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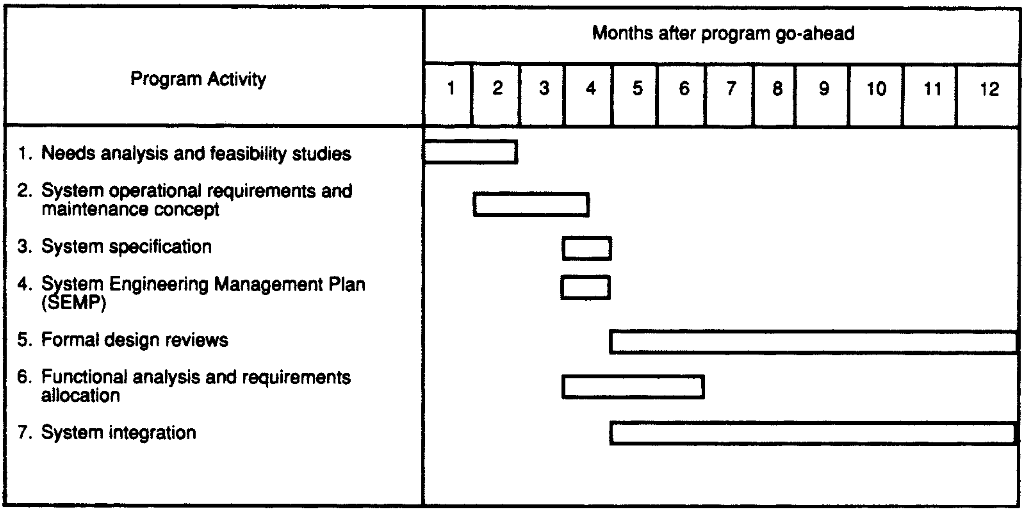

Figure 6.16 Partial bar chart.

4. *Program networks:* Network scheduling methods include the Program Evaluation and Review Technique (PERT), the Critical Path Method (CPM), and various combinations of these. PERT and CPM are ideally suited for early planning where precise task time data are not readily available, and the aspects of probability are introduced to help define risk leading to improved decision making. These techniques

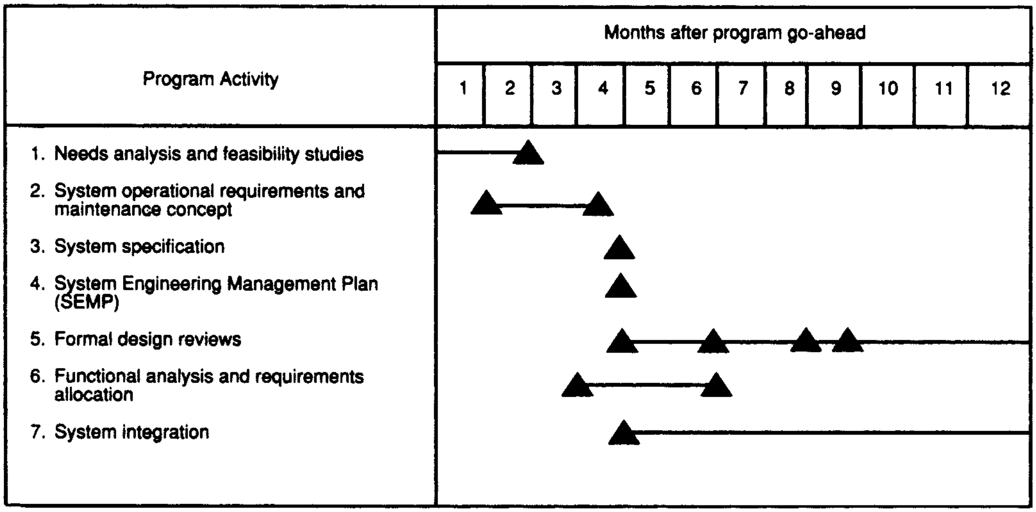

Figure 6.17 Sample milestone chart.

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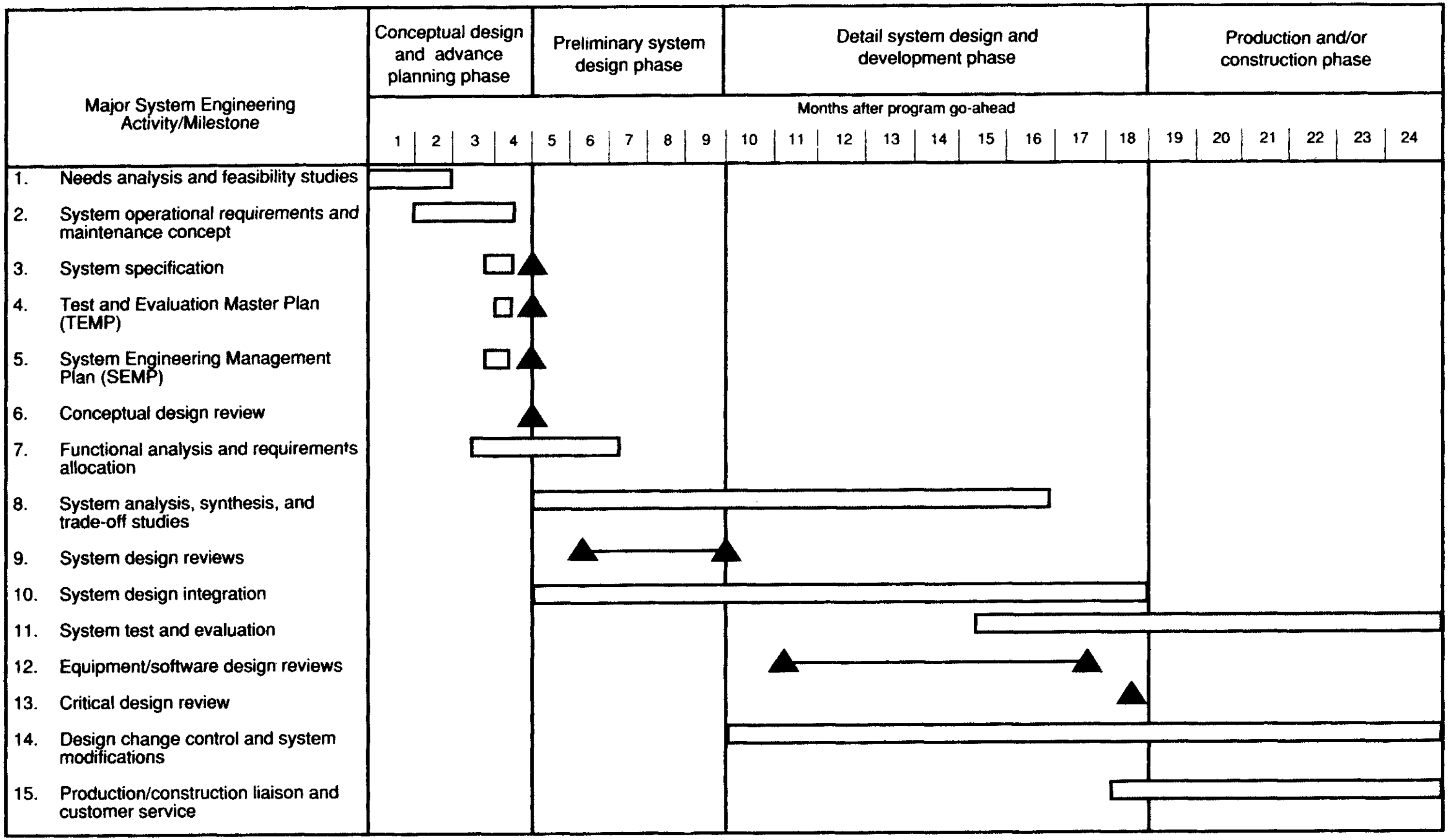


