

PART I

OVERVIEW

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SYSTEMS, PROJECTS, AND MANAGEMENT

1.1 INTRODUCTION

This is a book about management, with emphasis on managing the design, development, and engineering of systems. It addresses two primary questions:

1. What does the Project Manager (PM) need to know?
2. What does the Chief Systems Engineer (CSE) need to know?

The focus is therefore on the essentials of what the PM and CSE must master in order to be successful in building various types of systems and managing project teams.

This chapter is largely introductory, dealing with the preliminary definitions of systems and projects, problems encountered in building systems, the systems approach, key managerial responsibilities, and organizational matters that significantly impact the way in which systems are planned, designed, and constructed.

1.2 SYSTEMS AND PROJECTS

There are many definitions of systems, one of which is simply that “a system is any process that converts inputs to outputs” [1.1]. We look here at systems by example and, for that purpose, start by examining a radar system. This is certainly a system, performing the functions of search and tracking of objects

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in space, as in an air route or surveillance radar at or near an airport. A system normally has functions that it carries out (such as search and tracking), and it does so by means of its subsystems. At the same time, such airport radar systems, together with other systems (such as communications and landing systems), are part of a larger system known as an air traffic control (ATC) system. Examined from the perspective of an air traffic control system, the radar systems actually serve as subsystems of the larger system. In the same vein, the air traffic control system may be regarded as a subsystem of a larger national aviation system (NAS) that consists also of airports, air vehicles, and other relatively large systems (e.g., access/egress) in their own right.

Our view of systems, therefore, is rather broad. In the preceding context, the radars, air traffic control, and national aviation system are all systems. Such systems normally are composed of hardware, software, and human elements, all of which must interoperate efficiently for the overall system to be effective. We adopt this broad perspective in the definition of systems, drawing on examples that affect our everyday life, such as automobile systems, telephone systems, computer systems, heating and cooling systems, transit systems, and information systems.

Projects are formal enterprises that address the matter of designing and developing the various systems just cited. A project is an assemblage of people and equipment, and it is normally managed by a Project Manager (PM). Project personnel work toward satisfying a set of goals, objectives, and requirements, as set forth by a customer. Projects may also have a limited scope of work, dealing only with, for example, the design phase of a system, rather than its construction or entire life cycle. The success of a system is dependent on the skills of the people on a project and how well they are able to work together. Ultimately, the success, or lack of it, is attributed to the many skills that the PM is able to bring to bear in what is often an extremely complex situation and endeavor. The PM, in short, must not only have considerable technical skills, but must also have a deep understanding of the fine art of management.

1.2.1 Definitions of Systems Engineering

The Chief Systems Engineer (CSE) normally reports to the Project Manager and focuses upon building the system in question. The overall process that the CSE employs is known as *Systems Engineering*, a central theme in this text. We will define Systems Engineering in terms of increasing complexity and detail in various parts of this book, starting here with five relatively simple expressions, namely:

1. As developed by the International Council on Systems Engineering (INCOSE)
2. As articulated by the Department of Defense (DoD)

3. As represented in an earlier text by this author
4. As summarized by the Defense Systems Management College (DSMC)
5. As viewed by the National Aeronautics and Space Administration (NASA)

The INCOSE definition is that Systems Engineering is [1.2]:

An interdisciplinary approach and means to enable the realization of successful systems.

This definition is rather sparse and emphasizes three aspects: “interdisciplinary,” “realization,” and “successful.” Especially for large-scale systems, it is clearly necessary to employ several disciplines (e.g., human engineering, physics, software engineering, and management). Realization simply confirms the fact that systems engineering processes lead to the physical construction of a real-life system (i.e., it goes beyond the formulation of an idea or concept). Finally, our expectation is that by utilizing the various disciplines of systems engineering, the outcome will be a successful system, although this result is certainly not guaranteed.

A definition provided by the Department of Defense (DoD), a strong supporter as well as user of systems engineering as a critical discipline, is that Systems Engineering [1.3]:

Involves design and management of a total system which includes hardware and software, as well as other system life-cycle elements. The systems engineering process is a structured, disciplined, and documented technical effort through which systems products and processes are simultaneously defined, developed and integrated. Systems Engineering is most effectively implemented as part of an overall integrated product and process development effort using multidisciplinary teamwork.

Key words from this definition include: “design and management,” “hardware and software,” “structured, disciplined and documented,” and “overall integrated” effort that involves “multidisciplinary teamwork.” These important notions will be reiterated and expanded upon in later parts of this book.

A third definition, formulated by this author, is that Systems Engineering is an [1.4]:

Iterative process of top-down synthesis, development, and operation of a real-world system that satisfies, in a near-optimal manner, the full range of requirements for the system.

Here, key ideas have to do with “iterative,” “synthesis,” “operation,” “near-optimal,” and “satisfies the system requirements.” Designing and building a system usually involves several loops of iteration, for example, from synthesis

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to analysis, from concept to development, and from architecting to detailed design. The notion of synthesis is emphasized, since the essence of systems engineering is viewed from the perspective of design rather than analysis. Design precedes analysis; if there is no coherent design, there is nothing to analyze. The term “near-optimal” suggests that large-scale systems engineering does not lead to a provably optimal design, except under very special circumstances. The normal cases all involve attempts to find an appropriate balance between a variety of desirable features. Trade-off analyses are utilized to move in the direction of a “best possible” design. Finally, in terms of the basic definition, we find a need to satisfy the full range of requirements for the system. The focus on constructing a system that is responsive to the needs of the user-customer is central to what systems engineering is all about.

The Defense Systems Management College text summarizes Systems Engineering as [1.5]:

An interdisciplinary engineering management process to evolve and verify an integrated, life cycle balanced set of system solutions that satisfy customer needs.

Here, key words emphasize a “management process,” “verification,” a “balanced set of solutions,” and “customer needs.” This definition, therefore, tends to see systems engineering through a “management” prism, requires a balanced set of solutions as well as verification of those solutions, and the satisfaction of what the customer states as a set of needs.

The last definition cited in this chapter is that represented by NASA, namely, that Systems Engineering is [1.6]:

A robust approach to the design, creation and operation of systems.

NASA expands this short explanation by emphasizing:

1. Identification and quantification of goals
2. Creation of alternative system design concepts
3. Performance of design trades
4. Selection and implementation of the best design
5. Verification that the design is properly built and integrated
6. Post-implementation assessment of how well the system meets the stated goals

The above five definitions of systems engineering, in the aggregate, give us a point of departure for our further exploration of systems engineering and the management thereof. We will also see other representations that tend to add further detail and structure to these short-form definitions. For example, Chapter 2 cites several standards that relate to systems engineering. Further,

Chapter 7 defines the thirty elements that this author considers to be the essence of large-scale systems engineering.

1.2.2 System Cost-Effectiveness

The project team, led by the PM and the CSE, are also in search of a *cost-effective* solution for the customer. In order that this concept have real substance, we must be in a position to ultimately quantify both the system cost as well as its effectiveness.

System cost will be approached from a life-cycle perspective. This means that a life-cycle cost model (LCCM) will eventually be constructed, with the following three major categories of cost:

1. Research, development, test, and evaluation (RDT&E)
2. Acquisition or procurement, and
3. Operations and maintenance (O&M)

The latter category, by our definition, will also include the cost of system disposal when it is necessary to do so. System cost will also be viewed as an independent variable, expressed as “cost as an independent variable” (CAIV). The Department of Defense (DoD) sees CAIV as a “strategy that entails setting aggressive yet realistic cost objectives when defining operational requirements and acquiring defense systems and managing achievement of these objectives” [1.3].

System effectiveness will also need to be calculated. One perspective regarding system effectiveness is that it is a function of three factors [1.4]:

1. Availability
2. Dependability
3. Capability

Availability is sometimes called the readiness reliability, whereas dependability is the more conventional reliability that degrades with time into the system operation. Capability is also referred to as system performance. The approach adopted here with respect to effectiveness is somewhat less restrictive, allowing the CSE’s team the flexibility to select those effectiveness measures that are fundamental to the system design as well as of special importance to the customer and user.

System cost-effectiveness considerations may thus be visualized as a graph of effectiveness (ordinate) plotted against total life-cycle cost (abscissa). As such, we see that this type of graph implies that several systems can be built, each representing a “point” on such a plot. Our overall task as architects and designers of systems is to find the point design that is to be recommended to the customer from among a host of possible solutions. This further implies

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that the process will include the exploration of several alternatives until a preferred alternative is selected.

1.2.3 Support for Systems Engineering

Systems engineering has had major supporters over the years, in both methodology as well as applications. In this section we take a brief look at systems engineering perspectives from both the Department of Defense (DoD) as well as the National Aeronautics and Space Administration (NASA).

A few years back, the Deputy Under Secretary of Defense (DUSD) for Acquisition, Technology and Logistics (A,T&L) confirmed a policy of support for systems engineering across the department [1.7]. A key sentence is quoted next:

All programs responding to a capabilities or requirements document, regardless of acquisition category, shall apply a robust SE (systems engineering) approach that balances total system performance and total ownership costs within the family-of-systems, systems-of-systems context.

