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and the prospective supplier each views this objective relative to his or her own individual position in terms of the risks associated with the numerous options that are available. At one extreme in contracting is the firm-fixed-price (FFP) contract in which the program risks are primarily assumed by the supplier. At the other end, there is a cost-plus-fixed-fee (CPFF) structure in which the contractor assumes most of the risk. Between these two extremes, there are a number of relatively flexible options.

The type of contract negotiated is important, because the results may well impact supplier performance which, in turn, may influence the contractor's ability to develop and produce a system that will meet the specified requirements and in a timely manner. Supplier performance, particularly in the acquisition of large subsystems, is critical to the successful accomplishment of system engineering objectives. Further, the risk factors associated with the type of contractual structure negotiated should be considered in the development of the risk management plan included as part of the System Engineering Management Plan (SEMP)—refer to Section 6.2.

Thus, it is important that the system engineer have some understanding of contracts, because he or she is not only affected by the type of contract negotiated, but is often directly involved in the negotiation process itself. Fixed-price contracts are tightly controlled, with the supplier assuming most of the risk (in this instance). Engineering design should be fairly well defined, as changes subsequent to contract negotiation may be quite costly. On the other hand, the cost-reimbursement type of contracts (i.e., cost-plus-fixed-fee, cost-plus-incentive-fee) are more flexible in terms of making changes after initial contract negotiation, and the bulk of the risk is assumed by the contractor. In any event, the system engineer should have some feel relative to the extent of design definition required and what can and cannot be done by virtue of various contractual arrangements.

Moreover, the system engineer often participates, from both a technical and a cost-estimating standpoint, in the initial preparation of the Request for Proposal (including the preparation of the development specification, the management plan, and the Statement of Work) that leads to contract negotiations. When the negotiations actually take place, the system engineer often participates once again relative to the interpretation of specifications and the technical aspects of task accomplishment. Throughout the negotiation process, the intended scope of work may change, and such changes must be evaluated for their impact on other system design and development activities.

To provide some additional understanding, the major categories of contracts are briefly described in the following paragraphs:

1. *Firm-fixed-price* (FFP) *contract:* A legal agreement to pay a specified amount of money when the items called for by the contract have been delivered and are accepted. No price adjustments are allowed for the contracted work after award, regardless of the actual costs experienced by the supplier. At a specified price, the supplier assumes all financial risks for performance, and the supplier's profits depend on his ability to initially predict cost, to negotiate, and to subsequently control costs. Concerning application of this type of contract, the component design should be fairly well established through appropriate specifications.

2. *Fixed-price-with-escalation contract:* Similar to the FFP contract, except that an escalation clause may be added to cover uncontrollable price increases or decreases. Escalation can be applied to both labor and material. Because there are many uncertainties relative to predicting the magnitude of escalation, an escalation ceiling is often established, with the supplier and the contractor sharing the risks up to that point. Unexpected costs above the established ceiling are assumed by the supplier.

3. *Fixed-price-incentive contract:* Applied in situations in which some cost uncertainties exist and there is an excellent possibility that cost reduction can be attained through good supplier management and by providing the supplier with some profit incentive. A target cost, a minimum cost, and a ceiling price are negotiated, along with a profit-adjustment formula. Profit adjustment, from the initial targeted profit, can be made based on total cost performance.

4. *Cost-plus-fixed-fee* (CPFF) *contract:* A cost-reimbursement contract whereby the supplier is reimbursed for all allowable costs associated with the project. A negotiated fixed fee (e.g., 10% of the estimated cost) is paid to the supplier on completion of work. Although this fee is fixed in terms of a percentage of the total cost, fee increases or decreases may occur as changes occur in the scope of work and the contract. This is particularly applicable when the contractor is willing to accept supplier-generated engineering change proposals to perform work beyond the scope of the initial contract.

5. *Cost-plus-incentive-fee* (CPIF) *contract:* Intended to cover situations in which uncertainties in program performance exist. Allowable costs are paid to the supplier, together with additional incentive fee payments based on designated accomplishments. At the time of negotiation, individual factors such as schedule milestones and specific performance measures may be identified as items in which incentives are to be specified in order to motivate suppliers to excel in these areas. Contract negotiation will result in a defined target cost, target fee, a minimum and maximum fee, and a fee-adjustment formula. On completion of the contract, the supplier's performance will serve as the basis for fee adjustment. An application of this type of contract can include the negotiation of incentives against each of the Technical Performance Measures (TPMs) specified for the system, as they apply to the item being procured.

6. *Cost-sharing contract:* Is primarily designed for research and development work conducted with educational institutions and nonprofit organizations. Such work is jointly sponsored, and reimbursement to the supplier is in accordance with a predetermined sharing agreement. No fee is awarded; however, in lieu thereof, the supplier anticipates that the work accomplished will derive other benefits (e.g., a patentable item, acquisition of technical know-how, a good publication).

7. *Time and material contract:* Allows for the payment for actual materials and services expended in the performance of designated tasks. This type of contract is employed when the extent and duration of work cannot be determined ahead of time and when costs cannot be estimated to any degree of accuracy. Appropriate applications include specific subcontracted research and development tasks, maintenance repair and overhaul services, and so on.

8. *Letter agreement:* Often used as a preliminary contractual document initiated with the intent of authorizing the supplier to start work on a project immediately.

These agreements serve as an interim means for providing a rapid response to an identified need that otherwise might be delayed pending the negotiation of a definitive contract. Letter agreements usually do not include total pricing information; however, an upper-limit dollar amount is usually specified to preclude excessive spending. Under this type of agreement, all costs incurred by the supplier for work accomplished are fully reimbursed by the contractor.

Associated with each major type of contract is the question concerning schedule of payments. When will the supplier be reimbursed for the successful completion of contracted tasks? What is the magnitude of expected payments? For incentive contracting, what type of incentive/penalty plan should be applied? These and comparable questions are significant, particularly for the larger contracts, because the contractor is generally tied to a specific budgeting cycle and the supplier must offset operating costs without going too far into debt. Thus, a payment schedule of some type should be developed.

Figure 6.36 presents an example of one type of plan, in which progress payments are tied to the successful completion of formal design reviews; that is, the system design review, the last equipment/software design review, and the critical design review. These particular design reviews will include coverage of supplier activity, and tying progress payments to these events should motivate the supplier to produce effective results, ensuring success.

If incentive contracting is used, an incentive/penalty plan should be developed as a supplement to the schedule for progress payments. Such a plan should specify the application of incentive and penalty payments to significant project milestones and/or demonstrated system performance and effectives characteristics. See Figure 5.2 (Chapter 5); the TPMs applied at the system level should be allocated to the subsystem or to the level applicable to the item being provided by the supplier. Performance measures that are realistic for the item being procured may be appropriate factors for consideration in the development of an incentive/penalty plan for the supplier.