Figure 6.18 Major system engineering activities and milestones.

provide visibility and enable management to control one-of-a-kind projects as opposed to repetitive functions. Further, the network approach is effective in showing the interrelationships of combined activities.[11] Figure 6.19 shows an example of a network diagram consisting of 17 "events" and 29 major "activities." Events are usually designated by circles and are considered as checkpoints showing specific milestones; that is, dates for starting a task, completing a task, and delivering an item under contract. Activities are represented by the lines between the circles, indicating the work that needs to be accomplished to complete an event. Work can start on the next activity only after the preceding event has been completed. The numbers on the activity lines indicate the time required in days, weeks, or months. The first number reflects an optimistic time estimate, the second number indicates the expected time, and the third number indicates a pessimistic time estimate.[12]

In applying PERT/CPM to a project, one must identify all interdependent events and activities for each phase of the project. Events are related to program milestone dates that are based on management objectives. Figure 6.20 describes the major activities that are reflected by the lines in Figure 6.19. Managers and programmers work with engineering organizations to define these objectives and identify tasks and subtasks. When this is accomplished to the necessary level of detail, networks are developed, starting with a summary network and working down to detailed networks covering specific segments of a program. The development of networks is a team approach.

When actually constructing networks, one starts with an end objective (i.e., Event 17 in Figure 6.19) and works backward in developing the network until Event 1 is identified. Each event is labeled, coded, and checked in terms of program time frame. Activities are then identified and checked to ensure that they are properly sequenced. Some activities can be performed concurrently, and others must be accomplished in series. For each completed network, there is one "beginning event" and one "ending event," and all activities must lead to the ending event.

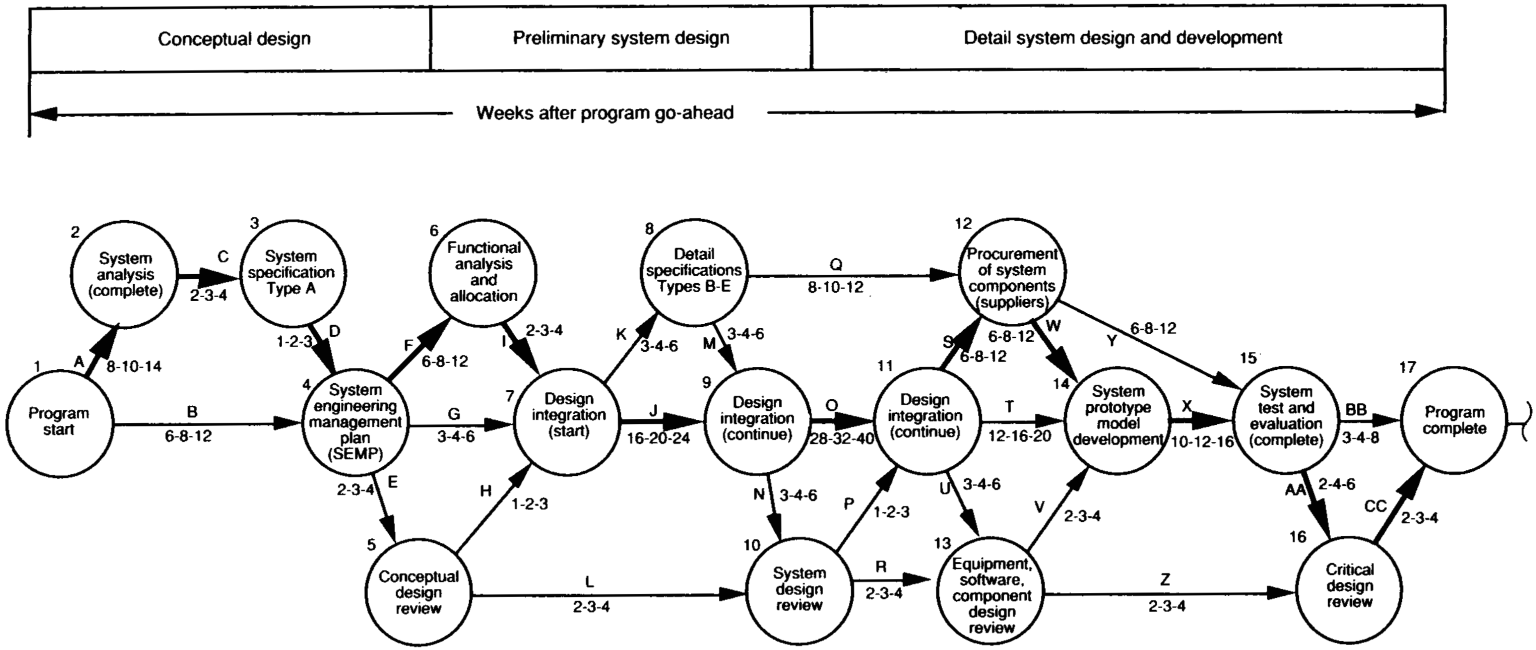
The next step in developing a network is to estimate activity times and to relate these times in terms of probability of occurrence. An example of the calculations that support a typical PERT/CPM network is presented in Figure 6.21 and described in the following list.

a. Column 1

   List each event, starting from the last event and working backward to the beginning (i.e., from Event 17 to Event 1 in Figure 6.19).

[11]Two good references covering project management scheduling methods are (1) H. Kerzner, *Project Management: A Systems Approach to Planning, Scheduling, and Controlling*, 7th ed. (New York: John Wiley & Sons, Inc., 2000); and (2) D. I. Cleland, *Project Management: Strategic Design and Implementation*, 3rd ed. (New York: McGraw-Hill, 1998).

[12]The level of detail and depth of network development (i.e., the number of activities and events included) are based on the criticality of tasks and the extent to which program evaluation and control are desired. Milestones that are critical in meeting the objectives of the program should be included, along with activities that require extensive interaction for successful completion. The author has had experience dealing with PERT/CPM networks including 10 to 700 events. The number of events/activities, of course, will vary with the project.



Critical Path: 1-2-3-4-6-7-9-11-12-14-15-16-17

Figure 6.19 Partial program summary network.

Activity	Description of Program Activity
A	Perform needs analysis, conduct feasibility studies, and and accomplish systems analysis (operational requirements, maintenance concept, and functional definition of the system).
B	Conduct advance planning, perform initial management functions, and complete the System Engineering Management Plan (SEMP).
C	Prepare the System Specification (Type A).
D	Develop system-level technical requirements for inclusion in the System Engineering Management Plan (SEMP).
E	Prepare system-level design data and supporting materials for the Conceptual Design Review.
F	Accomplish functional analysis and the allocation of overall system requirements to the sub-system level and below (as required).
G	Develop the necessary organizational and related infra-structure in preparation for the accomplishment of the required program design integration tasks.
H	Translate the results from the Conceptual Design Review to the appropriate design activities (i.e., approved design data, recommendations for improvement/corrective action).
I	Translate the results from the functional analysis and allocation activity into specific design criteria required as an input for the design integration process.
J	Accomplish preliminary design and related design integration activities.
K	Translate the results from system-level design into specific requirements at the sub-system level and below. Prepare Development, Process, Product, and/or Material Specifications as required.
L	Conduct the necessary planning and prepare for the System Design Review.
M	Translate the requirements contained within the various applicable specifications into specific design criteria required as an input for the design integration process.
N	Prepare design data and supporting materials (as a result of preliminary design) for the System Design Review:
O	Accomplish detail design and related design integration activities.
P	Translate the results from the System Design Review to the appropriate design activities (i.e., approved design data, recommendations for improvement/corrective action).
Q	Identify the appropriate system component suppliers, impose the necessary specification requirements through contracts, and monitor supplier activities.
R	Conduct the necessary planning and prepare for the Equipment/Software/Component Design Reviews (there may be a series of individual design reviews covering different system components).
S	Provide detail design data (as necessary) to support supplier operations.
T	Develop a prototype model, with associated support, in preparation for system test and evaluation.
U	Prepare design data and supporting materials (as a result of detail design) for the Equipment/Software/Component Design Reviews.
V	Translate the results from the Equipment/Software/Component Design Reviews for incorporation into the prototype model(s) as applicable. The prototype model that is to be utilized in test and evaluation must reflect the latest design configuration.
W	Provide supplier components, with supporting data, for the development of the system prototype to be utilized in test and evaluation activities.
X	Prepare for and conduct System Test and Evaluation (implement the requirements of the Test and Evaluation Master Plan).
Y	Provide test data and logistic support, from the various suppliers, throughout the system test and evaluation phase. Test data are required to cover individual tests conducted at supplier facilities, and logistic support (i.e., spare/repair parts, test equipment, etc.) is necessary to support system testing activities.
Z	Conduct the necessary planning and prepare for the Critical Design Review.
AA	Test results, in the form of either design verification or recommendations for improvement/corrective action, are provided as an input the Critical Design Review.
BB	Prepare system test and evaluation report.
CC	Translate the results from the Critical Design Review for incorporation into the final system configuration prior to entering the Production and/or Construction Phase of the Program.