Eight other notions emphasized in this policy document include:

1. A rigorous SE discipline is needed.
2. We are integrating increasingly complex systems.
3. Programs will formulate an SEP (Systems Engineering Plan).
4. We are attempting to institutionalize SE across all of the DoD.
5. Establish a senior-level SE forum, with participation by a flag officer.
6. Drive good SE practices back into the way we do business.
7. Make SE an important consideration during source selection.
8. Evaluate the adequacy of current policies and procedures and recommend changes where necessary.

The list is certainly a massive endorsement of SE as a key discipline with the DoD. It underscores the belief that a more widespread and rigorous application of SE will lead to better system performance, within schedule and budget. Also, with the large number of people and programs within the DoD, we can see a great need for very large-scale education and training with respect to the numerous elements of systems engineering. The aim of all of this, of course, is to provide “affordable, supportable and above all, capable solutions for the warfighter.”

In 2006, NASA established a set of “Systems Engineering Processes and Requirements” [1.8], promulgated through its Office of the Chief Engineer. From a top-level perspective, and using NASA’s words:

NASA missions are becoming increasingly complex, and the challenge of engineering systems to meet the cost, schedule and performance requirements within acceptable levels of risk requires revitalizing systems engineering. . . .

The engineering of NASA systems requires the application of a systematic, disciplined, engineering approach that is quantifiable, recursive, iterative, and repeatable for the development, operation, maintenance, and disposal of systems integrated into a whole throughout the life cycle of a project or program.

Next we cite eight key points in NASA's approach to documenting a desired set of systems engineering processes [1.8]:

1. Increasing system complexity will be accompanied by the reduction of operations staff;
2. Systems are moving toward increased autonomy;
3. A robust approach is needed to meet NASA objectives;
4. Systems-level thinking is also needed;
5. Common technical processes are critical to implementing NASA products and systems;
6. A revolutionary advancement of SE is essential;
7. NASA must also deal with the implications of past failures;
8. Consistency across the administration is required to meet stated goals.

It is important to recognize that NASA expressed the need for revitalization of all processes with respect to systems engineering. The language in this NASA approach has the ring of urgency as well as determination. This NPR (NASA Procedural Requirements—7123.1) document provides a thrust in the direction of strengthening and applying well-defined processes. Indeed, NASA's overall framework for an improved SE capability includes:

- a. Common technical processes
- b. Tools and methods
- c. Workforce considerations

The 17 items that NASA lists within the common technical processes are of special interest in this text, and are listed here:

System Design Processes

- Requirements Definition Processes
 1. Stakeholder Expectations Definition
 2. Technical Requirements Definition
- Technical Solution Definition Processes
 3. Logical Decomposition
 4. Physical Solution

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- Design Realization Processes
 5. Product Implementation
 6. Product Integration
- Evaluation Processes
 7. Product Verification
 8. Product Validation
- Product Transition Processes
 9. Product Transition

Technical Management Processes

- Technical Planning Process
 10. Technical Planning
- Technical Control Processes
 11. Requirements Management
 12. Interface Management
 13. Technical Risk Management
 14. Configuration Management
 15. Technical Data Management
- Technical Assessment Process
 16. Technical Assessment
- Technical Decision Analysis Process
 17. Decision Analysis

This articulation of key SE processes can be compared with process definitions and discussions provided in Chapters 2 and 7 (e.g., with respect to standards and elements of SE).

Of course, in addition to the DoD, NASA, and other government agencies, outstanding and continuous support has been provided by the International Council on Systems Engineering (INCOSE) [1.9]. This organization of leaders in the field has devoted time and energy to formulate, enhance, and apply the principles of systems engineering to numerous problems that arise in building and managing new and complex systems.

1.2.4 System Errors

In broad terms, all systems are said to exhibit fundamental errors known as Type I and Type II errors. These errors are related to the field of hypothesis testing whereby errors are made by (a) rejecting a hypothesis that is true (Type I error) or (b) accepting a false hypothesis (Type II error). From a

systems engineering perspective, a major task of the CSE's team is to reduce such errors so as to satisfy the system requirements. Three examples of these errors are briefly discussed below.

Many of us have car alarm systems that are intended to go off when an intruder is trying to get into our car. There is an error if and when the alarm does not go off when forced entry is being attempted (Type I). At the same time, we do not wish to be awakened at 3 o'clock in the morning when the alarm goes off from the car in front of our house, without any type of intrusion (Type II error).

On a somewhat larger scale, we have radar systems that are intended to detect targets at specified ranges. When they fail to do so, an error (Type I) has been committed. On the other hand, these systems also claim, from time to time, that a target is present when no such target exists. This latter case (a Type II error) is called a false alarm. These types of errors for a search radar are explored in some detail in later chapters of this text. Specific detection and false alarm probabilities are calculated, and the relationship between them is examined.

On an even larger scale, we have situations presented by our national air transportation system. When the system fails to get you to your destination at the expected time of arrival (ETA), an error has been committed that all of us have experienced. And, if you're trying to get to New York from Washington, and wind up in Philadelphia due to bad weather, the system is delivering an unintended result.

Whether a system is large or relatively small, many times errors are the reason for failure of all or a part of the system. Therefore, often it is critical to *define and control* the most significant errors that might occur. To do so, usually an *error model* is constructed that:

- a. Identifies all primary error sources, as well as their likely magnitudes.
- b. Establishes mathematical relationships between these error sources.

If the errors can be shown to be independent and additive, often we can make good use of a well-known relationship from elementary probability theory: the variance of a sum is equal to the sum of the variances (of random variables). By definition, the square root of the variance is the standard deviation, which is designated as "sigma". Then we continue to work with the standard deviations to represent the errors in question. Given such an error model, we then must figure out the maximum tolerable errors and how to control (i.e., reduce) the errors to make sure the overall system error budget is not exceeded. As an example, if we are dealing with a shipboard air defense system or a spacecraft that is being placed in a precise orbit, if the error budget is exceeded, it is likely that these types of systems will fail or become severely degraded. The consequences may well be mission failure and loss of life.

One of the more important aspects of error analyses is to decide how to relate the errors defined in the system requirements document to the errors

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in the error model. Specifically, this question must be answered: Does the maximum error requirement correspond to the one-, two-, or three-sigma error (or greater) value? Under fairly general conditions for error modeling and analysis, designing a system for one of these three “assumptions” will result in:

1. An overall system error probability of about 32 percent (plus and minus one-sigma designation)
2. An overall system error probability of about 5 percent (plus and minus two-sigma designation)
3. An overall system error probability of about 0.27 percent (plus and minus three-sigma designation)

A simple one-sigma choice means that it is “allowable” for the overall system to fail about one third of the time. This is certainly not a recommended approach, and systems engineers must understand this issue in order to design the system properly. The issue is also directly related to the “six-sigma” notion that has been applied by numerous enterprises pursuing a specific high-quality approach to delivering products and services. More about error analyses will be presented in chapters eight and eleven, along with numerical examples.

Understanding when systems are likely to fail to do what they’re supposed to do, and also do what they’re not supposed to do, is often a central theme of the systems engineering activities. These, of course, can be expressed as problems that need to be solved by the management and technical personnel working on the system. At the same time, there are many problems that might be considered chronic issues when managing an engineering project. A sample of such problems is presented and discussed in the next section.

1.3 PROBLEMS IN MANAGING ENGINEERING PROJECTS

An article in the *Washington Post* [1.10] described an industry contract with the Federal Aviation Administration (FAA) in the terms “out-of-control contract” and “how a good contract goes sour.” It went on to describe how a “cure letter” was sent to the contractor saying that “delays in a \$4 billion contract to modernize the computers used in the nation’s air traffic control system were unacceptable.” Although this admonition pointed to delays and therefore could be connected to not getting the work done on time, it is likely that time delays resulted from performance issues and were also related to the cost of the program. In general terms, problems that surface on a typical project usually show themselves ultimately in terms of three main features:

1. Schedule (time)
2. Cost (as compared with the original budget)
3. Performance

These are the “big three” of project management and systems engineering management. Projects are originally planned to meet the performance requirements within the prescribed time and budget constraints.

Although there are numerous reasons why projects do not satisfy these three key aspects of a system development [1.11, 1.12, 1.13], several of the most common such reasons are:

1. Inadequate articulation of requirements
2. Poor planning
3. Inadequate technical skills and continuity
4. Lack of teamwork
5. Poor communications and coordination
6. Insufficient monitoring of progress
7. Inferior corporate support

The following discussion expands on these reasons for problems and lack of success.

1.3.1 Inadequate Articulation of Requirements

Requirements for a system are normally defined by the customer for the system and are at times referred to as “user” requirements. Such systems can be completely new or they can represent upgrades of current systems. Especially if they are new, the customer often has difficulty in expressing these requirements in a complete and consistent fashion, and in terms that can be utilized by a system developer. It is also the case that it may be simply too early to understand all system requirements. Poor requirements invariably lead to poor system design. This situation remains a problem if the requirements cannot be negotiated and modified for various contractual reasons. Both users and developers complain about requirements, but from their own perspectives. They agree that something new has to be done regarding how requirements are defined and satisfied and several proposals have been made (such as the “spiral model” for software development) to improve the situation. Flexibility is called for in contractual situations that can be quite formal and unyielding. Project Managers must keep this high on their list of potential problem areas.