In developing an incentive/penalty payment plan, it is necessary to identify the parameters to which incentives and penalties are to be applied. In many instances there is more than one parameter, resulting in a multiple structure. The appropriate sum of money for each incentive is difficult to determine and will depend on the type of component (or service) and the importance of the item to which the incentive is to be applied. It is unlikely that all selected parameters will be equally important; therefore, it will be necessary to assign an "importance value" or "weighting" to each parameter and to estimate the magnitude of the incentive/penalty values accordingly. An example of the multiple approach, involving two component characteristics, is illustrated in Figure 6.37. A target value is established based on specification requirements, which may also be considered as a "contracted value." If, after test and evaluation, the actual measured value is an improvement over the target value, an incentive fee is awarded to the supplier at the designated time, as indicated in the schedule in Figure 6.36. More specifically, if the measured MTBM exceeded the upper confidence limit of approximately 238 hours in Figure 6.37, the assigned fee would be split, with 20% going to the contractor and 80% going to the supplier. Conversely, if the measured

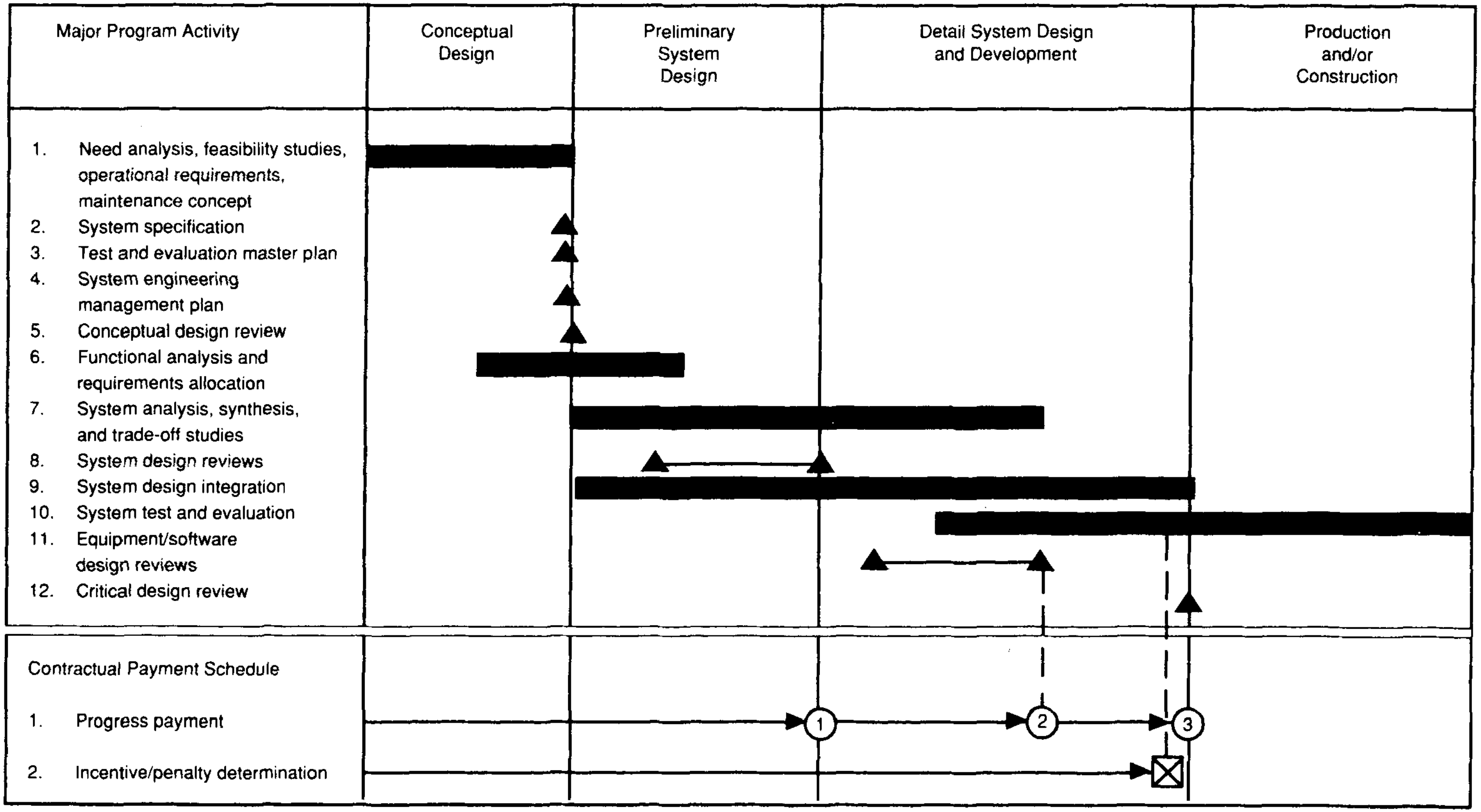

Figure 6.36 Schedule of proposed contractual payments.

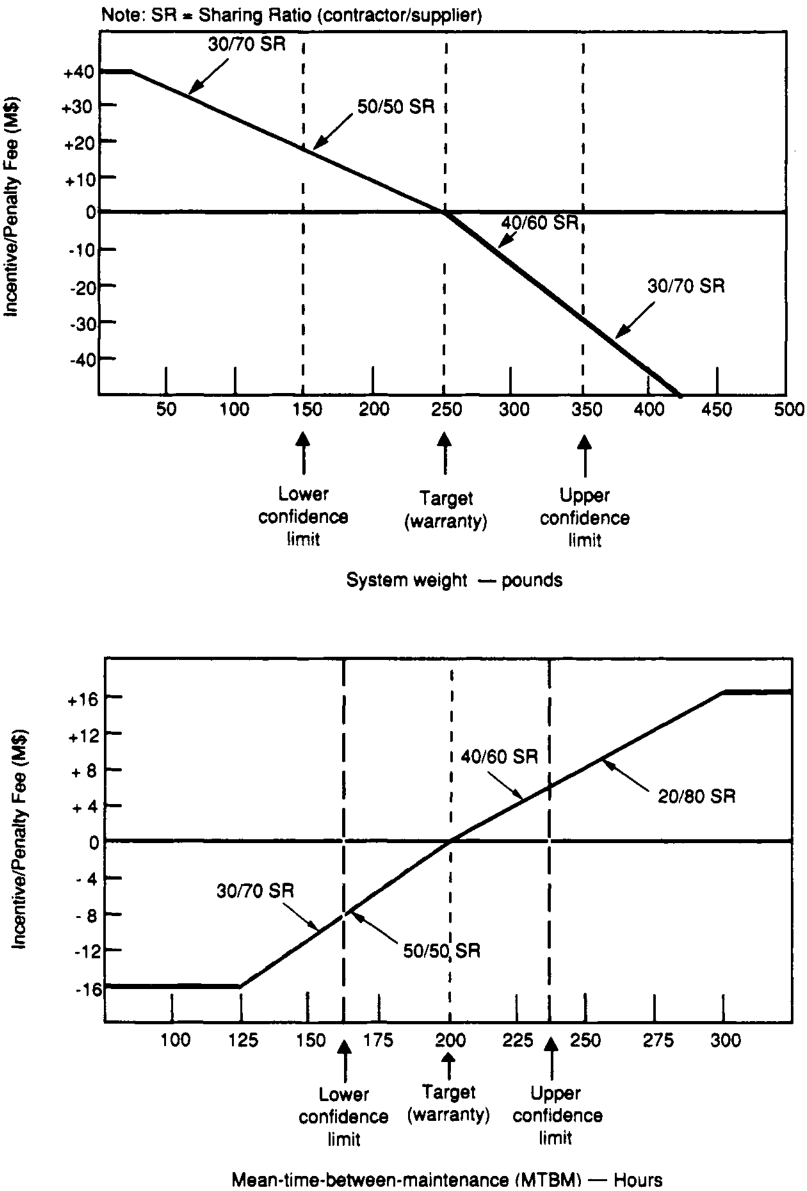

Figure 6.37 Multiple incentive/penalty plans.

MTBM fell below the target objective, a penalty of 50% of the indicated ordinate value would be paid by the supplier. Similar applications involving other key parameters may be covered through incentive/penalty contracting.

Although there are a variety of possible contract types, care must be taken in adapting the appropriate contract structure to the particular procurement action. For example, if design and development activity is required on the part of the supplier, then it may be appropriate to negotiate either a cost-plus-fixed-fee (CPFF) or a cost-plus-incentive-fee (CPIF) type of contract. In such instances, when considering the flexibility, the contractor may have to implement tighter monitoring and control activities to ensure the timely completion of tasks by the supplier. At the same time, the contractor needs to be careful not to impose (or cause) any design changes that may have an impact on the supplier. If the contractor even suggests a possible improvement to the supplier's product, or a change in direction relative to activity, then the supplier is likely to claim a change in the scope of work and charge the contract accordingly. In addition, a supplier knowledgeable of contracting may initially submit a proposal representing a "minimal effort" in order to keep the price low and win the competition. At the same time, the supplier is planning to initiate changes and/or additions at a later time to cover items that perhaps should have been included in the initial proposal. These changes are likely to be processed through a series of individual engineering change proposals (ECPs), and the ultimate costs will increase accordingly. In such situations, it is important that the system engineer not only be familiar with contracting methods in general, but also thoroughly familiar with the item(s) being proposed, its technical makeup and how it fits into the system hierarchy, and the various interface and support requirements that are applicable.