Figure 6.20 List of activities in the program network.

1	2	3	4	5	6	7	8	9	10	11	12
Event number	Previous event number	t_a	t_b	t_c	t_e	s^2	TE	TL	TS	TC	Probability (%)
17	16	2	3	4	3.0	0.111	115.2	115.2	0	110	6.4
	15	3	4	8	4.5	0.694	112.1	115.2	3.1	115	47.9
16	15	2	4	6	4.0	0.444	112.1	112.2	0	120	91.9
	13	2	3	4	3.0	0.111	86.5	112.2	25.7		
15	14	10	12	16	12.3	1.000	108.2	108.2	0		
	12	6	8	12	8.3	1.000	95.9	108.2	12.3		
14	13	2	3	4	3.0	0.111	86.5	95.9	9.4		
	12	6	8	12	8.3	1.000	95.9	95.9	0		
	11	12	16	20	16.0	1.778	95.3	95.9	0.6		
13	11	3	4	6	4.2	0.250	83.5		13.6		
	10	2	3	4	3.0	0.111	53.8		42.1		
12	11	6	8	12	8.3	1.000	87.6	87.6	0		
	8	8	10	12	10.0	0.444	60.8	87.6	26.8		
11	10	1	2	3	2.0	0.111	52.8	79.3	26.5		
	9	28	32	40	32.7	4.000	79.3	79.3	0		
10	9	3	4	6	4.2	0.250	50.8		30.7		
	5	2	3	4	3.0	0.111	21.3		59.0		
9	8	3	4	6	4.2	0.250	35.0	46.6	11.6		
	7	16	20	24	20.0	1.778	46.6	46.6	0		
8	7	3	4	6	4.2	0.250	30.8		15.8		
7	6	2	3	4	3.0	0.111	26.6	26.6	0		
	5	1	2	3	2.0	0.111	20.3	26.6	6.3		
	4	3	4	6	4.2	0.250	19.5	26.6	7.1		
6	4	6	8	12	8.3	1.000	23.6	23.6	0		
5	4	2	3	4	3.0	0.111	18.3		9.3		
4	3	1	2	3	2.0	0.111	15.3	15.3	0		
	1	6	8	12	8.3	1.000	8.3	15.3	7.0		
3	2	2	3	4	3.0	0.111	13.3	13.0	0		
2	1	8	10	14	10.3	1.000	10.3	10.3	0		

Figure 6.21 Example of program network calculations.

b. Column 2

List all previous events that lead into, or are shown as being prior to, the event listed in Column 1 (e.g., Events 15 and 16 lead into Event 17).

c. Columns 3 to 5

Determine the optimistic time (t_a), the most likely time (t_b), and the pessimistic time (t_c) in weeks or months for each activity. Optimistic time means that there is very little chance that the activity can be completed before this time, whereas pessimistic time means that there is little likelihood that the activity will take longer. The most likely time (t_b) is located at the highest probability point or the peak of the distribution curve. These times may be predicted by someone who is experienced in estimating. The time estimates may follow different distribution curves, where P represents the probability factor (see Figure 6.22). The three time estimates are also included in Figure 6.19 for each activity (A, B, C, etc.).

d. Column 6

Calculate the expected or mean time, t_e, from

$$t_e = \frac{t_a + 4t_b + t_c}{6} \tag{6.1}$$

e. Column 7

In any statistical distribution, one may wish to determine the various probability factors for different activity times. Thus, it is necessary to compute the variance (σ^2) associated with each mean value. The square root of the variance, or the standard deviation, is a measure of the dispersion of values within a distribution and is useful in determining the percentage of the total population sample that falls within a specified band of values. The variance is calculated from Equation (6.2):

$$\sigma^2 = \left(\frac{t_c - t_a}{6}\right)^2 \tag{6.2}$$

f. Column 8

The earliest expected time for the project, *TE,* is the sum of all times, t_e, for each activity, along a given network path, or the cumulative total of the expected times through the preceding event remaining on the same path throughout the network. When several activities lead to an event, the highest time value (t_e) will be used. For instance, in Figure 6.19, Path 1–4–7–9–11–14–15–17 totals 98; Path 1–2–3–4–7–9–11–14–15–17 totals 105; and Path 1–2–3–4–6–7–9–11–12–14–15–16–17 totals 115.2. The highest value for *TE* (if one were to check all network paths) is 115.2 weeks, and this is the value selected for Event 17. The *TE* values for Events 16, 15, and so on, are calculated in a similar manner, working backward to Event 1.

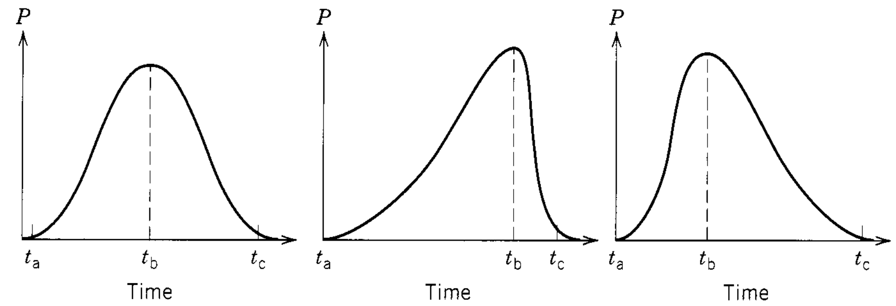


Figure 6.22 Sample distribution curves.

g. Column 9

The latest allowable time for an event, *TL*, is the latest time for completion of the activities that immediately precede the event. *TL* is calculated by starting with the latest time for the last event (i.e., where *TE* equals 115.2 in Figure 6.21) and working backward, subtracting the expected time (t_e) for each activity, remaining on the same path. The *TL* values for Events 16, 15, and so on, are calculated in a similar manner.

h. Column 10

The slack time, *TS*, is the difference between the latest allowable time (*TL*) and the earliest expected time (*TE*):

$$TS = TL - TE \tag{6.3}$$

i. Columns 11 and 12

TC refers to the required scheduled time for the network based on the actual need. Assume that management specifies that the project reflected in Figure 6.19 must be completed in 110 weeks. It is now necessary to determine the likelihood, or probability (*P*), that this will occur. This probability factor is determined as follows:

$$Z = \frac{TC - TE}{\sqrt{\Sigma \text{ path variances}}} \tag{6.4}$$

where *Z* is related to the area under the normal distribution curve, which equates to the probability factor. The "path variance" is the sum of the individual variances along the longest path, or the critical path, in Figure 6.19 (i.e., Path 1–2–3–4–6–7–9–11–12–14–15–16–17).

$$Z = \frac{110 - 115.2}{\sqrt{11.666}} = -1.522$$

From the normal distribution tables, the calculated value of −1.522 represents an area of approximately 0.064; that is, the probability of meeting the scheduled time of 110 weeks is 6.4%. If the management requirement is 115 weeks, then the probability of success would be approximately 47.9%; or if 120 weeks were specified, the probability of success would be around 91.9%.

