

existence of good communication channels (both vertically and horizontally). The personnel within the system engineering organization must maintain effective communications with all other project organizational elements, with many different functional departments, with a variety of suppliers, and with the customer. These requirements are facilitated through the project organization approach.

3. The successful fulfillment of system engineering objectives requires the specification of technical requirements for the system, the conductance of trade-off studies, the selection of appropriate technologies, and so on. Personnel within the system engineering organization must be current (i.e., up to date) relative to the latest technology applications and/or must have access to technical expertise in the appropriate disciplines. A strong technical thrust is required, and good communications must be established with the functional departments (as applicable). Thus, the preferred organization structure should include selected functional elements, in addition to the project orientation.

Although the implementation of system engineering requirements can actually be fulfilled through any one of a number of organizational structures, the preferred approach should respond to these three major considerations. It appears that the best organizational structure includes a combination of project requirements and functional requirements. Although a major *project* orientation is required in response to customer needs, a *functional* orientation is necessary to ensure consideration of the latest technology applications. The combined project-functional organization approach may vary somewhat, depending on the size of the industrial firm. For a large firm, the organization structure illustrated in Figure 7.11 may be appropriate. Project activities are relatively large in scope (and in personnel loading), with supporting functional activities covering selected areas of expertise where centralization is justified. For smaller firms, the functional departments are relatively large, and they provide support to individual projects according to demand. This support is assigned on a task-by-task basis. Figure 7.12 illustrates an organizational structure in which the emphasis is on the functional end of the spectrum. In essence, the degree of "project" emphasis and "functional" emphasis often shifts back and forth, depending on both the size of the firm and the nature of the activity; that is, whether conceptual design, preliminary system design, or detailed design and development activities are in progress.

As shown in the figures, there may be a variety of approaches within the same firm. One or two large projects may exist along with numerous smaller projects. The large projects will tend to support an organizational structure similar to that presented in Figure 7.11, whereas the smaller projects will likely follow the format in Figure 7.12. Where the larger projects can afford to support significant numbers of personnel on a full-time basis, the smaller projects may be able to support a select number of individuals on only a part-time basis. The specific requirements are dictated through the generation of program tasks by the project organization; that is, a request for assistance is initiated by the project manager, with the task(s) being completed within the functional department.

Project size will vary not only with the type and nature of the system being developed, but also with the specific stage of development. A large-scale system in the