At the other end of the spectrum, there will undoubtedly be many different system components that are well defined, for which no additional design effort is required. In this instance, the implementation of a firm-fixed-price (FFP) contract may be preferred. For the performance of services, such as in the accomplishment of maintenance and repair actions, the basic time and materials type of contract may be the most appropriate.

The ultimate achievement of definitive contract terms and conditions is accomplished through formalized negotiations between the contractor and the supplier. Negotiations per se can assume a simplified approach involving several representatives from each side, meeting on a given day to discuss requirements in general. On the other hand, for relatively large subsystems and/or major system components, the contract negotiation process can become quite complex. In a more formalized negotiation, the contractor, in response to the supplier's proposal, will interrogate the supplier relative to the validity of his or her proposed technical approach, management approach, and/or price. Questions along a technical line will attempt to ascertain whether the supplier has demonstrated that his or her technical approach is the best (based on the results of design trade-off studies), and that he or she has the technical expertise and experience to follow through in developing and producing the proposed item. Concerning cost, the object is to verify that the supplier's price is fair and reasonable and that it was developed through a logical cost analysis. From the supplier's standpoint, the negotiation initially takes the form of defending the proposal as submitted to the contractor. The supplier may be required to provide any amount of supporting material to help convince the contractor that he or she is thorough, honest, and offering the best deal possible.

Negotiation, in general, is an art and usually requires some strategy on both sides. Initially, a plan is developed that identifies the location where the negotiations are to be held and includes an agenda for each meeting that is scheduled. The contractor and the supplier each identify the personnel who will participate in the negotiations process. Both technical and administrative personnel will be included, and a representative from the contractor's system engineering organization should be present for technical discussions covering system-oriented requirements. During the formal negotiations at the "bargaining table," both sides will assume a minimum-risk position, considering the contractual terms and conditions mentioned earlier. Interruptions will occur, short strategy meetings will be held to discuss pertinent events, attempts will be made to gain a measure of sympathy from the opposition, and, it is hoped, an agreement will be made after some compromises on both sides. This process may evolve through a number of iterations, perhaps consuming more time than initially anticipated. However, the final objective is to realize a signed formal contract between the contractor and the supplier.

6.3.5 Supplier Monitoring and Control

With the identification, approval, and establishment of formal contractual relationships with suppliers, the contractor's main activity now includes program coordination, evaluation, and control. This ongoing activity can be rather significant for the following reasons:

1. The magnitude of supplier activity and the number of individual product/component suppliers for a given system may be extensive. For some systems, as much as 50 to 75% of the planned development and production activity will be accomplished by suppliers.
2. In addition to the large number of suppliers involved in system acquisition, the geographic distribution of these suppliers may be worldwide. Many systems utilize components that are developed and manufactured in Pacific Rim countries, Europe, Africa, Canada, Mexico, South America, and so on. The requirements in system acquisition may dictate a truly international communications and distribution network.
3. In the acquisition of relatively large-scale systems, where there are many different component suppliers, the variety of tasks being accomplished at any given time can be rather extensive. Some suppliers may be undertaking a full-scale design and development effort, others may be performing manufacturing and production functions, and many suppliers may be providing standard off-the-shelf components in response to routine purchase orders. There are some programs that are staggered and discontinuous, and there are other programs that are continuous over a long period of time. Figure 6.38 presents a sample plan of supplier project activities.

In this type of environment (i.e., many different suppliers, located worldwide, performing a wide variety of functions) the contractor is faced with a formidable and challenging task. As discussed earlier, specific supplier requirements must be carefully developed and clearly stated from the beginning, and an appropriate contracting structure must be established to ensure that the requirements will be met. The type of contract, of course, should be tailored to the supplier level of effort.

In Figure 6.38, Suppliers A, C, D, F, and G are each involved in a project that includes some design and development activity. As part of this effort, trade-off studies

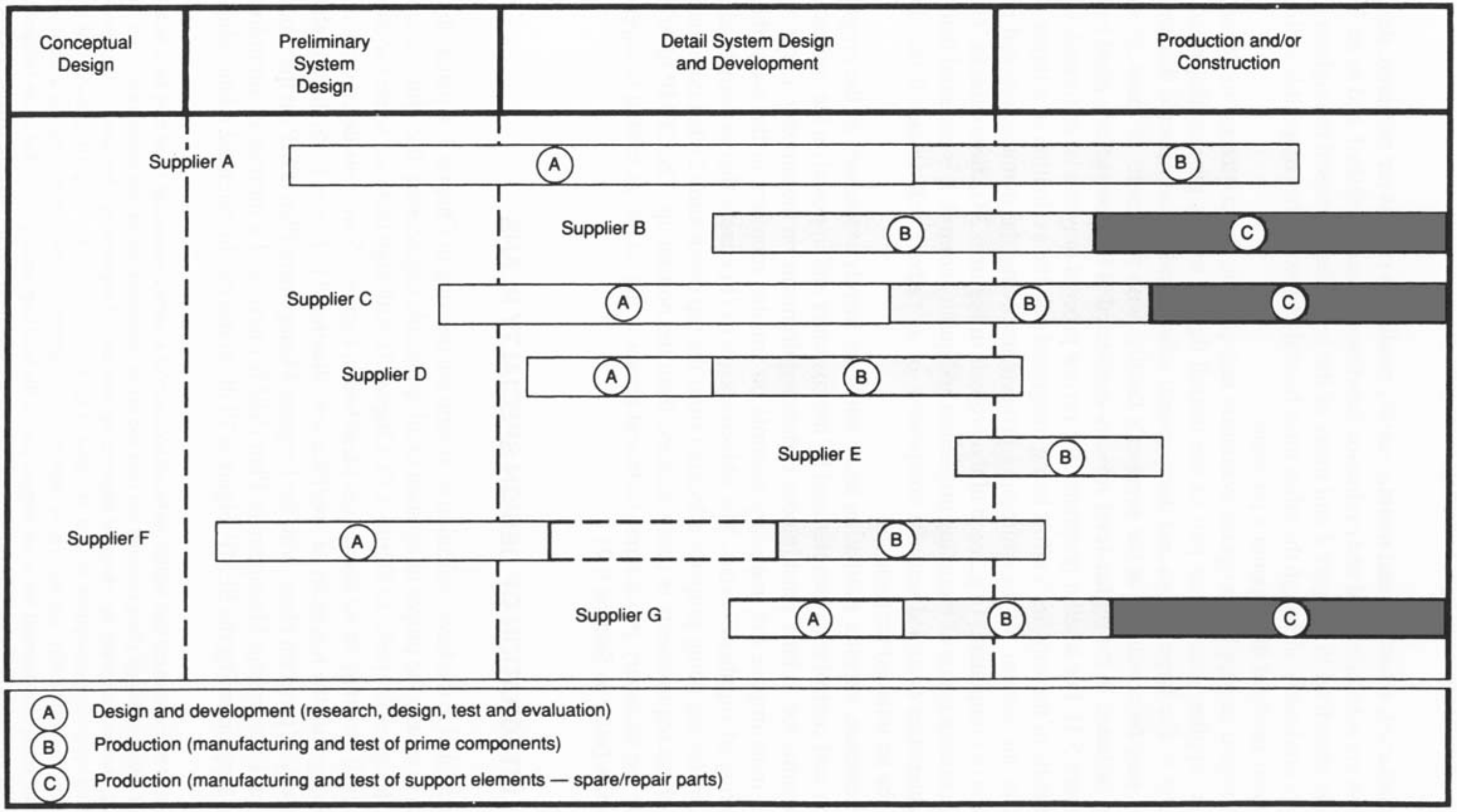

Figure 6.38 A sample of supplier project activities.

are conducted, reliability and maintainability prediction reports are prepared, design reviews are scheduled, test and evaluation functions are accomplished, and so on. The process described in Chapter 2 and many of the activities discussed throughout this text are applicable, although the effort must be scaled down to be compatible with the particular needs of the supplier's program.