1.3.2 Poor Planning

Projects normally follow a “project plan” written at the initiation of a project. The ingredients of such a plan are described in detail in Chapter 3. Such plans often are “locked in” as part of a proposal and cannot be easily modified from the point of view of the customer. Because system developments are rather dynamic, most project plans are obsolete 6 to 12 months after they have been

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written. They therefore need to be continually updated to reflect the current understanding and status of the system. Basing communications and future actions on outmoded or nonexistent plans can lead to large amounts of trouble.

1.3.3 Inadequate Technical Skills and Continuity

Many PMs complain that they are not able to access the necessary personnel resources in order to run their projects. In a company setting, there is obvious competition for the best people and some projects suffer simply because they cannot find or hire such people. When they are able to hire from outside the company, even if the new personnel are technically competent, it takes time for them to climb the learning curve in terms of the project itself as well as the corporate culture. Another side of the coin is the loss of key technical capabilities to other “more important” projects in a company or the possibility that various people may just get up and go to another firm. It is critically important for a PM to maintain an excellent technical staff or else face the strong possibility of inadequate technical performance, which will also show up as problems in schedule and cost.

1.3.4 Lack of Teamwork

Even with a cadre of strong technical people, if they do not operate as a team, the project is in jeopardy. The skills of the Project Manager are paramount here, as he or she must be able to forge a spirit of teamwork and cooperation. Today’s systems are very complex and require day-to-day interactions of the members of the project. If these interactions do not take place, or are negative, the project suffers and loses ground. There are times, as well, that a PM must “bite the bullet” with a project person who is not able to be part of a team, preferring instead to be isolated, or act so as to represent a divisive force in a team effort. This should not be tolerated and decisive action is required to solve this type of problem. A variety of issues surrounding how to build a productive team are addressed in considerable detail in Chapter 6.

1.3.5 Poor Communications and Coordination

One of the key skills of a Project Manager, and a leader, is communication. Effective communication is critical both within the project itself and outside the project to supporting company elements (e.g., company management, accounting/finance, contracts, etc.) as well as the customer. Special efforts are required to keep necessary people continually informed about what is going on and why. Surprises as well as insufficient data and lead times can be deadly in a project situation. Project staff are especially sensitive to a PM who does not provide important information and feedback. Some staff require a special amount of “TLC” so that they can perform. Such are the facts of life

in dealing with high-technology engineering projects. Many projects fail for this reason alone. A responsible PM must always be aware of the need for communication and be prepared to spend the time necessary to communicate and coordinate.

1.3.6 Insufficient Monitoring of Progress

For reasons that are not particularly clear, many Project Managers kick off their projects and then let them run “open loop” until a critical project review is scheduled. Peters and Waterman’s “management by walking around (MBWA)” [1.14] is something to keep in mind in this regard. A good PM keeps in touch with people and progress every day, mostly by “walking around” and informally exploring issues, problems, and needs. Even highly competent personnel require monitoring, as long as it is done in an inobtrusive and helpful way. By careful and sensitive monitoring of progress between key milestones, one is able to keep the project on track and avoid disasters during the formal project reviews when both management and customer are present. This is especially true during the early days of a project because one “never gets a second chance to make a good first impression.” Consistent and constructive monitoring and feedback from the beginning set the stage for project success.

1.3.7 Inferior Corporate Support

All organizations are expected to provide assistance and support to the projects that are often the lifeblood of these organizations. Support should be forthcoming from the PM’s boss as well as the various designated support groups such as accounting and finance, contracts, graphics, production, manufacturing, and an assortment of matrixed functional elements (such as mechanical design, electrical design, software engineering, etc.). For example, accounting/finance may be expected to provide project cost reports to the PM and the project team on a periodic basis, such as monthly. If these reports are late or incorrect most of the time, the PM is operating at a distinct disadvantage. The PM should not allow this situation to continue. Although finding solutions to inadequate internal support can be a nontrivial adventure, it is usually worth the time and effort necessary to solve such a problem. However, even a good PM may have to enlist the good offices of line management to do so.

The preceding sections present just seven ways a project can go off track. There are clearly many others. If you are a Project Manager or Chief Systems Engineer, it makes sense to understand these and other problem areas so that you can find solutions before they lead to cost and schedule overruns and inadequate system performance. These key problems can be restated in terms of specific guidance to the Project Manager, as described in Exhibit 1.1:

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Exhibit 1.1: Selected Ways for the PM to Avoid Problems

1. Review and analyze requirements continuously and in detail and raise problems with requirements with your management and, as necessary, with your customer.
2. Prepare the best project plan that you can and update that plan at least once a quarter; make sure that your plan is concise and readable by your project personnel.
3. Do not accept poor technical performers on your project; insist on the best technical talent who meet the highest standards of performance and creativity.
4. Build a high-energy responsive team that is able to communicate freely and solve project problems; discharge personnel that prove to be incorrigible nonteam players.
5. Maintain high standards of open and honest communication and coordination with your boss, other company people, project staff, and the customer.
6. Monitor project status and progress through informal MBWA, being sensitive to the work habits and needs of your people; establish more formal periodic status reviews.
7. Set up efficient and productive support mechanisms within your company or organization so as to maximize the effectiveness of these interactions; insist upon high standards of performance from support organizations.

Most government agencies develop systems and therefore have been struggling with these types of problems for a long time. They often try, therefore, to provide guidance internally and also to contractors as to issues and problems that they have faced in the past. For example, the National Aeronautics and Space Administration (NASA) has been building high-technology systems since its inception and attempted to head off problems by publishing a document called *Issues in NASA Program and Project Management* [1.15]. The contents of this document are as follows:

1. An Overview of the Project Cycle
2. Systems Engineering and Integration (SE&I) Management for Manned Space Flight Programs
3. Shared Experiences from NASA Programs and Project: 1975
4. Cost Control for Mariner Venus/Mercury '73
5. The Shuttle: A Balancing of Design and Politics
6. Resources for NASA Managers

Clearly, NASA is trying to learn from its history, experiences, and mistakes and have its contractors benefit from the past. A relatively new “theory” of

management emphasizes “the learning organization” and proposes methods of assuring that such learning occurs [1.16]. Learning from one’s own as well as another’s errors is a basic rationale for this as well as other books.

1.4 THE SYSTEMS APPROACH

The “systems approach,” at times difficult to define and execute, is basically a recognition that all the elements of a system must interoperate harmoniously, which, in turn, requires a systematic and repeatable process for designing, developing, and operating the system. The architecture for a system must be sound, and it must at least satisfy all the requirements for the system as set forth by the user or customer. By following a systematic and repeatable “systems” process, the developer maximizes the chances that this will be the case.

The key features and results of a systems approach may be stated as follows:

1. Follow a systematic and repeatable process.
2. Emphasize interoperability and harmonious system operations.
3. Provide a cost-effective solution to the customer’s problem.
4. Assure the consideration of alternatives.
5. Use iterations as a means of refinement and convergence.
6. Satisfy all user and customer requirements.
7. Create a robust system.

Figure 1.1 provides an overview of a systems approach, the elements of which are briefly cited in what follows:

Box 1: Requirements. Requirements for the system are defined by the customer and user and become the touchstone for all design and development efforts. These are considered inviolate unless a negotiation leads to changes that should be reflected in all contractual documents. Requirements are normally provided in a formal “requirements” document. At times, a derivative document called a specification is forthcoming from the customer. The specification, however, is often written by the developer.

Box 2: Project Plan. The PM is able to develop a project plan from the statement of requirements. This is a roadmap (discussed in Chapter 3) for the important aspects of the project. If the key members of the project team have been selected, they will work with the PM in order to develop the plan. If not, they must ultimately buy into the plan as defined by the PM, or modify it appropriately.

Box 3: Functional Design of Alternatives. The architectural design of the system operates at the functional level, that is, it concentrates on the functions that the system is to perform in distinction to how these