When evaluating the resultant probability value (Column 12 of Figure 6.21), management must decide on the range of factors allowable in terms of risk. If the probability factor is too low, additional resources may be applied to the project in order to reduce the activity schedule times and improve the probability of success. On the other hand, if the probability factor is too high (i.e., there is practically no risk involved), this may indicate that excess resources are being applied, some of which may be diverted elsewhere. Management must assess the situation and establish a goal.

In Figure 6.19, the critical path, which is reflected by the heavy arrows (i.e., Path 1–2–3–4–6–7–9–11–12–14–15–16–17), includes the series of activities requiring the greatest amount of time for completion. These are *critical* activities where slack times are zero, and a slippage of schedule in any one of these activities will cause a schedule delay in the overall program. Thus, these activities must be closely monitored and controlled throughout the program.

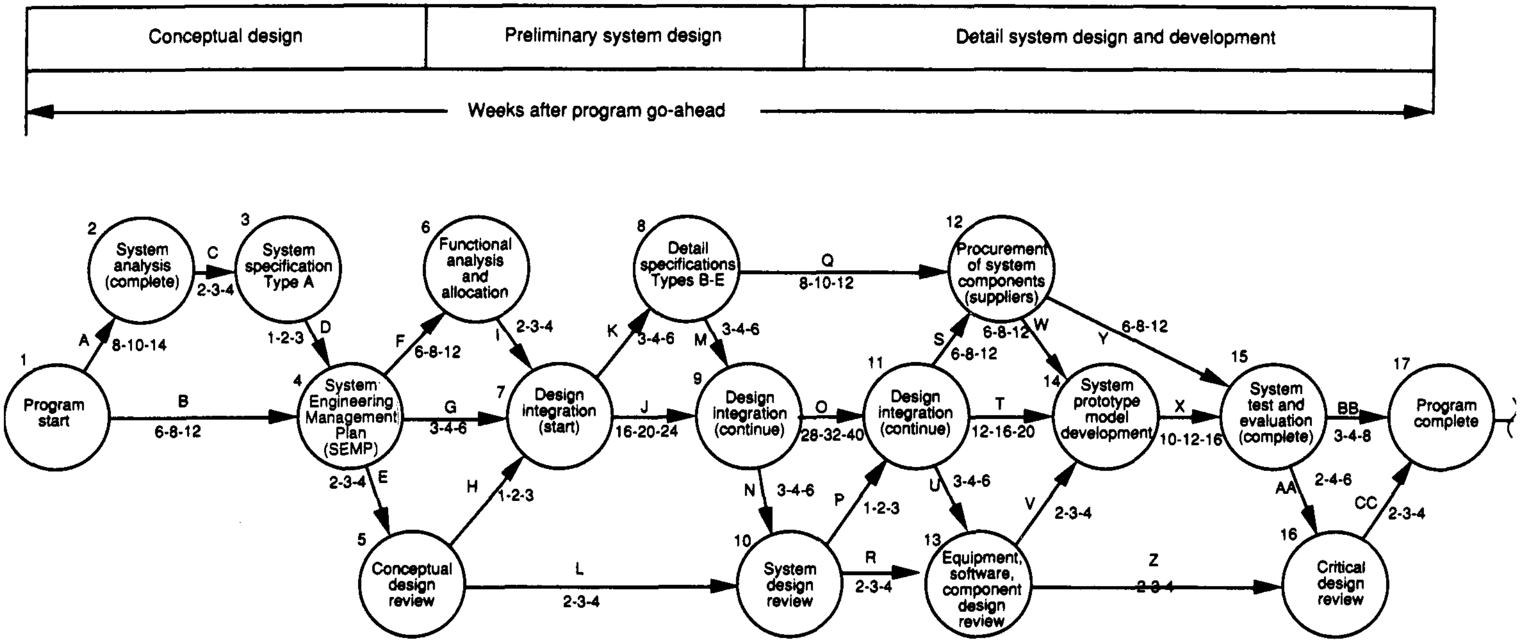
The network paths representing other program activities shown in Figure 6.19 include slack time (*TS*), which constitutes a measure of program scheduling flexibility. The slack time is the interval of time in which an activity could actually be delayed beyond its earliest scheduled start without necessarily delaying the overall program completion time. The availability of slack time will allow for a possible reallocation of resources. Program scheduling improvements may be possible by shifting resources from activities with slack time to activities along the critical path.

An additional point relative to program schedules is that a hierarchy of individual networks may be developed following a pattern similar to the WBS development approach illustrated in Figure 6.11. To provide the proper monitoring and control actions, scheduling may be accomplished at different levels. Figure 6.23 shows a breakdown of the program network (illustrated in Figure 6.19) into a lower-level network covering reliability program requirements. A similar network may be developed for maintainability, another network for electrical design, and additional detailed networks as appropriate. These lower-level networks must, of course, directly support the overall program network.

The utilization of the PERT/CPM scheduling technique offers a number of advantages:

a. It is readily adaptable to advanced planning and essentially forces the detailed definition of tasks, task sequences, and task interrelationships. All levels of management and engineering are required to think through and evaluate the entire project carefully.

b. With the identification of task interrelationships, it tends to force the initial definition and subsequent management and control of the interfaces between customer and contractor, organizations within the contractor's structure, and between the contractor and various suppliers. Management and



Top-level program network

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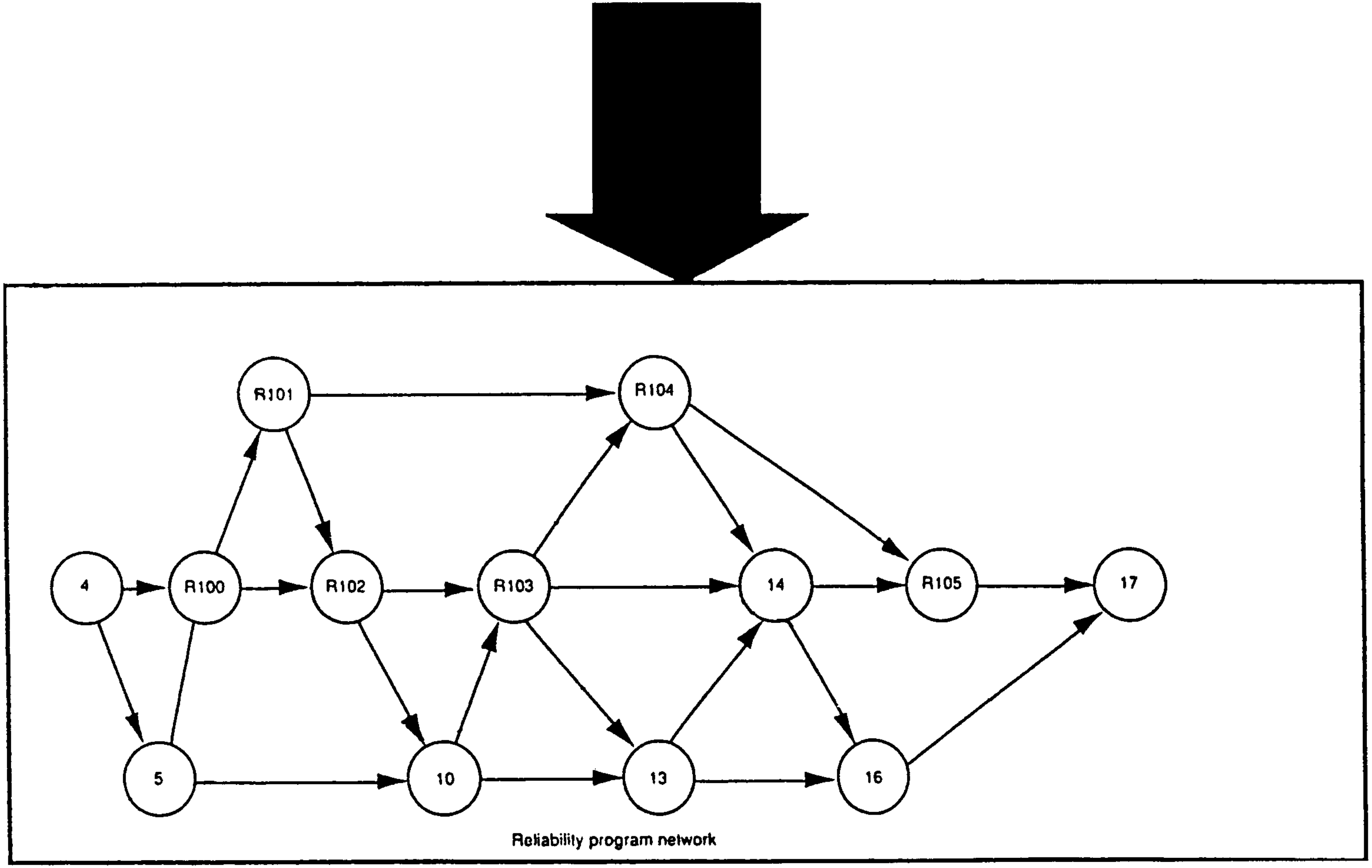