In regard to supplier program evaluation and control, the contractor must incorporate supplier activities as part of the overall design review process described in Chapter 5. For large design and development efforts, individual selected design reviews may be conducted at the supplier's facility, with the results of these reviews being included in the higher-level reviews conducted at the contractor's plant (refer to Figure 5.1). For smaller programs, the review process may not be as formal, with the results of the supplier's effort being integrated into the evaluation of a larger element of the system. When addressing projects involving the manufacture and production of components (e.g., each of the projects in Figure 6.38), the contractor's primary concern is that of incoming inspection and quality control. It is essential that the characteristics designed into the component, or as "advertised" in an off-the-shelf item, be maintained throughout.

In essence, supplier evaluation and control are merely extensions of the program review and control activities initiated by the customer and imposed on the contractor. The contractor, in turn, must impose certain requirements on the supplier. Large suppliers must impose the necessary controls on smaller suppliers in the event that a "layering of suppliers" exists. The objectives are to (1) ensure that system-level requirements are being properly allocated from the top down and (2) that compliance with these requirements is being realized from the bottom up. The SEMP must describe the necessary procedures, technical reviews, and so on, as related to supplier activities (refer to Section 6.2).

6.4 INTEGRATION OF DESIGN SPECIALTY PLANS

As indicated in the basic definition of system engineering in Chapter 1, a major objective is to ensure the proper integration of all applicable engineering disciplines into the total design effort (refer to Figure 2.29, Chapter 2). Although there are some variations with each program, those disciplines identified in Figure 6.5 are considered critical.

Along with the hierarchy of specifications illustrated in Figure 6.15, there is also a hierarchy of program plans, with the Program Management Plan (PMP) at the top, the System Engineering Management Plan (SEMP) next, and a number of subordinate plans supplementing the SEMP. Figure 6.39 illustrates this hierarchical relationship.[19]

[19]It should be emphasized that within the broad spectrum of system engineering, there may be a wide variety of different design plans covering not only the prime functional design disciplines (e.g., civil engineering, electrical engineering, chemical engineering, mechanical engineering), but some of the basic engineering supporting disciplines as well. Relative to the latter, many of the supporting disciplines (e.g., reliability, maintainability, logistics) have been treated as separate entities, each requiring a stand-alone plan, and being implemented not as an integral part of the total engineering effort, but on an independent basis. The emphasis in Figure 6.39 is to ensure that these plans are integrated into the overall process.

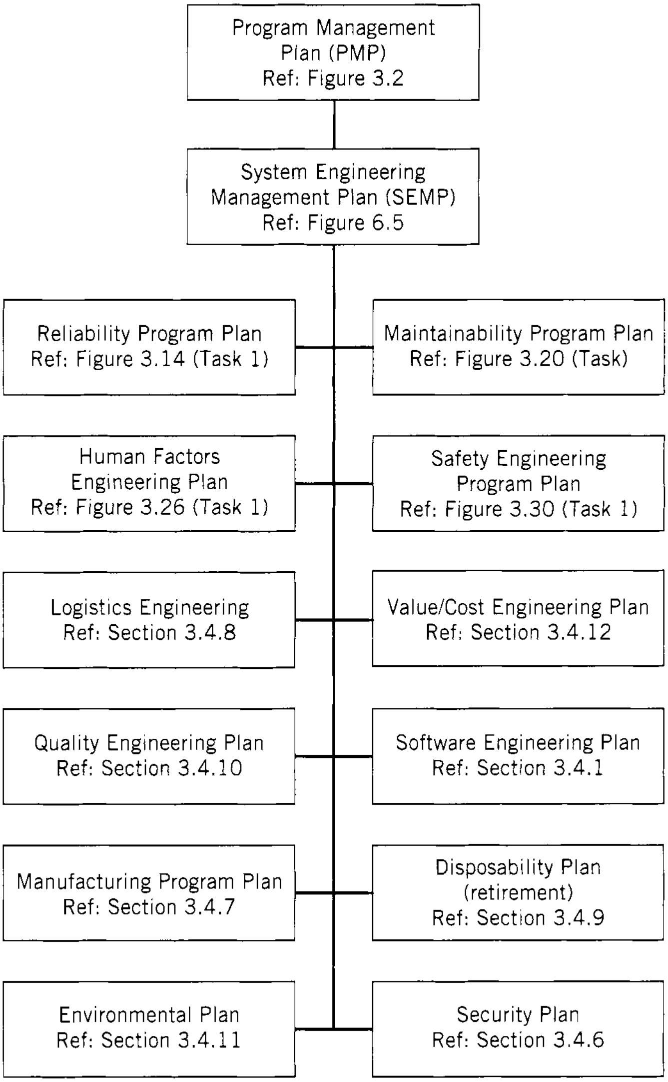

Figure 6.39 The integration of individual design discipline plans.

In Chapter 3 there is a description of the requirements for each of these supporting disciplines. An evaluation of the requirements illustrates the importance of reliability, maintainability, human factors, supportability/serviceability, producibility, quality, and so on, in design. Further, these requirements are closely interrelated in addition to being key to the system engineering process. Thus, these factors must be properly addressed in the design process, in a timely manner, and commencing from the beginning during the conceptual design phase.

From a review of the individual sections in Chapter 3, one can see that there are many tasks that are similar across the board. The first task in each of the design disciplines represented is the *preparation of a program plan,* a document that specifies the tasks to be accomplished in order to fulfill program requirements. Within each area of activity, there are analysis tasks, prediction tasks, design review and evaluation tasks, and test and demonstration tasks. In the accomplishment of design tradeoffs, as part of the ongoing analysis effort, the net results must reflect a *balanced* approach. This, in turn, forces the proper mix of reliability characteristics in design, maintainability characteristics in design, and so on. In other words, these factors (as they impact the design process) must be carefully integrated throughout.

In the past, common practice has resulted in the preparation of these program plans on a separate and independent basis, and often at different times in the system development process. This has caused some differences in stated objectives, inconsistencies in schedules, redundancies in program task requirements, and conflicts in output. In view of the importance of these disciplines in meeting system engineering objectives, it is recommended that the respective plans be prepared and integrated into the System Engineering Management Plan (SEMP). This is illustrated in Figure 6.39.

In the integration shown in Figure 6.39, the intent is not to hamper or in any way curtail the efforts of the individual disciplines in fulfilling program requirements. The purpose is to ensure the proper relationships among the many tasks that must be accomplished, as well as eliminate possible redundancies. For instance, the results of reliability prediction must feed into the accomplishment of maintainability prediction and the supportability analysis; the preparation of the failure mode, effect, and criticality analysis (FMECA) constitutes an input to other reliability tasks, the maintainability analysis, the supportability analysis, and the safety analysis; the fault-tree analysis (FTA) constitutes an input to the safety hazard analysis; the accomplishment of the human-factors operator task analysis (OTA) must be compatible with and directly support the maintenance task analysis (MTA); and the reliability analysis (model), maintainability analysis, operator task analysis, and logistic support analysis must evolve from the system-level functional analysis (refer to Section 2.7). It is essential that the system engineer completely understand the many interrelationships among these disciplines and that such activities be properly integrated through the SEMP.

6.5 INTERFACES WITH OTHER PROGRAM ACTIVITIES

Although it is important to provide the proper integration of the individual design discipline plans, as conveyed in Figure 6.39, it is also necessary to ensure that the proper communications links exist between the SEMP and other related program plans. Of particular interest are those noted in Figure 6.40 and identified in the following paragraphs.