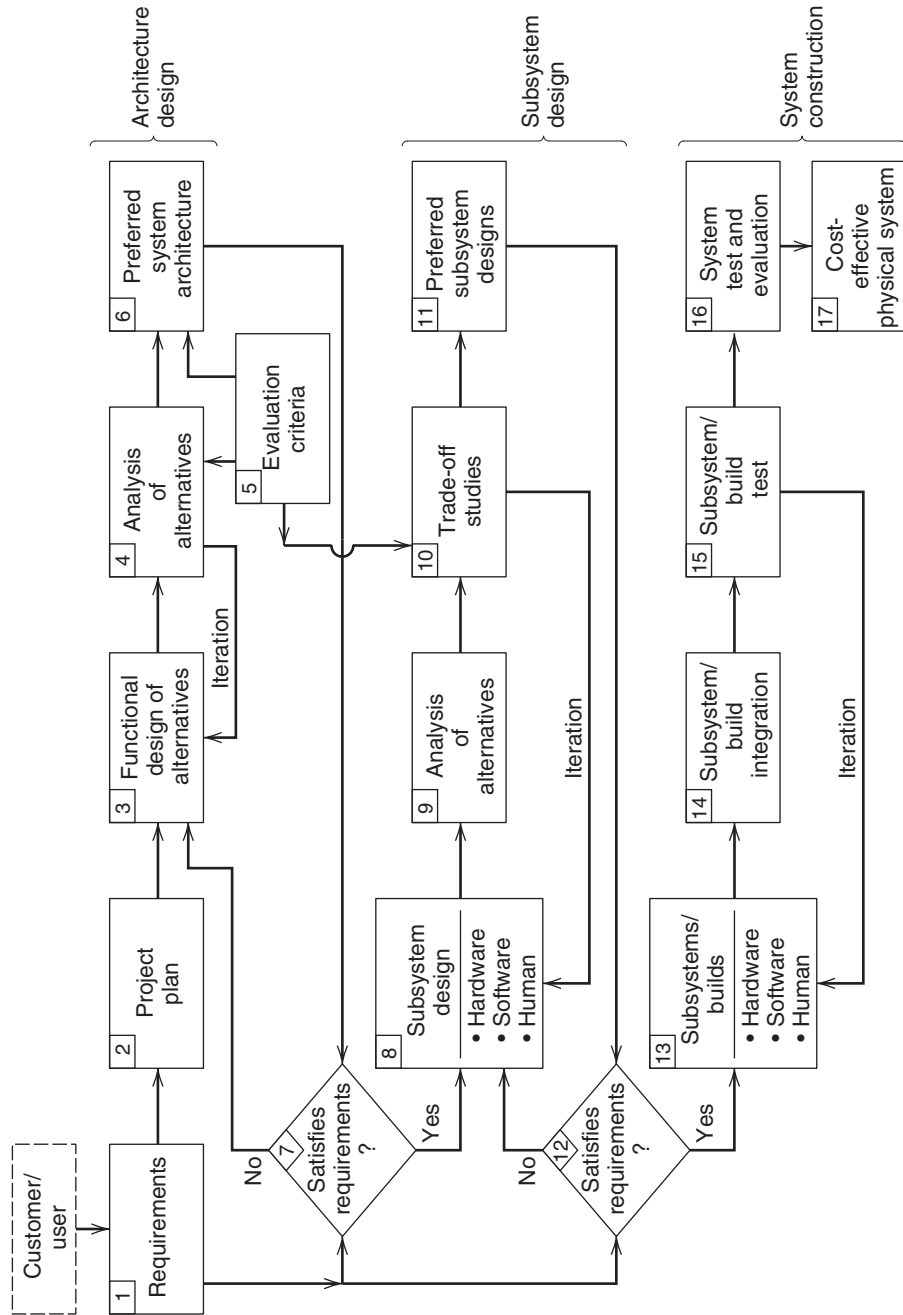


Figure 1.1. Overview of the systems approach.

functions are to be implemented in hardware, software, and human components. Several such designs are configured, each representing a feasible alternative. Often, these alternatives span concepts that range from low cost to high performance.

Box 4: Analysis of Alternatives. Each of the alternatives is analyzed in terms of cost, performance, and satisfaction of requirements. By interacting back and forth between the postulation of alternatives and their analyses, it is ultimately possible to determine the quantitative and qualitative attributes of the various viable alternatives. At the system level, two to four alternatives might be considered desirable.

Box 5: Evaluation Criteria. The analysis of alternatives could not be carried out without the clear identification of criteria against which the alternatives are evaluated. These criteria are derived from the requirements and may include such features as interoperability, growth potential, and societal risk as well as the detailed performance items listed in the requirements document. A formal evaluation framework is normally necessary in order to carry out the evaluation.

Box 6: Preferred System Architecture. This step is a selection of the system-level architecture that is most cost-effective. It represents a choice among the competing alternatives. Many projects go astray because they leap to a preferred architecture without the explicit consideration of alternatives. As an example, this may constitute the selection of time-division multiplexing as preferred over a frequency-division multiplexing approach for a communications system. System architecture is a very important part of the systems approach and the system engineering and design process and is discussed again in Chapter 9.

Box 7: Satisfies Requirements? We make this step explicit in order to emphasize the significance of assuring that the preferred system architecture meets all the designated requirements. If even one mandatory requirement is not completely met, then it is necessary to loop back and consider additional alternatives. If all the key requirements are satisfied, then and only then can the project team move on to the matter of subsystem design.

Box 8: Subsystem Design. By knowing the preferred architecture at the system level, it is then possible to move into detailed subsystem design. These subsystems involve the interplay among hardware, software, and human elements. Subsystems are naturally divided into subordinate elements, which can be called builds, configuration items (CIs), components, or other names that can be mutually understood.

Box 9: Analysis of Alternatives. Following a process similar to that utilized to develop a preferred architecture, alternatives are set forth and analyzed at the subsystem level of design. This is critical because there are numerous ways to implement a given function. Issues of timing and sizing are usually important here.

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Box 10: Trade-Off Studies. A variety of trade-offs are generally considered in trying to optimize at the subsystem level. These may be power–weight–space–performance trades, attempting to find the proper balance of attributes. An iteration loop is shown explicitly to account for the possible need to postulate additional alternative subsystem designs.

Box 11: Preferred Subsystem Designs. Preferred subsystem designs flow from the previous steps, representing near-optimal choices with all relevant factors explicitly considered in the trade-off studies. At this stage of the process, one is still at the design level and the system has not, as yet, been built. There are some exceptions to this, as with the notion of rapid prototyping of subsystems in order to prove certain critical high-risk parts of a system.

Box 12: Satisfies Requirements? We again wish to make explicit the checking of the preferred subsystem designs to assure that all requirements have been met. If not, an iteration loop is shown that means we are “back to the drawing board.” If so, we move on to the physical building of the system.

Box 13: Subsystems/Builds. The physical construction of the subsystems is now in order, occurring for the hardware, software, and human components, and in consonance with the subsystem designs. Builds is used here as a generic name for configuration items, components, subsystems, and so on. The physical construction proceeds through the various levels of indenture defined in the design process.

Box 14: Subsystem/Build Integration. After a given build (or CI) has been constructed, it must be integrated with all interoperating builds (or CIs). This is performed at all subordinate levels of the system.

Box 15: Subsystem/Build Test. Physical testing takes place as builds (CIs) are integrated to assure that they work together, are compatible, and perform as required. If integrated builds fail these tests, the process is iterated until the test leads to success. Clearly, all test plans and procedures must be based on the original or derivative requirements. Many people have suggested, especially with respect to software, that a “build a little, test a little” orientation is most likely to lead to success.

Box 16: System Test and Evaluation. A final system-level test and evaluation (T&E) step confirms that the system meets both development and operational requirements. This can be a long and protracted step, especially for systems that are to operate in a hostile field environment such as aboard a ship or aircraft. It represents an end-to-end check of the full system and a final verification that all requirements have been met.

Box 17: Cost-Effective Physical System. The result of all the previous steps, and many implicit substeps, is a cost-effective physical system.

Although these steps represent most of the elements of the systems approach, there are several that are implicit and therefore are examined in later

chapters. However, this overview explains the key aspects of such an approach. It is intended to lead to a system that meets all requirements and is cost-effective and robust. These terms are examined in the chapters dealing with systems engineering management.

The Project Manager and Chief Systems Engineer are clearly key players in assuring that the systems approach is carried out with discipline and good sense. We now more formally explore their roles and responsibilities in a corporate setting.

1.5 THE PROJECT ORGANIZATION

An illustrative organization chart for a project is shown in Figure 1.2. This chart shows only the project and not the organization in which the project may be embedded, which is addressed later in this chapter.

The Project Manager (PM) is shown at the top of the chart with two other key players, the Chief Systems Engineer (CSE) and the Project Controller (PC). In this book, we strongly suggest that the chief engineer of a project be called the Chief *Systems* Engineer, stressing that the main task of the chief engineer is the systems integrity of the overall system. Some organizational structures might list the lead engineer as the chief engineer and have the systems engineer and systems engineering function in parallel with the other engineering functions such as hardware and software engineering. Some projects might be more limited in scope and therefore not require some of the functions shown. Others might indeed be larger and include additional functions such as manufacturing, production engineering, installation, operations and maintenance, and others. We will now consider the specific responsibilities of the Project Manager, Chief Systems Engineer, and the Project Controller.

1.5.1 Responsibilities of the Project Manager (PM)

Clearly, the Project Manager (PM) has responsibility for the overall project, in all its dimensions. At the top level, this focuses on the schedule, cost, and technical performance of the system. An estimate of the time that a PM might spend on each of these features might be 20% schedule, 30% cost, and 50% performance, assuming that one could divide all job-related activities into these three categories. If one includes purely administrative activities as a fourth category, the percentages might be 15% schedule, 25% cost, 35% performance, and 25% administrative. The last item would include such matters as interviewing personnel, preparing their evaluations, and similar duties.

The classical responsibilities of a PM are usually described in terms of four activities: (1) planning, (2) organizing, (3) directing, and (4) monitoring. Some people use the word “controlling” in place of this alternative of “monitoring,” for which all control is subsumed within the “directing” activity.