Figure 6.23 Top-level network breakdown by program element.

engineering gain a greater appreciation of the project in terms of total resource requirements.

c. It enables management and engineering to predict with some degree of certainty the probable time that it will take to achieve an objective. Areas of program risk/uncertainty can be readily identified.

d. It enables the rapid assessment of progress and allows for the early detection of possible delays and problems.

The implementation of PERT/CPM in a comprehensive and timely manner is possible because the technique is particularly adaptable to computer methods. In fact, there are a number of computer models and associated software that are available for network scheduling.

5. *Network/cost:* PERT/CPM networks may be extended to include cost by superimposing a cost structure on the time schedule. When implementing this technique, there is always the time–cost option, which enables management to evaluate alternatives relative to the allocation of resources for activity accomplishment. In many instances, time can be saved by applying more resources. Conversely, cost may be reduced by extending the time to complete an activity.

The time–cost option can be attained through the following general steps:

a. For each activity in the network, determine possible alternative time and cost estimates (and cost slope) and select the lowest cost alternative.

b. Calculate the critical path for the network. Select the lowest cost option for each network activity, and check to ensure that the total of the incremental activity times does not exceed the allowable overall program completion time. If the calculated value exceeds the program time permitted, review the activities along the critical path and select the alternative with the lowest cost slope. Reduce the time value to be compatible with the program requirement.

c. After the critical path has been established in terms of the lowest cost option, review all network paths with slack time, and shift activities to extend the times and reduce costs wherever possible. Activities with the steepest time–cost slopes should be addressed first.

PERT/CPM–COST has proven to be a very useful technique in the planning of program events and activities, and it allows for the necessary program schedule–cost status monitoring and control requirements accomplished throughout system development.

6. *Gantt chart:* This technique is used primarily in production and/or construction planning to show activity or job requirements, facility loading, and work status on a day-to-day basis. It was designed for and is most successfully utilized to support highly repetitive operations. An example of one basic form of a Gantt chart is shown in Figure 6.24. Gantt charts, used for both long-range planning and short-range scheduling on a day-to-day basis, may take the form of machine-loading control charts, labor-loading control charts, and/or job progress control charts.

7. *Line of balance (LOB):* This technique is similar to the Gantt chart relative to determining production/construction status. Although the Gantt technique primarily

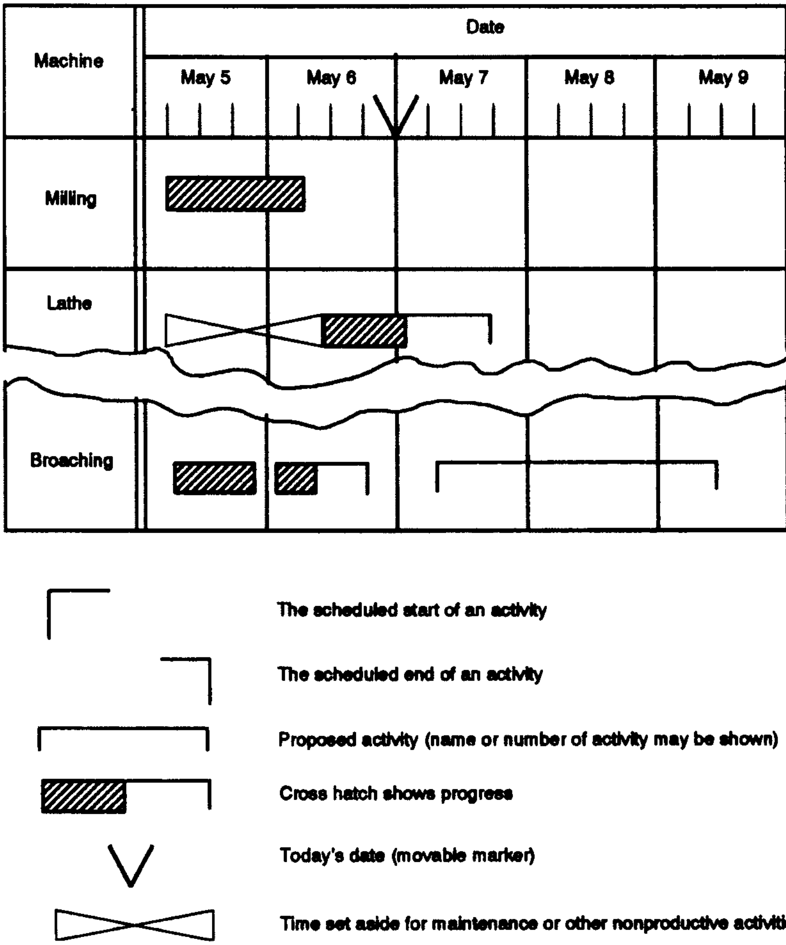

Figure 6.24 Gantt chart for a machine used in production.

relates information on the effective and efficient utilization of resources expended (e.g., labor loading, machine loading), LOB is more product-oriented. LOB is not directly concerned with the resources expended, but is utilized in determining production progress in terms of percentage of task completion. Major "bottlenecks" in the production process are emphasized.

Application of the scheduling methods described herein will vary from project to project and from one organization to the next. In addition, the technique used may be different for each phase of the system life cycle. For instance, the use of PERT/CPM may be readily adaptable to a research and development program, whereas Gantt charts are more appropriate for a production program.

In considering the objectives of system engineering, the use of PERT/CPM (or an equivalent network approach), as compared with bar charts or milestone charts, seems appropriate. There are many different one-of-a-kind tasks accomplished relatively early in the system life cycle, and the organizational task interfaces are numerous. There is a need for a high degree of visibility across the project, and it is important that potential problems be detected as early as possible. The use of the network scheduling technique should help in maintaining the necessary communications and in providing the appropriate monitoring and control functions.

6.2.8 Preparation of Cost Projections[13]

Good cost control is important to all organizations, regardless of size. This is particularly true in our current environment where resources are limited and competition is high.