1. *Individual design plans:* For some programs, individual plans may be prepared by the traditional design disciplines such as civil engineering, electrical engineering,

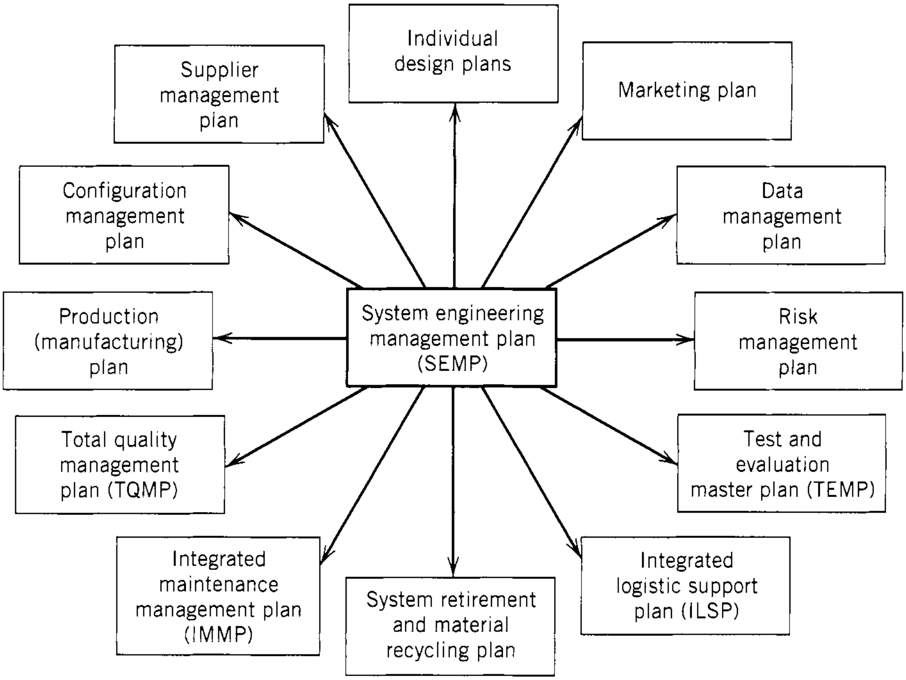

Figure 6.40 Interfaces with other planning activities.

industrial engineering, mechanical engineering, and other such disciplines. It is essential that these plans be supportive of the material presented in the SEMP and be referenced accordingly. An objective of system engineering is to allow the integration of *all* engineering disciplines, requiring that these plans "communicate" with each other.

2. *Configuration management plan:* The importance of configuration management (CM), or "baseline" management, is critical to the fulfillment of system engineering objectives and has been emphasized throughout this text. Maintaining the design baseline and controlling design changes are essential for system evaluation and cost control.

3. *Data management plan:* The proper integration of all design and supporting data is necessary to ensure that the various elements are compatible (i.e., "track" where applicable) and available at the right place and in a timely manner, that data redundancies are minimized (if not eliminated), and that data costs are minimized to the extent possible. Although the data environment is rapidly changing with the advent of new technologies (i.e., the conversion of data to a digital format and using a shared database approach), there is still a need for some degree of consistency in presentation, data format, control of data/documentation changes, and so on (refer to Section 2.10 and Figure 2.31 in Chapter 2).

4. *Test and Evaluation Master Plan* (TEMP): As indicated in Section 2.11 and Figure 2.32, there is a need for *integrated* test planning from the beginning. As system-

level requirements are initially defined and TPMs are established, one has to determine how the system will ultimately be evaluated to ensure that the initially specified requirements will be met. This constitutes the *validation* loop within the system engineering process; hence, the preparation of the TEMP has been identified as one of the critical tasks in implementing a system engineering program (refer to Figure 6.6, task 4).

5. *Marketing plan:* Individual company/agency marketing plans are often directed toward the "short term" and do not address the necessary long-term, *life-cycle* considerations that are essential in system/product acquisitions. Further, some marketing plans may be directed toward the establishment of certain *partnership* relations with organizations that may, or may not, be sympathetic to the concepts methods of system engineering. Thus, all marketing plans must be prepared to convey the *system engineering approach.*

6. *Supplier management plan:* With the increasing trend toward "outsourcing" and the selection of suppliers from various sources around the world, it may be feasible to develop a plan (in support of the marketing plan) incorporating the criteria for initial supplier selection and the follow-on procedures leading to some form of contracting, subsequent monitoring and control activities, and so on. For some programs, more than 50% of the components of a given system may be subcontracted, and it is imperative that the specifications being imposed on a contract are complete and well prepared, include performance-based requirements, and are supportive of the system specification (Type "A"). The objective is to ensure that all of the components of the system that are procured from an outside source will properly *fit* or can be *integrated* into the system as an entity without unexpected problems occurring. Thus, it is essential that system engineering criteria be included in the supplier selection process, in the preparation of specifications for the purposes of subcontracting, and for the follow-on supplier monitoring and control activity.

7. *Production/manufacturing plan:* What may initially appear to be a well-designed and configured set of prime mission-oriented elements of a system may turn out not to be so after they are subjected to the production process. The production process is highly *dynamic,* with variances introduced throughout, and may have a significant impact on the products being manufactured. This would certainly be the case if *producibility* considerations were not initially incorporated in the design of the applicable product(s). The concurrency approach, whereby the product and the manufacturing life cycles must be properly integrated, is critical in the implementation of system engineering concepts and methods.

8. *Integrated logistic support plan* (ILSP): See Section 3.4.8, the ILSP covers all of the activities associated with the design of the prime elements of the system for *supportability,* design of the support infrastructure, the procurement and acquisition of the elements of support (maintenance personnel, spares and repair parts, test equipment, facilities, transportation and handling provisions, computer resources, and technical data), and for the sustaining maintenance and support of that system throughout its planned life cycle. Within the ILSP, there is a *logistics engineering* section that should either be incorporated within the SEMP or constitute a major reference required for the successful completion of system engineering requirements (refer to

Figure 6.39). Further, as one progresses through the development process, there is an ongoing need for the evaluation of the overall support infrastructure, and for the data collection and feedback process as the system is being utilized by the consumer in the field.

9. *Integrated maintenance management plan* (IMMP): Whereas the ILSP deals with the major issues pertaining to the system support infrastructure in the defense sector, the IMMP may serve in a comparable role in the commercial sector. Whether one is dealing with a transportation system, a communications system, a healthcare or hospital complex, or manufacturing plant, there is still a need to *plan for maintenance.* This includes the design for reliability and maintainability, the design of the maintenance and support infrastructure, the procurement of the elements of support, and the sustaining maintenance and support of the system throughout its planned life cycle.

10. *Total quality management plan* (TQMP): Within the context of total quality management (TQM), there are activities associated with *quality engineering* dealing with the design of products, the design of the manufacturing process, and the design of the maintenance and support infrastructure. These areas should either be incorporated within the SEMP or constitute a major reference required for the successful completion of system engineering requirements (refer to Figure 6.39). Further, as one progresses through the development, manufacturing, and support processes, there is an ongoing requirement to maintain the *quality* that has been built into the design.

11. *System retirement and material recycling plan:* Although the system retirement and material recycling and disposal part of the life cycle has not been properly addressed in many programs, the environmental concerns described in Section 3.4.11 are assuming an increasing degree of importance. The engineering aspects pertaining to the *design for the environment* should be addressed within the context of the SEMP, and the life-cycle activities associated with system development, construction and/or production, operations and support, and retirement should be monitored in terms of their impact on the environment. Further, as the system evolves through the consumer utilization and support phase, there must be an ongoing assessment relative to the possible impact of external environmental factors on the system; that is, the impact of ecological, technological, political, economic, and related factors on system operations. Is the system still performing as initially intended, or has there been some degradation due to external factors?