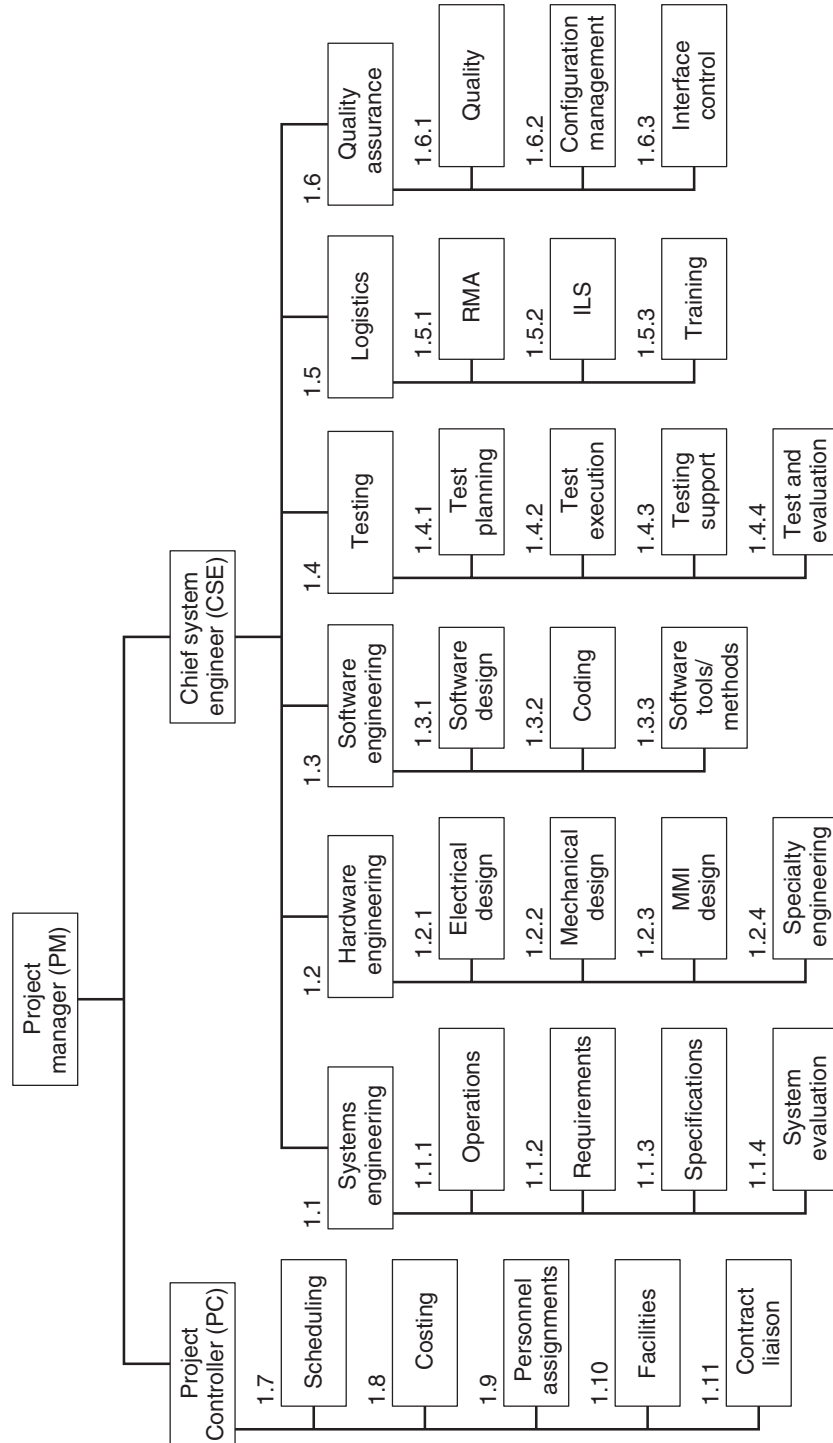


Figure 1.2. Illustrative project organization. RMA = reliability-maintainability-availability; ILS = integrated logistics support; MMI = man-machine interface.

The *planning* activity is dominant in the early stages of a project, especially with respect to the coherent preparation of a project plan. Steady-state planning involves updating this plan and thinking about and planning how to handle special problems and contingencies.

The *organizing* responsibility involves deciding how to organize the project itself (e.g., the chart of Figure 1.2), and reorganizing when and where necessary. It also means the allocation of resources to the various tasks of the project. This shows up as the preparation of initial tasking, work breakdown structures, responsibility matrices for the project, and the like.

The *directing* activity is the formal and informal day-to-day running of the project and its various meetings as well as the delineation of assignments when changes or fine-tuning is required to solve problems.

The *monitoring* duty involves the continuous reading of the status of all aspects of the project in relation to the system requirements and the project plan. If monitoring results in the discovery of problems, remedial action is taken under the directing activity.

An often frustrating factor comes into play when the PM's responsibilities and authority are not congruent. Because the PM usually has full responsibility for the success or failure of the project, it can be extremely difficult if this person cannot, for example, hire or fire, negotiate with outside vendors and subcontractors, and make final arrangements with a counterpart customer. Incommensurate authority is one of the "red flags" of most PMs. A summary list of the various responsibilities and duties of a Project Manager is provided in Exhibit 1.2.

Exhibit 1.2: Selected Duties and Responsibilities of a PM

Cost/Budget

- Confirming that the project can be completed within budget
- Reviewing periodic (e.g., monthly) cost reports
- Obtaining valid cost-to-complete estimates
- Assessing and mitigating project cost risks
- Assuring the validity of system life-cycle costs

Schedule

- Establishing an up-to-date master schedule
- Assuring that all interim milestones are met
- Determining ways to make up time when slippage occurs
- Obtaining valid time-to-complete estimates
- Scheduling internal and customer status reviews

Technical Performance

- Assuring that the system satisfies all technical requirements
- Confirming the validity of the technical approach
- Continuous tracking of technical performance status

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- Installing systems and software engineering methods/practices
- Obtaining computer tools for systems and software engineering

Administrative

- Personnel interviewing, hiring, and evaluation
- Interfacing with corporate management
- Interfacing with internal project support groups
- Coaching and team building
- Assuring the availability of required facilities

1.5.2 Responsibilities of the Chief Systems Engineer (CSE)

As suggested by the organization chart of Figure 1.2, the Chief Systems Engineer (CSE) is the key manager of all the engineering work on the project. Thus, the CSE is both a technical contributor as well as a manager. Indeed, the CSE might well have twice as many direct reports as does the PM.

The CSE, under the PM, assumes primary responsibility for the technical performance of the system. In terms of time allocations, the CSE might experience 15% schedule, 15% cost, and 70% technical performance. The CSE has some administrative responsibilities, largely having to do with the management of the technical team. The CSE is definitely a *systems* engineer and should spend a great deal of energy in finding the correct technical solution for the customer.

The fact that both the PM and the CSE have, to some extent, overlapping responsibilities, suggests that it is critically important that these two people work together productively and efficiently. Friction between these key players will seriously jeopardize project success. They must communicate and share information extremely well, and understand each other's weaknesses and strengths. One-on-one meetings are standard so that potential problems are solved before they might hurt the efforts of the entire team. A summary list of the key responsibilities and duties of the Chief Systems Engineer is shown in Exhibit 1.3.

Exhibit 1.3: Ten Responsibilities and Duties of the Chief Systems Engineer (CSE)

1. Establish the overall technical approach
2. Evaluate alternative architectural system designs
3. Develop the preferred system architecture
4. Implement a repeatable systems engineering process
5. Implement a repeatable software engineering process
6. Oversee use of computer tools and aids
7. Serve as technical coach and team builder
8. Hold technical review sessions

9. Attempt to minimize overall project time period
10. Develop cost-effective system that satisfies requirements

1.5.3 Responsibilities of the Project Controller

The Project Controller (PC) is the third player in the project management triumvirate. The PC has no technical performance responsibilities, focusing instead on schedule, cost, personnel assignment, facilities, and contract liaison issues. Time spent on these matters is estimated as 25% schedule, 45% cost, 10% personnel, 10% facilities, and 10% contract liaison. Cost issues have to do with assuring that the PM and CSE get the cost reports that they need and also that the overall project stays within budgeted costs.

The Project Controller is likely to be the “keeper” of the master schedule for the project, although inputs are obviously required from engineering personnel. The PC need not be an engineer, although an understanding of what engineering does is clearly a requirement. Good PCs can anticipate problems by in-depth analyses of project cost and schedule data. By examining trends and timetables, the PC may be able to spot trouble spots before they are evident to other project personnel. This person therefore can be worth his or her weight in gold, primarily to the PM. A brief citation of some of the PC’s responsibilities and duties is provided in Exhibit 1.4.

Exhibit 1.4: Ten Responsibilities and Duties of the Project Controller (PC)

1. Maintain overall project schedule
2. Assess project schedule risks
3. Assure validity and timeliness of project cost reports
4. Track special cost items (e.g., travel, subcontractors)
5. Develop project cost trends
6. Assess project cost risks
7. Maintain life-cycle cost model for system
8. Verify and maintain personnel assignments
9. Assure that necessary facilities are available
10. Maintain appropriate liaison with contracts department

1.6 ORGANIZATIONAL ENVIRONMENTS AND FACTORS

There are many who claim that the organizational environment in which a project is performed is the critical factor in the ultimate success or failure of a project [1.17]. This item was alluded to earlier under the topic of “inferior corporate support.” We examine this issue here in somewhat greater detail with respect to the particular corporate entities with which the Project Manager (and the Chief Systems Engineer and Project Controller) must interact.