Cost control starts with the initial development of cost estimates for a given program and continues with the functions of cost monitoring and the collection of data, the analysis of such data, and the initiation of corrective action before it is too late. Cost control implies good overall cost management, which includes cost estimating, cost accounting, cost monitoring, cost analysis, reporting, and the necessary control functions. More specifically, the following activities are applicable.

1. *Define elements of work:* Develop a Statement of Work (SOW) in accordance with the requirements described in Section 6.2.1. Detailed project tasks are identified in Section 6.2.2 (refer to Figure 6.6).

2. *Integrate tasks into the work breakdown structure* (WBS): Combine project tasks into work packages, and integrate these elements of work into the work breakdown structure (WBS). Work packages are identified with each block in the WBS. These packages and WBS blocks are then related to organizational groups, branches, departments, suppliers, and so on. The WBS is structured and coded in such a manner that project costs can be initially allocated (or targeted) and then collected for each block. Costs may be accumulated both vertically and horizontally to provide summary figures for various categories of work. WBS objectives and requirements are described in Section 6.2.4 (refer to Figures 6.12 and 6.13 for system engineering functions in the WBS).

3. *Develop cost estimates for each project task:* Prepare a cost projection for each project task, develop the appropriate cost accounts, and relate the results to elements of the WBS.

[13]The various aspects of cost estimating, cost/schedule control, cost analysis, cost performance measurement, cost variance reporting, and related areas, are covered in most texts on program/project management. A good reference is H. Kerzner, *Project Management: A Systems Approach to Planning, Scheduling, and Controlling*, 7th ed. (New York: John Wiley & Sons, Inc., 2000). It should be noted that the emphasis in this section is primarily on the costing of internal projects versus the application of life-cycle cost analysis methods described in Appendix C, although the results here constitute an integral part of an overall life-cycle cost analysis projection.

4. *Develop a cost data collection and reporting capability:* Develop a method for cost accounting (i.e., the collection and presentation of project costs), data analysis, and the reporting of cost data for management information purposes. Major areas of concern are highlighted; that is, current or potential cost overruns and high-cost "drivers."

5. *Develop a procedure for evaluation and corrective action:* Inherent within the overall requirement for cost control is the provision for feedback and corrective action. As deficiencies are noted, or potential areas of risk are identified, project management must initiate the necessary corrective action in an expeditious manner.

An initial step in developing a good cost control capability is cost estimating and the preparation of cost projections. Each task is broken down into subtasks and other detailed elements of work, and personnel projections are developed on a month-to-month basis. Figure 6.25 identifies selected activities for a project involving the design and development of a relatively large-scale system. In this instance, a 12-month design period is assumed, and projections are made in terms of the number of individuals by job classification required to complete the task, scheduled on a month-to-month basis. For instance, under system engineering there is a need for the assignment of four individuals with the grade of "Senior Engineer" during Month 3 of the project. Although not completely shown in the figure, *all* major program activities should be covered through an appropriate breakout of job classification requirements; that is, principal engineer, senior engineer, engineer, junior engineer, engineering technician, analyst, draftsperson, data specialist, and shop mechanic. These resource requirements are projected for each project task and are related to the WBS (e.g., 3B1 100 in Figures 6.12 and 6.13).

Given a projection, presented in terms of labor requirements by grade, the next step is to convert these into cost factors on a month-to-month basis. Most organizations have established job classifications with computed salary pay scales. These factors are used in estimating the direct labor costs for a designated activity extended into the future. In addition, material costs are determined for each month, and the appropriate inflationary factors are added to both labor and material. The net results include a projection of *direct labor costs* and *direct material costs,* inflated as necessary to cover future economic contingencies. These projections must, of course, support all program tasks identified in Sections 6.2.1 and 6.2.2 and should be compatible with the related task schedules described in Section 6.2.7.

As individual project activities are being further defined through the preparation of cost estimates, not only must these activities be tied to a particular block in the WBS, but the results must be assigned to a specific cost account (refer to Figure 6.14). A partial breakdown structure for a project is presented in Figure 6.26. The objective is to show the various project cost accounts in a hierarchical manner, indicating the structure that will be used for subsequent cost accounting and reporting purposes.

Relative to application, cost estimating may be accomplished at any time or during any phase of the system life cycle. Sometimes during the early phases of conceptual and/or preliminary system design, when the availability of engineering data is

Program	WBS no.	Cost account	Projection (months)												Total
			1	2	3	4	5	6	7	8	9	10	11	12	
Project management	2A1000	2000	1	1	2	3	4	4	4	4	4	4	3	3	37
System engineering	3B1100	3000	-	-	-	-	-	-	-	-	-	-	-	-	
Principal engineer			1	1	1	1	1	1	1	1	1	1	1	1	12
Senior engineer			2	3	4	4	4	3	2	2	2	2	2	2	32
Design engineering	3B1200	7000	-	-	-	-	-	-	-	-	-	-	-	-	-
Principal engineer			2	3	3	3	3	2	2	2	2	2	2	2	28
Senior engineer			3	6	8	8	8	7	6	5	5	4	4	3	67
Engineer			5	7	10	15	17	20	20	20	20	17	16	9	176
Junior engineer			3	4	5	6	10	10	10	10	15	15	20	20	128
Engineering technician			1	1	1	5	7	7	8	9	10	10	12	15	86
Design data	2I1200	4000	2	2	3	5	5	10	15	15	20	25	25	25	152
System software	2E1000	8000	1	1	2	2	3	3	5	7	7	10	12	15	68
Design support	3B1300	5000	2	2	5	5	5	10	10	25	30	30	30	25	179
Intergrated logistic support	3B1400	6000	2	3	3	3	5	6	6	10	10	15	15	15	93
System test & evaluation	2J1000	9000	1	1	1	1	1	1	5	5	10	15	15	20	76
Total			26	35	48	61	73	84	94	115	136	150	157	155	1134

Figure 6.25 Project labor projection (man-months).

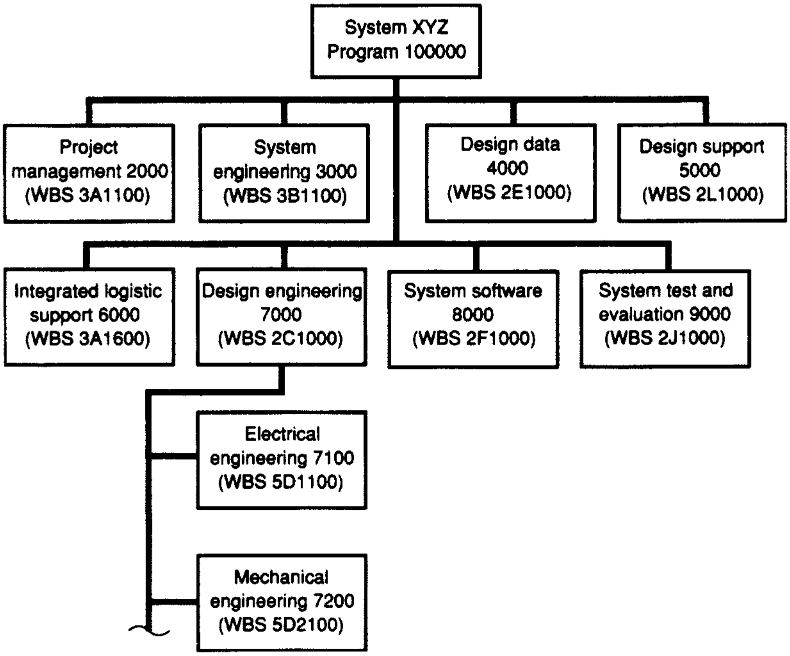

Figure 6.26 Partial cost account code breakdown structure.

limited, estimates may take the form of "rough orders of magnitude;" that is, approximations within plus or minus 30% of reality. The use of regression analysis, linear and nonlinear estimating relationships, learning curves, parametric analysis, or a combination of these, aids in the development of cost figures of merit (FOMs). Later, as engineering experience is acquired, estimating methods are more precise. Plans, specifications, design data, supplier cost proposals, updated project "cost-to-complete" reports, and so on, are available. Cost estimates, using actual engineering data and/or the development of data through analogous methods, are prepared with an expected accuracy in the order of plus or minus 5%.