12. *Risk management plan:* Inherent within any system development effort is the aspect of *risk;* that is, risk due to technical decisions, risk due to management decisions, and so on. The objective is, of course, to minimize risk throughout, and a major goal in system engineering is to implement a *risk management plan* that will allow for the early identification of potential areas of risk, the assessment of risk, and risk abatement. As shown in Figure 6.5 (item 10.0), the SEMP should address the area of risk management. This subject is discussed further in Section 6.7.

Although the successful implementation of a system engineering program requires close coordination with all of the design-related activities, a special emphasis is required to ensure close working relationships with those organizations responsible for the activities covered in these plans.

6.6 MANAGEMENT METHODS/TOOLS

A major system engineering challenge is to be able to evolve through the process illustrated in Figure 1.12 (Chapter 1) following an organized, logical, and methodical approach and utilizing whatever techniques/tools are available at the time. Inherent within this process is the requirement for accomplishing synthesis, analysis, and evaluation efforts, commencing as early in the life cycle as practicable. The goal is to gain early visibility, reduce the time that it takes for system acquisition, be able to make good design and management decisions as system development evolves, and to minimize the risks associated with the decision-making process. On the other hand, too much activity too early may turn out to be meaningless and costly. The challenge is to be able to quickly assess *what is required, when, and to what extent.* At the same time, it is essential that one be familiar with the techniques/tools that are available and can be applied in helping to meet this goal. The system engineer must take a leadership role here, and knowledge of the latest technology that can be applied in facilitating this process is required.

Although it is impossible to mention all of the analytical techniques/tools that may be utilized to assist the system engineer in successfully fulfilling the aforementioned objective, it is recommended that such professionals become familiar with at least the following:

1. Possible applications of electronic commerce (EC), information technology (IT), electronic data interchange (EDI), and the Internet in system development and in the implementation of the system engineering process (refer to Section 4.3).
2. Application of CAD, CAM, and CAS methods in design (refer to Sections 4.5, 4.6, and 4.7).
3. The utilization of simulation methods in design (refer to Section 4.4.1).
4. The use of rapid prototyping methods in software design and development (refer to Section 4.4.2).
5. The use of scaled models and mock-ups in design evaluation (refer to Section 4.4.3).
6. Application of statistical and operations research methods in system analysis (refer to Section 4.2).

The challenge is to know what techniques/tools to use in solving certain design-related problems and in accomplishing various types of analyses. These design-enhancement capabilities should be described in the System Engineering Management Plan (SEMP), in terms of their application. Care must be taken to ensure that their application is compatible with the capabilities of suppliers when they are required. For example, if the prime contractor utilizes a specific CAD software and depends on "live" inputs from one or more suppliers, then one needs to ensure that the supplier(s) utilizes software that is compatible. The compatibility of technologies across the spectrum of the design team members is essential.

6.7 RISK MANAGEMENT PLAN[20]

Risk is the potential that something will go wrong as a result of one or a series of events. It is measured as the combined effect of the probability of occurrence and the assessed consequence given that occurrence. The potential for risk becomes increasingly higher as complexities and new technologies are introduced in the design of systems. Risk, as used in the context described herein, refers to the potential of not meeting a specified technical and/or program requirement; for example, not meeting a requirement specified by a TPM, a schedule, or a cost projection.

Risk management is an organized method for identifying and measuring risk, and for selecting and developing options for handling risk. Risk management is not a separate program thrust by itself, but should be an inherent part of any sound management activity. Risk management includes the following basic activities:

1. *Risk assessment:* This involves the ongoing review of technical design and/or program management decisions and the identification of potential areas of risk.
2. *Risk analysis:* This includes conducting an analysis to determine the probability of events and the consequences associated with their occurrence. The purpose of risk analysis is to identify the cause(s), the effects, and the magnitude of the risk perceived and to identify alternative approaches for risk avoidance. There are many tools available that can be used as an aid in conducting risk analyses: for example, scheduling network analysis, life-cycle cost analysis, FMECA, the Ishikawa cause-and-effect or "fishbone" diagram, hazard analysis, and trade-off studies in varying forms.
3. *Risk abatement:* This involves the techniques and methods developed to reduce (if not eliminate) or control risk. A plan must be implemented for the handling of risk.

One of the first steps in risk management is the identification of the potential areas of risk. Although there is some degree of risk associated with any program area of activity where decisions are being made, one needs to identify those in which the potential consequences of failure can be significant. Program areas of risk may include funding, schedule, contract relationships, political, and technical. Technical risks relate primarily to the potential of not meeting a design requirement, not being able to produce an item in multiple quantities, and/or not being able to support a product in the field. Design engineering risks can be tied directly to the technical performance measures (TPMs) identified in Section 2.6 and in Figure 5.2. These TPMs, which reflect critical factors in design, can be prioritized to reflect relative degrees of importance.

Given the identification of performance characteristics to which the system is to

[20]"Risk" and "risk management" constitute a very important part of a system engineering program. Three good references for a more in-depth discussion of this area are (1) E. M. Hall, *Managing Risk: Methods for Software Systems Development* (Reading, MA: Addison-Wesley, 1998); (2) Y. Haimes, *Risk Modeling, Assessment, and Management,* (New York: John Wiley & Sons, Inc., 1998); and (3) EIA/IS-632, *Processes for Engineering a System,* (Washington DC: Electronic Industries Association, EIA).

be designed (i.e., those parameters that require monitoring on a regular basis), the next step is to evaluate these by indicating possible causes for failure. In the event of failure to meet a specific design requirement, one must ask, What are the possible causes and what are the probabilities of occurrence? Although the output measure being monitored may be a high-priority TPM, the cause of a possible failure may be the result of a misapplication of a new technology in design, a schedule delay on the part of a major supplier, a cost overrun, or a combination of these.

The causes are evaluated independently to determine the degree to which they can impact the TPM(s) being monitored. Sensitivity analyses are conducted, using various analytical models as appropriate, to determine the magnitude of the potential risk. This, in turn, will lead to the classification of factors in terms of "high," "medium," or "low" risk. These classifications of risk are then addressed within the program management review and reporting structure. High-risk items are monitored to a greater extent, with a higher priority relative to initiating a risk abatement plan, than low-risk items.

To facilitate the risk management implementation process, it is often feasible to develop a model of some type. One approach is to address risk in terms of two major variables: the probability of failure (P_f) and the effect or consequence of that failure (C_f). Consequences may be measured on the basis of technical performance, cost, or schedule. Mathematically, this model can be expressed as:[21]

$$\text{Risk factor } (RF) = P_f + C_f - (P_f)(C_f) \tag{6.5}$$

where P_f is the probability of failure and C_f is the consequence of failure. The quantitative relationships of these parameters are described in Figure 6.41.

To illustrate the model application, with Figure 6.41 as the prime source of information, consider the following system design characteristics:

1. System design uses off-the-shelf hardware with minor modifications to the software.
2. The design is relatively simple, involving the use of standard hardware.
3. The design requires software of somewhat greater complexity.
4. The design requires a new database to be developed by a supplier (subcontractor).

The characteristics of the system suggest that there is potential risk associated with the software development task. Using the criteria in Figure 6.41 (and applying the weighting factors as indicated), the probability of failure (P_f) is calculated as follows:

[21]This model was adapted from the procedure included in 1986 edition of the *Systems Engineering Management Guide*, published by the Defense Systems Management College (DSMC), Fort Belvoir, VA. Although there are other models in use today, presentation of the material included herein will provide an idea as to an approach in the quantification of risk. It should be emphasized, however, that one needs to develop a model tailored to the system and the program in question.

(1) Risk Factor = $P_f + C_f - P_f \bullet C_f$
(2) $P_f = (a)(P_{Mhw}) + (b)(P_{Msw}) + (c)(P_{Chw}) + (d)(P_{Csw}) + (e)(P_D)$

where

P_{Mhw} = Probability of failure due to degree of hardware maturity

P_{Msw} = Probability of failure due to degree of software maturity

P_{Chw} = Probability of failure due to degree of hardware complexity

P_{Csw} = Probability of failurè due to degree of software complexity

P_D = Probability of failure due to dependency on other items

and where: a, b, c, d, and e are weighting factors whose sum equals one.