Interactions with project staff, in the main, are reserved for the discussions in Chapters 5 and 6.

1.6.1 Corporate Organizational Structures

Although to a large extent a project has a great deal of internal structural coherence, it exists within a given overall corporate organizational structure. That corporate structure, depending on its configuration and processes, can have major impacts on how well a project is able to function.

In general, it can be said that there are three generic types of corporate structures, as illustrated in Figure 1.3: (a) the functional structure, (b) the project structure, and (c) the matrix structure.

As shown in the figure, the functional structure is organized fundamentally by functional areas such as engineering, marketing, sales, manufacturing, production, and so forth. Projects, as such, either for internal or outside customers, are formed *within* a functional group for the duration of the project and then are dissolved. As projects come and go, the basic functional structure remains. A PM is selected from the functional group that is likely to have the most to do with the project from a functional discipline perspective. Depending upon how high up the PM is in the functional organization, as well as other factors such as the technical scope of work of the project, the PM may have to reach across functional lines to access resources for the project. This can work very well because all functional managers are in the same position of requiring resources from other groups from time to time. Projects therefore can do very well in functionally structured organizations, but only if the functional line management is supportive of project needs and requirements.

Figure 1.3 next shows the “pure” project structure, in which the entire organization consists of a set of projects. This structure is prevalent in service organizations, and especially in professional services contractors that do work for the federal government. In such cases, each contract tends to establish a project, and projects come and go as the contracts under which they are operating are completed without renewals or further work requirements. The PM usually starts a project with key personnel from a project that is phasing down or being completed. Such an overall corporate orientation is conducive to project autonomy and support because it is its only focus. Projects can flourish in that type of environment, but from time to time, they do not have ready access to specialized expertise that might reside in a functional group.

The third type of overall corporate structure shown in Figure 1.3 is the matrix structure. This might be viewed as a hybrid between the previous two forms, with the coexistence of functional groups together with the formal recognition of a project group. In principle, this structural corporate form can provide an ideal mix of the advantages of both project autonomy and functional expertise. However, real-world pressures and competition between project and functional groups can also yield a nonsupportive environment. Theories aside, much of the success of a matrix structure, in terms experienced by the Project Manager, depends on the quality of corporate management.

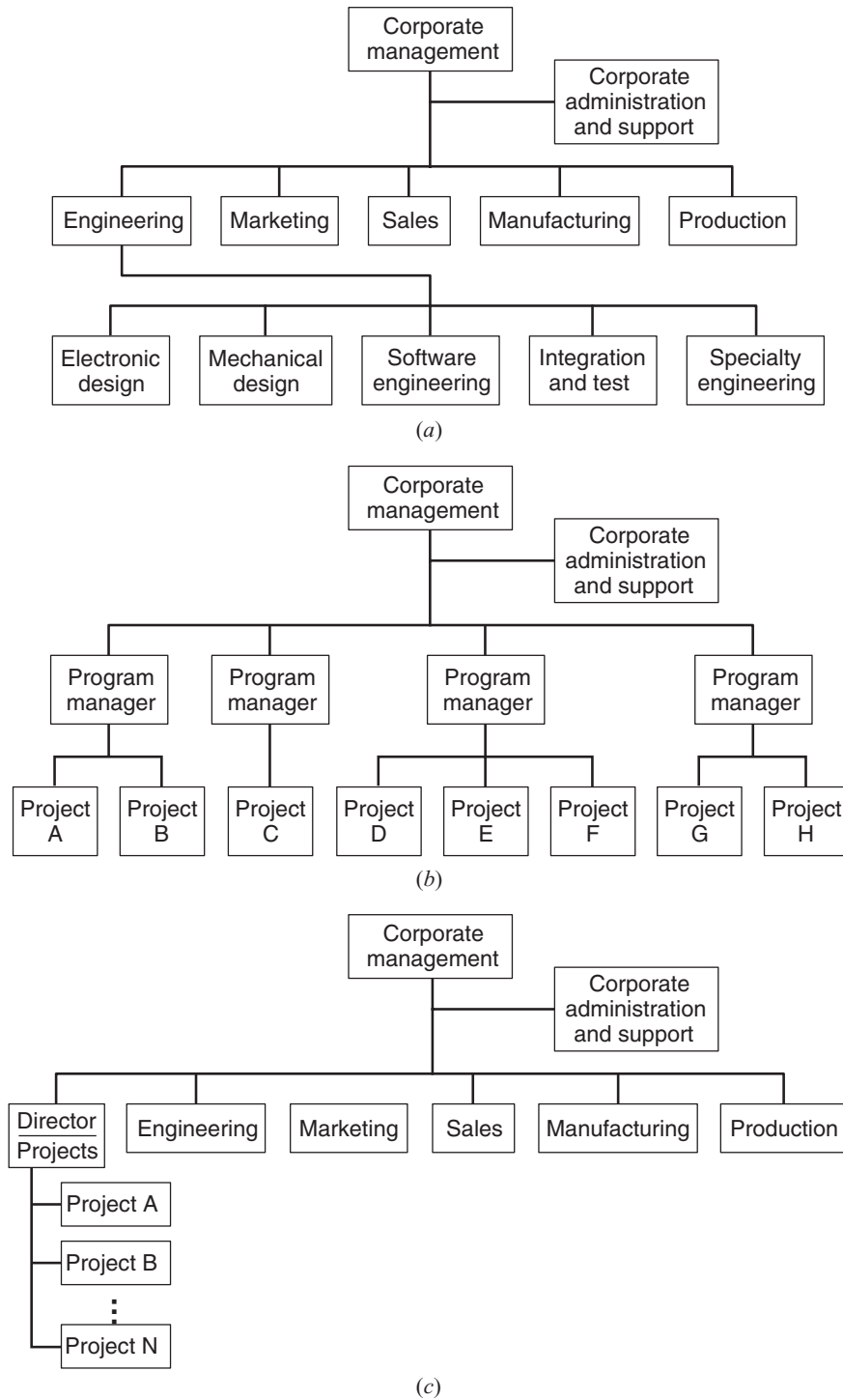


Figure 1.3. Corporate organizational structures.

1.6.2 Interactions with Management

The PM reports “upward” to management, as represented perhaps by a program manager, or a division director, or a vice president. The specific title may be less important than the nature of the relationship between the PM and the boss. A project management position may carry with it the assumption that the PM runs the project, that is, that the PM has full responsibility and authority for the project. This can be true for the former, but in real life is rarely true for the latter. That is, the PM’s authority is limited, and that is a key matter that has to be negotiated between the PM and the boss. Failure to resolve this issue can lead to significant stress for both parties, which will carry over to the CSE, PC, and other members of the project team. Some organizations attempt to recognize and solve this problem through the formal use of an “authority matrix,” which defines the boundaries of authority at the various levels in the organization. Such a matrix might deal with precise definitions of limits with respect to such activities as:

1. Hiring personnel and setting salaries
2. Giving raises and bonuses
3. Negotiating and signing contracts
4. Expenditures of monies for different categories
5. Signing and verifying time cards and charges
6. Negotiating with customers

In the absence of a culture that requires such matrix definitions, it falls to the two parties, the PM and the boss, to negotiate a working relationship. If you are a PM, or aspire to be one, you should seriously consider how to begin a dialogue with your boss with respect to your authority and lack of it. A good working understanding is crucial to the success of the project.

1.6.3 Interactions with Matrixed Functional Managers

Depending on the organizational structure of the enterprise at large, it may be necessary to interact with matrixed functional managers so as to obtain resources, the principal one of which is people. Especially in large organizations, there are managers of software engineering, or electronic engineering, or mechanical engineering groups. If a PM needs three software engineers for the project, the corporate culture may call for requesting such persons from the head of the software engineering group or department. This involves interviews with candidates, selections of the best persons for the job, conflicts with current assignments, and ultimately commitments of people for various specific lengths of time. Depending as well on the circumstances (e.g., the project load and level of business) as well as the people and personalities involved, this interaction may be easy or it may be difficult. If a PM cannot get

satisfaction in terms of obtaining the necessary commitments of the right personnel, it may be necessary to work up the chain of command and across to the functional manager chain of command at a higher level than the PMs counterpart. Such are the necessary vagaries of working “across the company” in order to secure the needed project personnel and support. Much of this can be avoided if the PM has a go-ahead to hire, but the well-run organization will almost always have an eye out for borrowing or transferring people from one group to another to maximize productivity for the enterprise at large.

1.6.4 Interactions with Accounting/Finance

Another kind of interaction occurs when an accounting/finance group has responsibility for project cost accounting, and this group does not report to the PM. This is a very common situation, calling for an early understanding of what types of reports will be provided to the project management team.

The centerpiece of such reports is likely to be project cost reports, which define the costs expended to date, and during the last reporting period (e.g., month), by various categories of cost (e.g., direct labor, overhead, and general and administrative costs). The PM may designate the Project Controller as the point of contact in obtaining the required cost reports with the desired format and frequency. A smooth interaction in this regard that works effectively is considered critical to the success of the project. No project can be run efficiently without timely and accurate cost information.