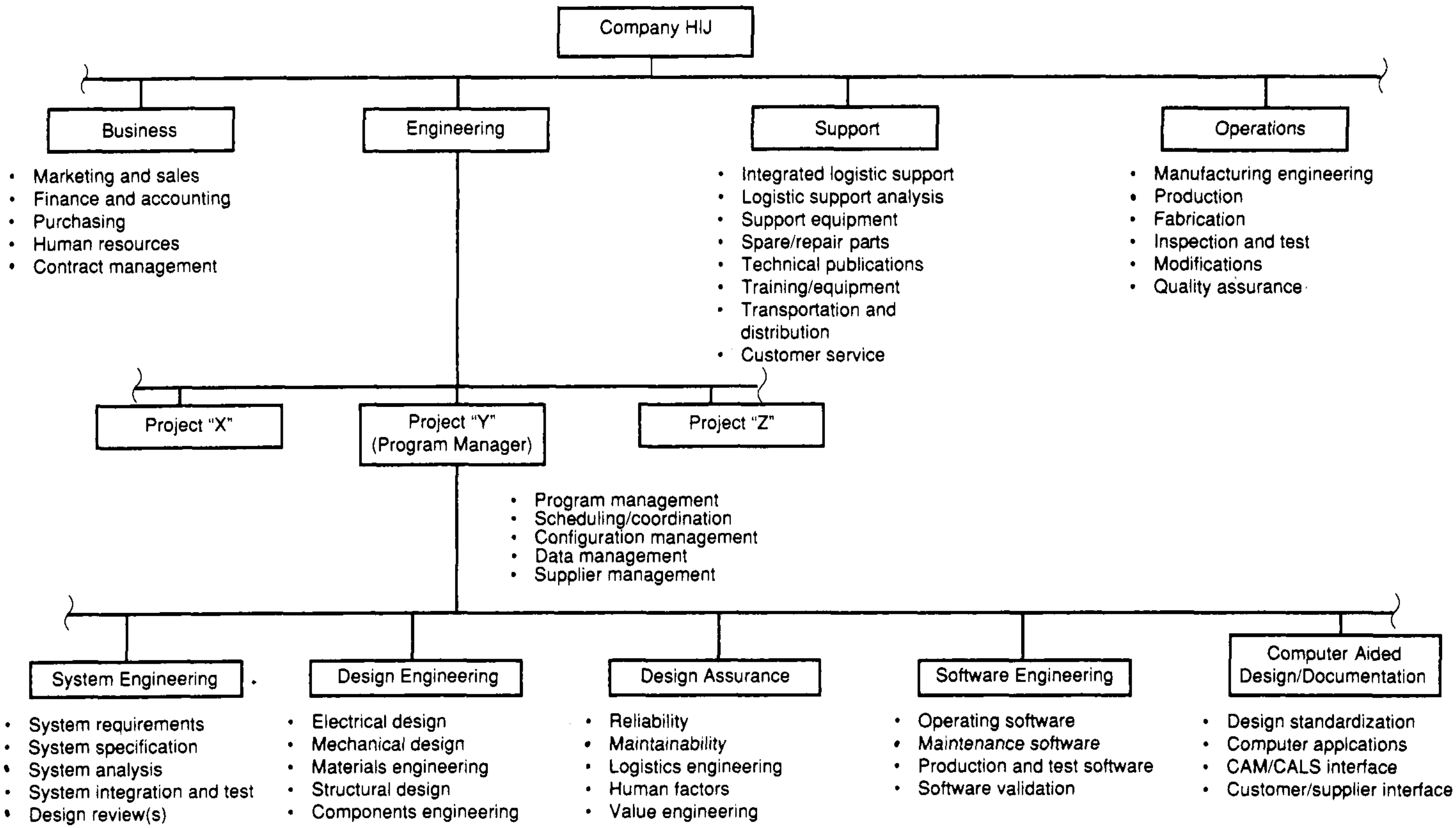

Figure 7.11 Producer organization (combined project-functional structure).

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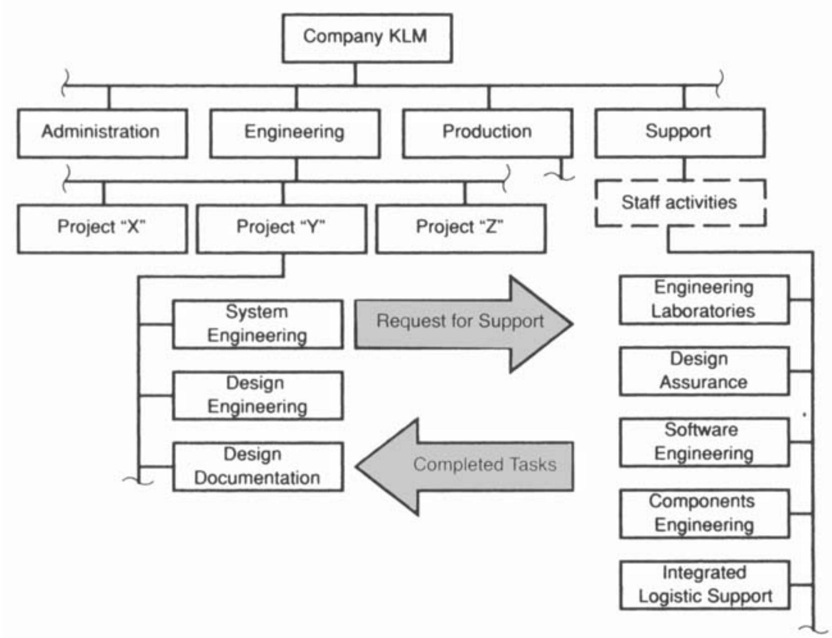

Figure 7.12 Producer organization (work flow).

early stages of conceptual design may be represented by a small project organization, as shown in Figure 7.12. As system development progresses into the phases of preliminary system design and detail design and development, the organization structure may shift somewhat, replicating the configuration in Figure 7.11. In other words, the characteristics and structures of organizations are often dynamic by nature. The organization structure must be adapted to the needs of the project at the time, and these needs may shift as system development evolves.

In regard to system engineering, the tasks identified in Figure 6.6 (Chapter 6) can be allocated by phase as follows:[6]

1. *Conceptual design phase:*
   (a) Perform needs analysis and conduct feasibility studies.
   (b) Define operational requirements, the system maintenance concept, technical performance measures (TPMs), and accomplish system-level functional analysis.
   (c) Accomplish system integration.
   (d) Prepare the System Specification (Type "A").

[6]It is not intended to imply that the system engineering organization does everything. The emphasis here is on providing a *technical* thrust and assuming a *technical* leadership role in the design and development of the system. The project/program manager must, of course, provide the necessary leadership from the overall organizational standpoint.