(3) $C_f = (f)(C_t) + (g)(C_c) + (h)(C_s)$

where

C_t = Consequence of failure due to technical factors

C_c = Consequence of failure due to changes in cost

C_s = Consequence of failure due to changes in schedule

and where f, g, and h are weighting factors whose sum equals one.

Magnitude	Maturity Factor (P_M) Hardware PMhw	Maturity Factor (P_M) Software PMsw	Complexity Factor (P_C) Hardware PChw	Complexity Factor (P_C) Software PC_{sw}	**Dependency Factor** (P_D)
0.1	Existing	Existing	Simple design	Simple design	Independent of existing system, facility, or associate contractor
0.3	Minor redesign	Minor redesign	Minor increases in complexity	Minor increases in complexity	Schedule dependent on existing system, facility, or associate contractor
0.5	Major change feasible	Major change feasible	Moderate increase	Moderate increase	Performance dependent on existing system performance, facility, or associate contractor
0.7	Technology available, complex design	New software similar to existing	Significant increase	Significant Increase/major increase in # of modules	Schedule dependent on new system schedule, facility, or associate contractor
0.9	State of art some research complete	State of art never done before	Extremely complex	Extremely complex	Performance dependent on new system schedule, facility, or associate contractor

Magnitude	Technical Factor (C_t)	Cost Factor (C_c)	Schedule Factor (C_s)
0.1 (low)	Minimal or no consequences, unimportant	Budget estimates not exceeded, some transfer of money	Negligible impact on program, slight development schedule change compensated by available schedule slack
0.3 (minor)	Small reduction in technical performance	Cost estimates exceed budget by 1 to 5 percent	Minor slip in schedule (less than 1 month), some adjustment in milestones required
0.5 (moderate)	Some reduction in technical performance	Cost estimates increased by 5 to 20 percent	Small slip in schedule
0.7 (significant)	Significant degradation in technical performance	Cost estimates increased by 20 to 50 percent	Development schedule slip in excess of 3 months
0.9 (high)	Technical goals cannot be achieved	Cost estimates increased in excess of 50 percent	Large schedule slip that affects segment milestones or has possible effect on system milestones

Figure 6.41 A mathematical model for risk assessment. *Source:* Defense Systems Management College, *Systems Engineering Management Guide* (Fort Belvoir, VA: DSMC, 1986).

$$P_{Mhw} = 0.1, \text{ or (a) } (P_{Mhw}) = (0.2)(0.1) = 0.02$$
$$P_{Msw} = 0.3, \text{ or (b) } (P_{Msw}) = (0.1)(0.3) = 0.03$$
$$P_{Chw} = 0.1, \text{ or (c) } (P_{Chw}) = (0.4)(0.1) = 0.04$$
$$P_{Csw} = 0.3, \text{ or (d) } (P_{Csw}) = (0.1)(0.3) = 0.03$$
$$P_{D} = 0.9, \text{ or (e) } (P_{D}) = (0.2)(0.9) = \underline{0.18}$$
$$0.30$$

Given the preceding criteria, P_f of this item is 0.30.

If the consequence of the item's failure due to technical factors causes problems of a correctible nature, but the correction results in an 8% cost increase and a two-month schedule slippage, the C_f is calculated as follows:

$$C_t = 0.3, \text{ or (F) } (C_t) = (0.4)(0.3) = 0.12$$
$$C_c = 0.5, \text{ or (g) } (C_c) = (0.5)(0.5) = 0.25$$
$$C_s = 0.5, \text{ or (h) } (C_s) = (0.1)(0.5) = \underline{0.05}$$
$$0.42$$

Based on the preceding (using the weighting factors indicated), the C_f factor is 0.42 and, from Equation (6.5), the calculated risk factor (*RF*) is 0.594. This can be classified within the category of medium risk, as noted in Figure 6.42. In this instance, the risk is primarily associated with the system software and the reliance on a supplier.

A similar approach can be applied in performing a risk analysis on all other applicable parameters. The net result is the development of a list of critical items, presented in order of priority, that require special management attention. Risk reports are prepared at different times (i.e., frequency of distribution) depending on the nature of the risk. High-risk items require frequent reporting and special management attention, whereas low-risk items can be handled through the normal program review, evaluation, and reporting process.

For items classified under "high" and "medium" risk, a risk abatement plan should be implemented. This constitutes a formal approach for eliminating (if possible), reducing, and/or controlling risk. The accomplishment of such may involve one or a combination of the following:

1. Provide increased management review of the problem area(s) and initiate the necessary corrective action through an internal allocation or shift in resources.
2. Hire outside consultants or specialists to help resolve existing design problems.
3. Implement an extensive testing program with the objective of better isolating the problem and eliminating possible causes.
4. Initiate special research and development activities, conducted in parallel, in order to provide a "fall-back" position.

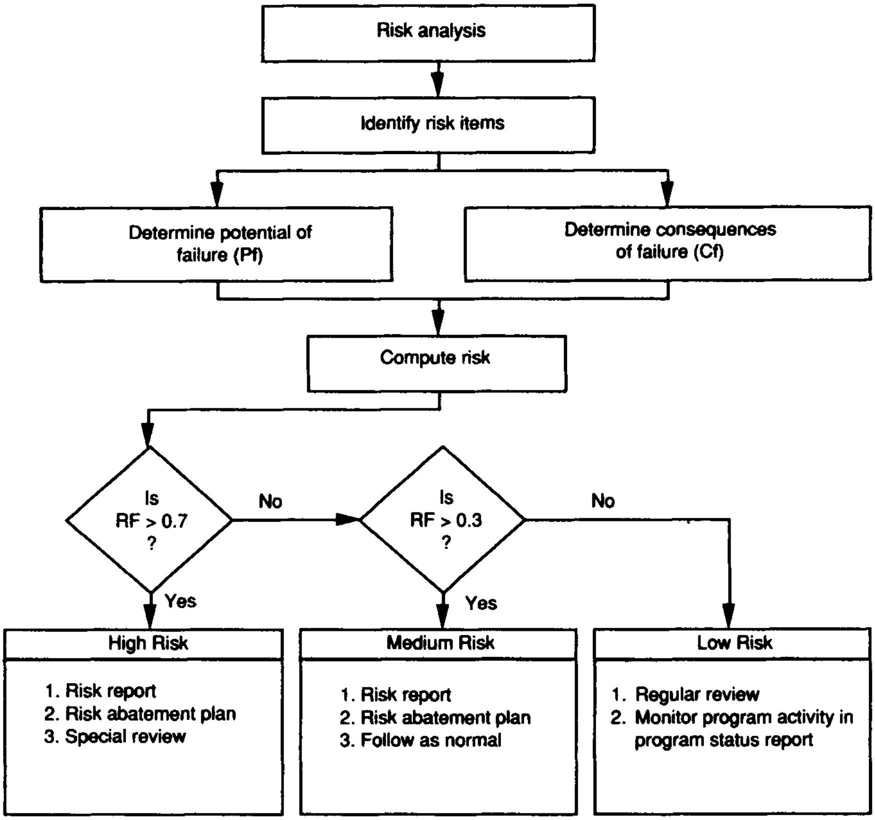

Figure 6.42 Risk analysis and reporting procedure.

The purpose of a Risk Abatement Plan is to *highlight* those areas where special management attention is required. The identification of technical risks is of particular interest in regard to system engineering, because the fulfillment of design objectives is highly dependent on the proper and expeditious handling of these risks. In this respect, risk management should be an inherent aspect of system engineering management.