1.6.5 Interactions with Contracts

As with accounting and finance, most organizations have a contracts department that does not report to the PM. Thus, a linkage has to be established with certain contracts personnel in order to understand the precise requirements of the contract, provide all the necessary contract deliverables, and, when appropriate, negotiate modifications to the contract. Various types of contracts (e.g., cost type vs. fixed price vs. time and materials) will be handled by a PM in different ways. Contract provisions may allow certain costs to be traded without contracting officer approval, or they may not. Certain contracts have limits on expenditures by category (e.g., use of travel or consultant fees), and so forth. The PM must thoroughly understand these types of contract provisions in order to effectively manage the project. The PC may also be utilized by the PM as the primary point of contact with contracts so as to conserve the time demands on the PM but still have a solid and constructive interaction. PMs who neglect this relationship are headed for trouble.

1.6.6 Interactions with Marketing/Sales

For purposes of this discussion, we can consider two circumstances. For the first, the company is primarily focused upon developing products to sell to

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other businesses or to the public at large (e.g., consumer products), and for the second, the company does most of its system development under a contract with a specific customer. We call the first case “commercial” and the second “contract.”

In the commercial case, marketing/sales has the task of trying to figure out what types of which products should be made, and for what classes of customers. When they have made such a determination, they then establish a requirement that engineering make the selected products, including the features that are considered most desirable. Timetables are also established and a project is up and running to meet these needs. Thus, there is a direct link between the project and sales/marketing such that the requirements for the system (product) in question are determined by the marketing/sales staff. The vagaries of the marketplace often come into play such that the PM, CSE, and PC are under enormous pressure with difficult schedules and performance requirements. In smaller companies and projects, this can lead to twelve-hour-a-day work assignments, due to the usual lack of resources. The project team thus needs to be functioning well, and also needs to stay in constant touch with the marketing/sales people.

In the contract case, as with doing work for federal, state, and local governments, marketing/sales get involved early in talking to the customer and conveying the system requirements to the project team, usually before a request for proposal (RFP) has been written or conveyed. Both the project team and marketing/sales work together in order to shape the proposal response so as to maximize the probability of a win. Once the contract is indeed won, marketing/sales usually shift their focus to the potential follow-on contract, talking to both project team and customer to make sure that the PM, CSE, and PC are considering the future contract as well as the current one. Thus, there is continual contact between the project team and the marketing/sales organization in order to be in a position to make the most competitive bids, and win as many of them as possible.

1.6.7 Interactions with Human Resources

Typically, the Human Resources Department (HRD) focuses upon at least the following:

1. Recruiting in order to satisfy project needs
2. Administering benefit programs (health insurance, etc.)
3. Managing the overall personnel review/evaluation process
4. Recommending salary and total compensation increases
5. Advising on special personnel problems

The need for new people for a project is usually established by the PM and the HRD is tasked to find these people. This is a most critical link in the relationship with the HRD, since without the right people at the right time,

the project risks begin to escalate. Less interaction is required relative to the benefit programs, since they tend to be standard for all employees. Personnel performance reviews are held periodically and guidance is usually given to the PM by the HRD for consistent execution. This leads to salary and compensation increases, which tend to result in at least some unhappy people. This, in turn, might result in the HRD folks working with the PM in order to convey the correct messages to the employees in question. Typically, the PM, CSE, and PC are the most important folks in determining what the compensation will be for each member of the project team. The best results are usually obtained when there is good communication with the Human Resources people.

1.6.8 Interactions with Corporate Information Officer (CIO) Office

The Office of the CIO has, among others, the following responsibilities:

1. Identify information needs of the entire enterprise
2. Focus these needs at the project level
3. Build or acquire the systems in order to satisfy these needs
4. Operate these systems in order to provide support to the various projects
5. Reengineer the systems as the needs change

As suggested earlier in the interactions with Accounting/Finance, there is a critical need for the PM, CSE, and PC to be able to track cost, schedule, and technical performance of the project. The cost information typically comes from accounting/finance, but may have to be converted into a project management format by the CIO office. A well-run organization understands that this highly critical interface issue needs to be worked and resolved successfully. This means that the reports sent to the project team must be timely and accurate. Certain special needs may have to be satisfied, such as cost at the task and subtask levels, and being able to establish “crosswalks” to the project work breakdown structure (WBS), as an example. Schedule information may be captured in a Project Management Software package (such as Microsoft Project). In such a case, project cost information may have to be transferred into such a package in order to analyze and display cost and schedule status charts. In all cases, project people need to provide timely inputs, such as monthly cost to complete and time to complete estimates, usually at the task and activity level.

1.6.9 Interactions with Corporate Technology Officer (CTO) Office

Tasks that are typically carried out within the Office of the CTO are:

1. Identifying technologies that are needed now and into the future by the entire enterprise
2. Relating these technologies to individual programs and projects

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3. Investing in and acquiring the necessary technologies
4. Training project personnel with respect to these technologies
5. Assisting project personnel with technology transfer and insertion in order to provide additional value to the customers as well as a highly competitive position

Interaction with the CTO office can ultimately have a profound effect upon the success of a project, especially the so-called high-tech projects. Such projects are continuously exploring new technologies that will result in superior performance at an affordable cost. If this can be achieved, the project will enhance its chances of success, both immediately and into the future. As we see in the next chapter, a project will often have a requirement to formulate a Systems Engineering Management Plan (SEMP), one of whose elements has to do with technology transitioning. This means that the project must consider and ultimately define how various technologies need to transition from current to future systems.

Another type of technology that is usually needed by a project team can be described by a set of computer-based tools. Computer-Aided Software Engineering (CASE) tools are an example, and they provide the software engineering team the tools that it needs to get its job done. A project team that is provided with superior tools of this type will be able to operate at higher levels of productivity, which will translate into higher efficiency and a better overall result for the customer. Technology of all types can be viewed as discriminators that lead to better solutions, which, in turn, lead to project success.

1.6.10 Interactions with Customers

Finally, but certainly not last in importance, is the matter of interactions with customers. Usually, there is a customer counterpart with whom the PM has direct and day-to-day contact. This is true whether the customer is in the same organization or is an outside client. Although more is discussed on this critical subject in other parts of this book, there is little that is more important than an honest, trusting, and effective relationship with the customer. At the same time, the relationship cannot transcend or violate the terms and conditions of the contract between the two entities. For example, the PM cannot agree to do tasks that are not called for under the scope of work of the contract. All increases or modifications in scope must be handled through formal changes in the contract itself.

Another key factor in customer interaction involves the PM's boss and his or her boss, and so forth up the organization. No PM "owns" the customer; the formal relationship is between corporate groups. A good organization has multiple points of contact up and down the organization. This can be particularly effective when problems occur that cannot be resolved between

the PM and the client counterpart. Relationships up the chain of command can be brought to bear in attempts to resolve difficulties that arise and find solutions acceptable to both parties. The nature and success of a PM's interaction with the customer are affected and supported by bosses up the chain of command. This is yet one more reason for establishing a solid working relationship between a PM and the boss. For better or worse, this relationship can dominate the life of a PM, working smoothly and successfully, or with stress and possible failure.

The effective PM truly sees the Project Manager, Chief Systems Engineer, and Project Controller as a triumvirate that works together on a day-to-day basis to anticipate and respond to the myriad demands of managing a project. It is one of the most difficult jobs, with lots of stumbling blocks and hurdles. The PM must be a highly skilled and competent individual in order to stay focused on the key issues and create a team that moves forward effectively and solves the many problems that invariably arise.

1.7 LARGE-SCALE ORGANIZATION AND MANAGEMENT ISSUES

The focus of this book is upon project and systems engineering management. Some of the above discussion suggests that success or failure of a project depends significantly upon the larger organizational structure within which the project is being carried out. If it is embedded in a highly bureaucratic situation, success becomes more difficult. Examples of such situations, of course, can be found in both industry and government. Large bureaucratic organizations often chip away at problems, but tend not to be able to truly solve them. The reasons for this are varied, but they clearly can affect the PM, CSE, and PC, who are laboring in the trenches, trying to make a difficult problem more tractable.

The federal government, with its large size and tendency toward bureaucracy, is a good example of a set of large-scale organizations (i.e., the various executive departments) that have a wide variety of internal problems that are extremely difficult to solve. One can get some idea as to what these problems are by looking at reports produced on a continuing basis by the General Accountability Office (GAO), whose job it is to investigate problem areas in the executive agencies. Exhibit 1.5 provides a sample listing of some of the reports of the GAO.