On completion of the cost projections for individual tasks, one can then combine these into an overall cost projection for the project as a whole, as shown in Figure 6.27. Initially, an estimate for all direct labor is developed, with an organizational overhead factor applied on top. Direct material costs are then determined, and a second burden rate (i.e., a general-and-administration factor) is applied to cover some additional indirect costs associated with both labor- and material-related activities. The net result is an overall cost projection for the project, including both direct and indirect costs.[14]

[14]In the cost projection shown in Figure 6.27, direct labor costs were determined from the personnel labor figures in Figure 6.25. An average rate of $4000 per labor-month was used to calculate the monthly cost figures. A 200% overhead rate and a 20% general-and-administrative rate were used for illustrative purposes. In reality, each company, government organization, or equivalent, will have different rates based on individual audited criteria.

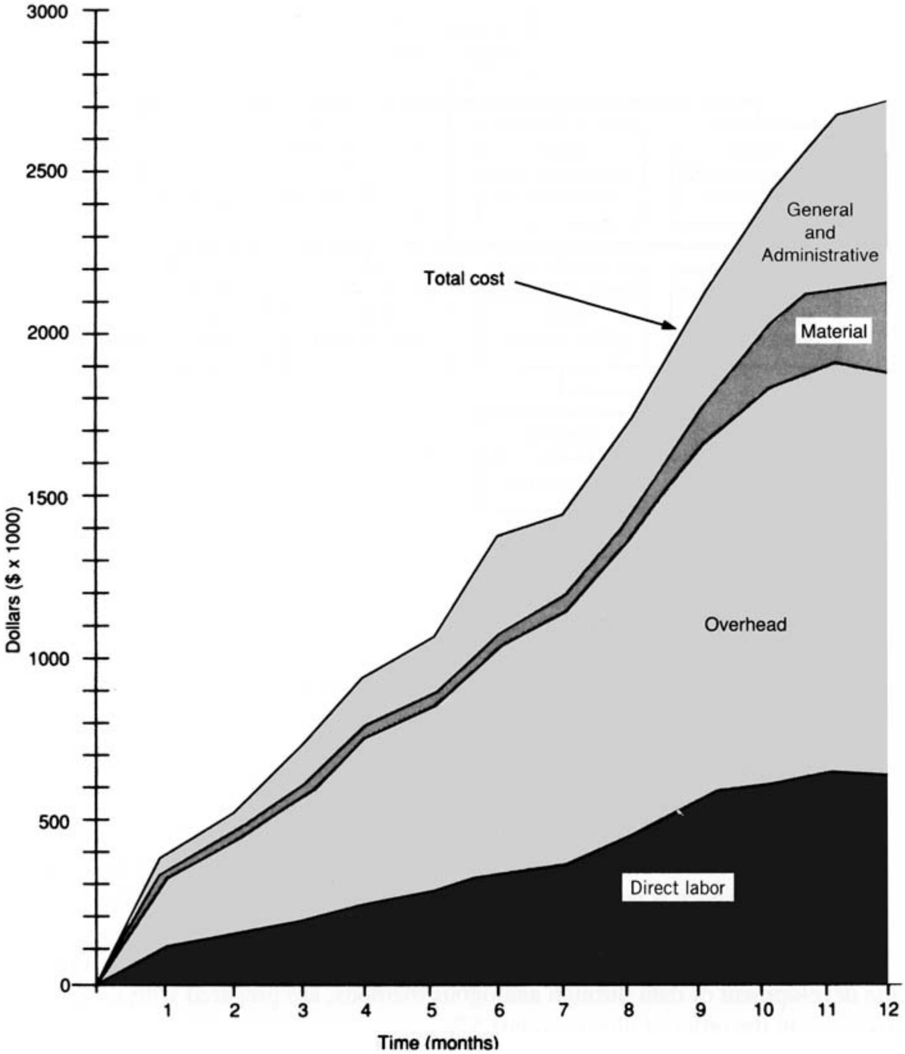

Figure 6.27 Project cost projection.

6.2.9 Technical Reviews and Audits

Technical reviews are an integral part of the system engineering process. These reviews can vary from the very formal design reviews described in Chapter 5 to the informal reviews concerned with specific project activities or task elements of the work breakdown structure (WBS). All such reviews share the common objective of determining the technical adequacy of the existing system design configuration and whether or not its meets the initially specified requirements. Further, as the design and development effort evolves, the reviews become more detailed and definitive.

The type, number, and basic objectives of the formal design reviews conducted for a given program will vary with the nature and complexity of the system being developed, the organizational structure and type of contracting mechanism in place, and so on. In Chapter 5, formal design reviews include four basic categories of reviews; that is, *conceptual, system, equipment/software,* and *critical.* These are considered to be *basic* and representative for most programs. On the other hand, for many large-scale defense programs, there may be many more reviews, including system requirements review (SRR), system functional review (SFR), system design reviews (SDRs), preliminary design reviews (PDRs), software specification reviews (SPRs), system verification review (SVR), critical design review (CDR), test readiness review (TRR), production readiness review (PRR), and so on.[15] Although the scheduling of design reviews has many benefits, as conveyed in Chapter 5, it is essential that care be taken so as not to schedule so many that they become meaningless. The conductance of such reviews may be quite costly, considering the personnel time and resources required.

In addition to the formal design reviews conducted on many projects, there may be a number of formal *program management reviews* scheduled as well. Sometimes the design reviews are perceived as being oriented to only *engineering* and involving responsible engineers representing the appropriate *engineering specialties.* Key levels of program management are not involved, even though many of the design decisions discussed may have significant implications from an overall program management perspective. On the other hand, during the periodic management-oriented reviews, where the emphasis is often directed to current status in terms of *performance, cost,* and *schedule,* there are decisions made that can have a direct impact on design. Under certain conditions, the two categories of reviews can be counterproductive unless care is taken to ensure that the technical and management reviews are mutually supportive. A system engineering goal is to facilitate the communications process and the scheduling of both categories of reviews so that the results are complementary in meeting the overall program/project objectives.

6.2.10 Program Reporting Requirements

Inherent within the planning process is the establishment of both *technical* and *management* requirements at program inception. In addition, one needs to review progress against these requirements on a periodic basis as system design and development evolves. A procedure must established for the initiation of corrective action, as necessary, in the event of problems.

In response, a management information system (MIS) should be developed to provide ongoing visibility and the reporting of progress against designated cost, sched-

[15]Refer to (1) *Systems Engineering Fundamentals* (Fort Belvoir, VA: Defense Acquisition University, December 2000); and (2) EIA/IS-632, *Processes for Engineering a System* (Washington, DC: Electronic Industries Association, EIA).

ule, and performance measures. Schedule and cost information is derived in accordance with the procedures described in Sections 6.2.7 and 6.2.8. Periodic reports are necessary for purposes of assessing *current* status against *planned* status. The frequency of reporting is a function of the overall project schedule and the risks associated with various design activities. The comparison process should address such questions as, Is the project on schedule? Are the program costs within the established budget limitations? Assuming that the current personnel loading continues as is, what tasks are likely to be in a "cost overrun" position six months from now? These and similar questions will have to be answered on many occasions throughout the program.