6.8 GLOBAL APPLICATIONS/RELATIONSHIPS

As a final step in the planning process, one needs to refer to the "system operational and maintenance flow" in Figure 1.20 (Chapter 1) and ensure that all activities within both the *forward* and *reverse* flows are adequately covered. Such coverage must address customer activities, prime contractor (producer) activities, subcontractor activities, and supplier activities. Many of these activities may be assigned to various organizations throughout the world (refer to Figure 6.30). In addressing the overall spectrum, care must be taken to ensure proper compatibility and integration of these activities throughout the program in question.

More specifically, there are cultural differences, variations in political structures, variations in technical capabilities (technology applications), different methods for doing business, different geographical and environmental factors to consider, different logistics and maintenance support infrastructures, and so on, which must be addressed (and planned for) as suppliers are selected and partnerships are established. In addition, and related to these factors, are the communication processes that must effective and in place from the beginning. Given the cultural and language differences throughout the world, it would be relatively easy to misinterpret or not completely understand a given requirement, or to not understand certain assumptions and symbols used in the design process. In any event, one may wish to address the following questions:

1. Have the appropriate processes been established and put in place to ensure good communications throughout the project and across the spectrum of customer, contractor, subcontractor, and supplier activities? Has a focal point been identified in the organizational structure for the resolution of possible conflicts in this area?
2. Are the technologies and technology applications used by the various project organizations compatible across the board? For example, does every organization involved in the design process utilize the same CAD/CAM/CAS configurations?
3. Are the business processes compatible in regard to all of the organizations participating as members of the project team?
4. Are the various logistics and maintenance support infrastructures compatible with the system requirements? For example, does each participating organization have the required transportation capability to move people and materials as required?
5. Are the political structures for each participating organization compatible and supportive of program/project objectives?

Although there are many questions of this nature that can be addressed, the objective here is to ensure success by covering some of the issues that are important in a *global* environment. These issues must be inherent in the development of the SEMP.

6.9 SUMMARY

With the focus of this chapter primarily oriented to the subject of *planning*, the major emphasis has been on the development of the System Engineering Management Plan (SEMP). This planning document serves as the vehicle through which system engineering functions/tasks are initially defined and later implemented. As this plan is the key to describing the system engineering requirements for a typical program, a summary in the form of a checklist, as it applies to the SEMP's content, may be helpful to the systems engineer:

1. Does the SEMP include
   (a) A Statement of Work (SOW)?
   (b) A description of system engineering tasks?
   (c) A description of work packages and a work breakdown structure (WBS)?
   (d) A description of the program/project organization, the system engineering organization, the critical organizational interfaces (i.e., customer interfaces, producer/contractor interfaces, supplier interfaces) and applicable policies and procedures?
   (e) A specification/documentation tree?
   (f) A detailed program schedule?
   (g) Program/task cost projections?
   (h) A procedure for cost/schedule/technical performance measurement, review, evaluation, and control?
   (i) A description of program reporting requirements?
   (j) A Risk Management Plan?
2. Does the SEMP adequately describe the system engineering process, including coverage of
   (a) A needs analysis?
   (b) Feasibility analysis?
   (c) System operational requirements?
   (d) Maintenance and support concept?
   (e) A procedure for identifying and prioritizing technical performance measures (TPMs)?
   (f) Functional analysis and allocation?
   (g) System synthesis, analysis, and design optimization?
   (h) Design integration and support?
   (i) Design reviews?
   (j) System test and evaluation (validation)?
   (k) Production and/or construction?
   (l) System utilization and sustaining support?
   (m) System upgrades and modifications?
   (n) System retirement and material recycling/disposal?
3. Does the SEMP cover the requirements for the integration of applicable engineering specialties into the total design process, including
   (a) Software engineering?
   (b) Reliability engineering?
   (c) Maintainability engineering?
   (d) Human factors engineering?
   (e) Safety engineering?
   (f) Security engineering?
   (g) Manufacturing and production engineering?
   (h) Logistics and supportability engineering?
   (i) Disposability engineering?

(j) Quality engineering?
(k) Environmental engineering?
(l) Value/cost engineering?

4. Does the SEMP describe the necessary communication links with other program planning documents such as
   (a) Program Management Plan (PMP)?
   (b) Individual functional design plans (as applicable)?
   (c) Marketing and supplier management plan?
   (d) Manufacturing/production plan?
   (e) Integrated Logistic Support Plan (ILSP) and/or integrated maintenance management plan?
   (f) Test and Evaluation Master Plan (TEMP)?
   (g) Configuration management plan?
   (h) Data management plan?
   (i) Total quality management plan (TQMP)?
   (j) System retirement and material recycling/disposal plan?
5. Does the SEMP support the requirements of the System Specification (Type "A")?
6. Does the SEMP address the globalization and international environmental requirements (as applicable)?
7. Does the SEMP include adequate coverage of the current technology requirements?
8. Does the SEMP adequately support the objectives of system engineering?

QUESTIONS AND PROBLEMS

1. System engineering planning commences early at program inception with the definition of overall program requirements. Why is it essential that this planning activity start as soon as possible? What is likely to happen if system engineering planning is initiated later?

2. How do the System Specification (Type "A") and the System Engineering Management Plan (SEMP) relate to each other?

3. Who is responsible for preparing the SEMP—consumer, producer, contractor, subcontractor, or supplier? Describe some of the conditions and interfaces as applicable.

4. Select a system of your choice, describe the acquisition process, and develop a detailed outline of a SEMP for the program in question.

5. Select a program of your choice, and describe the system engineering tasks for that program (justify the tasks selected). Identify some of the key interfaces that exist.

6. For the tasks identified in Question 5, develop (a) a detailed schedule in the form of a program network and (b) a cost estimate for the proposed scheduled activity.

7. The following data are available (in Figure 6.43):

Event	Previous Event	t_a	t_b	t_c
8	7	20	30	40
	6	15	20	35
	5	8	12	15
7	4	30	35	50
	3	3	7	12
6	3	40	45	65
	2	25	35	50
5	2	55	70	95
4	1	10	20	35
3	1	5	15	25
2	1	10	15	30

Figure 6.43 Problem 7 data.

(a) Construct a PERT/CPM chart from the data.
(b) Determine the values for standard deviation, *TE*, *TL*, *TS*, *TC*, and *P*.
(c) What is the critical path? What does this value mean?

8. When employing PERT/COST, the cost–time option applies. What is meant by the cost–time option? How can it affect the critical path?

9. What is the purpose of a WBS? What is the difference between a WBS, an SWBS, and a CWBS? How do work packages relate to the WBS? Construct a WBS for a program of your choice.

10. Describe in your own words the steps that should be followed in determining the "supplier requirements" associated with the acquisition of a new system.

11. Identify and describe some of the factors that should be considered in "make-or-buy" or "outsourcing" decisions.

12. Why is the development of a make-or-buy plan important? What is included?

13. Should the system engineering organization be involved in make-or-buy decisions? If so, in what capacity? If not, why not?

14. Development of an RFP in preparation for supplier proposals, evaluation, and selection is extremely critical from a system engineering standpoint. Identify and explain the reasons for such, and briefly describe key features that should be included.

15. How can political, social/societal, and economic factors influence the supplier selection process? Provide a few examples.

16. Describe in your own words some of the trends that are occurring in the world today as they relate to customer, contractor, and supplier activities.

17. What is meant by "postproduction support"? Provide some examples.

18. How does technical performance measurement fit into the system engineering planning process? What is the significance of the TPMs?

19. There are various types of contract structures that can be imposed through the contract negotiation process to include FFP, FP, CPFF, CPIF, cost sharing, and time and material. Describe each and include some discussion as to applications.

20. When establishing multiple incentives under incentive contracting, what steps would you follow? How will you determine the specific factors or characteristics on which to establish incentives?

21. Under incentive contracting, what is meant by an incentive/penalty sharing ratio? How is it applied? How does the SR relate to supplier/contractor risks?

22. Should the system engineer participate in the contract negotiation process? If so, in what capacity?

23. Describe some of the methods/tools that can be used to facilitate implementation of the system engineering process.

24. Why is it important to develop a risk management plan? What is included?