Exhibit 1.5: A Sampling of General Accountability Office (GAO) Report Titles

- Defense Transportation: Process Reengineering Could Be Enhanced by Performance Measures
- Managing for Results: Strengthening Regulatory Agencies' Performance Management Practices

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- Management Reform: Elements of Successful Improvement Initiatives
- Department of Energy: Need to Address Longstanding Management Weaknesses
- Executive Guide: Creating Value Through World-Class Financial Management
- Defense Acquisitions: Need to Revise Acquisition Strategy to Reduce Risk for Joint Air to Surface Standoff Missile
- Defense Acquisitions: Comprehensive Strategy Needed to Improve Ship Cruise Missile Defense
- Defense Acquisitions: Improvements Needed in Military Space Systems' Planning and Education
- Defense Acquisitions: Achieving B-2A Bomber Operational Requirements
- Air Traffic Control: FAA's Modernization Investment Management Approach Can Be Strengthened
- Combat Identification Systems: Changes Needed in Management Plans and Structure
- Defense Acquisitions: Advanced Concept Technology Demonstration Program Can Be Improved
- Defense Logistics: Actions Needed to Enhance Success of Reengineering Initiatives
- Internal Revenue Service: Custodial Financial Management Weaknesses
- Information Security: Opportunities for Improved OMB Oversight of Agency Practices
- Defense Information Resource Management (IRM): Critical Risks Facing New Materiel Management Strategy
- Department of Transportation: University Research Activities Need Greater Oversight
- Battlefield Automation: Army Needs to Determine Command and Control Priorities and Costs
- Department of Energy: Management Problems Require a Long-Term Commitment to Change
- Military Satellite Communications: Opportunity to Save Billions of Dollars
- Acquisition Reform: Contractors Can Use Technologies and Management Techniques to Reduce Costs
- Defense Management: Impediments Jeopardize Logistics Corporate Information Management
- Tactical Intelligence: Joint STARS Needs Current Cost and Operational Effectiveness Analysis
- NASA Aeronautics: Impact of Technology Transfer Activities Is Uncertain
- Financial Management: Reliability of Weapon System Cost Reports is Highly Questionable
- Drug Control: Heavy Investment in Military Surveillance Is Not Paying Off

- Simulation Training: Management Framework Improved, But Challenges Remain
- DoD Computer Contracting: Inadequate Management Wasted Millions of Dollars
- Financial Management: IRS Lacks Accountability Over its ADP Resources
- Patent and Trademark Office: Key Processes for Managing Automated Patent System Development Are Weak
- DoD Information Services: Improved Pricing and Financial Management Practices Needed for Business Area
- Information Security: Serious Weaknesses Place Critical Federal Operations and Assets at Risk
- Space Surveillance: DoD and NASA Need Consolidated Requirements and a Coordinated Plan
- Defense IRM: Strategy Needed for Logistics Information Technology Improvement Efforts
- Unmanned Aerial Vehicles: Maneuver System Schedule Includes Unnecessary Risk
- Department of State IRM: Modernization Program at Risk Absent Full Implementation of Key Best Practices
- Air Traffic Control: Complete and Enforced Architecture Needed for FAA Systems
- Tax System Modernization: Imaging System's Performance Modernization Improving But Still Falls Short of Expectations
- Air Traffic Control: Improved Cost Information Needed to Make Billion Dollar Modernization Investment Decisions
- Major Management Challenges and Program Risks: A Governmentwide Perspective

Scanning Exhibit 1.5 we see a variety of problem areas, including:

1. Overall management deficiencies
2. Risks that need to be reduced
3. Costs that are too high or not well enough known
4. Schedules that are not workable
5. Requirements difficulties
6. Need for better performance and effectiveness measurement of systems
7. Need for use of best practices
8. Investment decision issues
9. Overall financial management issues
10. Need for systems reengineering and improvements

These are all familiar themes in the worlds of project management and systems engineering. However, in the context of large-scale organizational issues, they

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may well be beyond the scope of what the PM, CSE, and PC are able to tackle and provide effective solutions for. Indeed, the last-cited item in Exhibit 1.5 offered solution areas for twenty individual federal government agencies, solutions that emphasized the following four areas:

1. Adopting a results orientation
2. Effectively using information technology to achieve program results
3. Establishing financial management capabilities that effectively support decision making and accountability
4. Building, maintaining, and marshaling the human capital needed to achieve results

Massive efforts will be required to address these areas for the twenty government agencies.

The last point to be made in relation to the above is the fact that we are seeing increasing amounts of software in our systems such that software itself, its development and maintenance, is fast becoming our number one “systems” problem. Exhibit 1.6 lists some of the GAO reports that highlight the various aspects of software that need to be addressed.

Exhibit 1.6: Selected GAO Reports That Focus Upon Software Issues

- Land Management Systems: Major Software Development Does Not Meet BLM’s Business Needs
- Weather Forecasting: Improvements Needed in Laboratory Software Development Processes
- Defense Financial Management: Immature Software Development Processes at Indianapolis Increase Risk
- Embedded Computer Systems: Defense Does Not Know How Much It Spends on Software
- Embedded Computer Systems: F-14D Aircraft Software Is Not Reliable
- Embedded Computer Systems: Significant Software Problems on C-17 Must Be Addressed
- Embedded Computer Systems: New F/A-18 Capabilities Impact Navy’s Software Development Process
- Space Station: NASA’s Software Development Approach Increases Safety and Cost Risks
- Mission-Critical Systems: Defense Attempting to Address Major Software Challenges
- Software Tools: Defense Is Not Ready to Implement I-CASE Departmentwide

The ubiquitous nature of software in our systems has led this author to include a separate chapter (Chapter 10) in this book that highlights significant software issues and attempts to define approaches that are and have been taken in order

to find effective solutions. The PM, CSE, and PC are all likely, in the twenty-first century, to have to deal with an increasing number of problems associated with software as critical parts of our future systems.

In addition to providing the above reports, the GAO apparently carries out an annual assessment of selected major weapon system programs. In a March 2005 report regarding these programs [1.18], the agency looked at 54 programs that represented an overall investment of some \$800 billion. The GAO tends to explore cost, schedule, and performance from a knowledge-based perspective. That is, the GAO looked at critical junctures in these programs and assessed the degree to which actual knowledge at those junctures was better or worse than knowledge suggested by best practices. In other words, at these points in the programs, did we know what we should have known? If not, we were implicitly accepting higher levels of risk with respect to cost, schedule, and performance. The three specific program elements examined in some detail had to do with:

1. Technology maturity
2. Design
3. Production

This is certainly an interesting approach and perspective. The GAO concluded that, of the fifty-four programs that were examined, the majority cost more and took longer to develop than planned. The potential impacts of accepting lower levels of knowledge were cited in terms of adverse cost and schedule consequences, leading to fewer quantity buys than were originally planned.

In March 2006, the GAO examined fifty-two weapon system programs at an investment level of over \$850 billion. Looking at the five-year investment numbers (from 2001 to 2006), we started at about \$700 billion and ended at nearly \$1.4 trillion (!). As before, a picture of shortfalls was portrayed in cost, schedule, and performance. Technology perspectives were highlighted, with these results:

Programs that began with immature technologies have experienced average research and development cost growth of 34.9 percent; programs that began with mature technologies have only experienced cost growth of 4.8 percent.

Another quote of special interest is:

DoD often exceeds development cost estimates by approximately 30 to 40 percent and experiences cuts in planned quantities, missed deadlines, and performance shortfalls.

A knowledge-based assessment with respect to technology, design, and production continued to be the dominant mode of analysis; actual results were compared with suggested best practices.

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If we look at space system acquisitions within the DoD, another report in April 2006 cited substantial cost and schedule overruns. The impacts of these problems, over the following five years, were estimated to be a reduction of some \$12 billion available for new systems or to explore new technologies. Several problem causes were articulated as well as methods for problem reduction. The latter included:

- Using practices suggested by the GAO
- Allowing the Science and Technology (S&T) community to bring the technologies to maturation
- Using an evolutionary development approach
- Improving collaboration on requirements
- Shifts in thinking about how to develop space systems
- Changes in incentives

Accepting inputs from another agency is quite a problematic undertaking, considering that all managers within the DoD operate within a definitive and well-thought-out management structure. We might infer from some of these results that being a weapon system manager within the DoD is a most stressful and difficult vocation.

QUESTIONS/EXERCISES

- 1.1** From your own experience or your reading, identify
 - a.** a project with major problems
 - b.** three reasons the project got into trouble
 - c.** what might have been done to
 - fix the problems
 - avoid the problems
- 1.2** For a project of your selection, discuss ways in which the systems approach
 - a.** was used effectively
 - b.** was not used, and the consequences
- 1.3** Critique the systems approach diagram of Figure 1.1 Are there ways that you would modify the diagram? Explain.
- 1.4** Discuss three advantages and disadvantages each for the following organizational structures:
 - a.** functional
 - b.** project
 - c.** matrix

- 1.5 Draw a project organization chart for a project of your own selection.
- 1.6 Identify three responsibilities, other than those listed in this chapter, of
 - a. the Project Manager
 - b. the Chief Systems Engineer
 - c. the Project Controller
- 1.7 Locate another two definitions of systems engineering from the literature. Which of the various definitions do you find most satisfying? Why?
- 1.8 Define three additional areas in which systems exhibit Type I and Type II errors. How would you describe such errors? Are these errors related to one another? Explain.
- 1.9 The section on errors shows specific error probabilities for plus and minus one-, two-, and three-sigma situations. Verify these numbers. What assumptions were needed in order to obtain these values? What is the corresponding “four-sigma” error probability?
- 1.10 For a system with three additive independent errors (standard deviations) of 2, 3, and 4, what is the variance associated with the overall maximum error? What is the maximum standard deviation?

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