Figure 6.28 presents an extract from a report covering schedule and cost data. The schedule (or time status) information reflects the output from a typical PERT/CPM network. Relative to performance, the technical performance measures (TPMs) identified in the system specification, and selected as being critical from a periodic review and control standpoint, must be included within the program reporting structure. These TPMs may include factors such as range, accuracy, weight, size, reliability (mean time between failure/MTBF and mean time between maintenance/MTBM), maintainability (mean corrective maintenance time/$\overline{M}ct$ and maintenance labor hours per system operating hour/MLHOH), downtime (mean maintenance downtime, MDT), availability, cost, power output, process time, and other parameters that relate directly to the mission of the system being developed. Figure 5.6 (Chapter 5) illustrates the TPM evaluation process as it is tied in with formal design reviews. The measurement, evaluation, and control of these parameters must also be covered through periodic program reporting.

The management information system (MIS) should readily point out existing problems, as well as potential areas in which problems are likely to occur if program operations continue as originally planned. To deal with such contingencies, planning should be initiated to establish a corrective-action procedure that includes the following steps:

1. Identify problems (or potential problem areas) and rank these in order of importance. Ranking should consider the criticality of the system function.

2. Evaluate each problem on the basis of ranking, addressing the most critical problems first. Alternative possibilities for corrective action are considered in terms of (a) effects on program schedule and cost, (b) impact on performance and effectiveness of the system, and (c) the risks associated with the decision as to whether to take corrective action. The most feasible alternative is identified.

3. Given the decision to take corrective action, planning is accomplished to initiate the steps required to resolve the problem. This may be in the form of a system configuration change, a change in management policy, a contractual change, and/or an organizational change.

4. After corrective action has been implemented, some follow-up activity is required to (a) ensure that the incorporated change(s) actually has resolved the problem and (b) assess other aspects of the program to ensure that additional problems have not been created as a result of the change.

Network/Cost Status Report

Project: System XYZ				Contract Number: 6BSB-1002					Report Date: 8/15/02			
Item/Identification				Time Status					Cost Status			
WBS. No.	Cost Account	Beginning Event	Ending Event	Exp. Elap. Time (te) (weeks)	Earliest Completion Date(D_E)	Latest Completion Date (D_L)	Slack D_L-D_E (Weeks)	Actual Date Completed	Cost Est. ($)	Actual Cost to Date ($)	Latest Revised Est. ($)	Overrun (Underrun) ($)
4A1210	3310	8	9	4.2	3/4/02	4/11/02	11.6	4/4/02	2500	2250	2250	(250)
4A1230	3762	R100	R102	3.0	5/15/02	4/28/02	-3.3		4500	4650	5000	500
5A1224	3521	7	9	20.0	6/20/02	8/3/02	0		6750	5150	6750	0

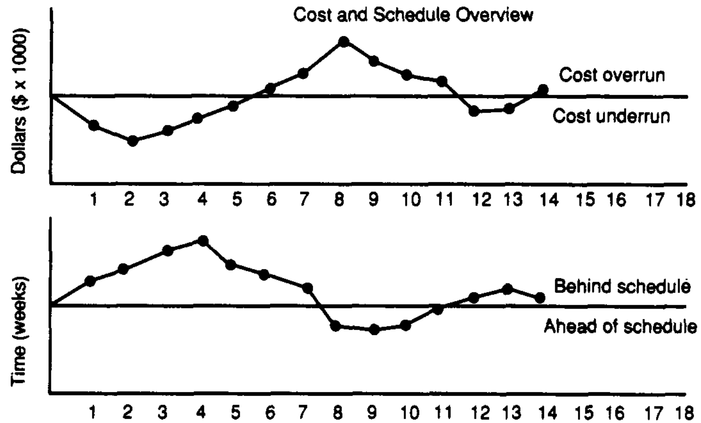

Figure 6.28 Program cost-schedule reporting.

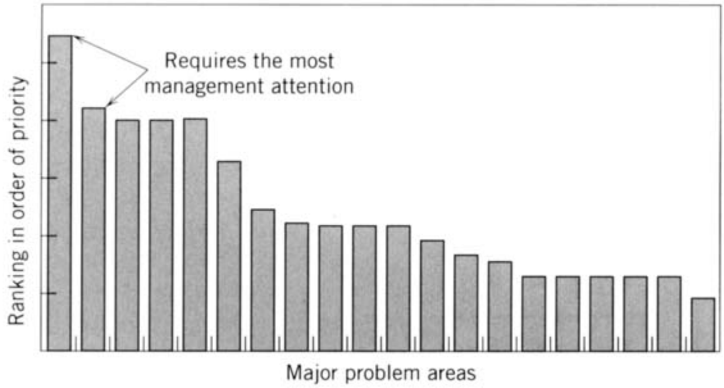

Figure 6.29 Pareto diagram identifying problem areas.

Relative to the ranking of problems (and their priorities) that need to be addressed, a Pareto analysis approach might be beneficial in creating visibility pertaining to degrees of importance. See Figure 6.29; the highest-ranked items need the most management attention. The implementation of any changes, of course, must be compatible with the procedures described in Section 5.4.

6.3 DETERMINATION OF "OUTSOURCING" REQUIREMENTS

The current demands for the delivery of more products, in shorter time frames and at least cost, and in a highly competitive international marketplace environment, has put greater emphasis on the practice of *outsourcing* and on the utilization of many different suppliers in fulfilling the requirements for developing, producing, and/or modifying systems. The term *outsourcing* refers to the identification, selection, and contracting with one or more outside suppliers for the procurement and acquisition of materials and services for a given system. The term *supplier* refers to a broad class of external organizations that provide products, components, materials, and/or services to a producer (or prime contractor). This may range from the delivery of a major subsystem or configuration item down to a small component part. More specifically, suppliers may provide services, including (1) the design, development, and manufacture of a major element of a system, (2) the production and distribution of items already designed (providing a manufacturing source), (3) the distribution of commercial and standard component parts from an established inventory (serving as a warehouse and providing parts from various sources of supply), and/or (4) the implementation of a process in response to some functional requirement.

For many systems today, suppliers provide a large number of their elements (e.g., more than 75% of the components in some instances), as well as the spares and repair parts that are required to support maintenance activities. Given the trends toward increased globalization and greater international competition, the suppliers associ-

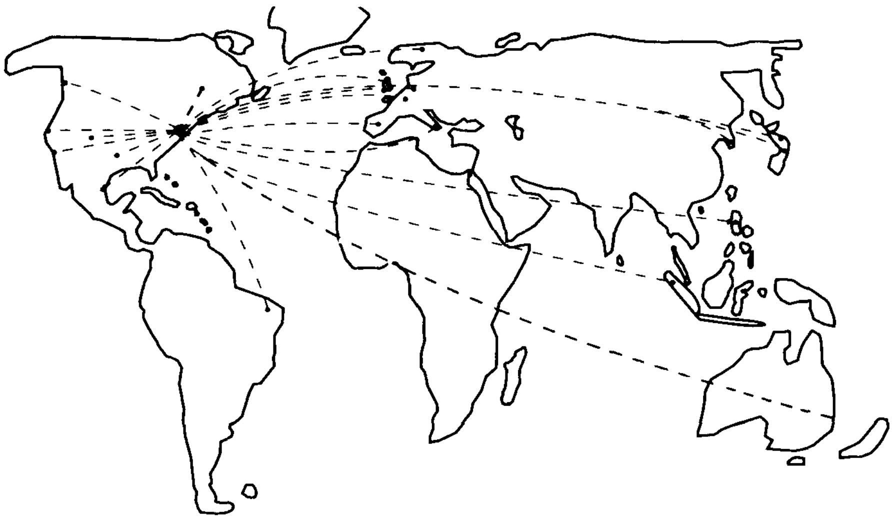

Figure 6.30 Potential suppliers for System "XYZ."

ated with any relatively large-scale program are likely to be geographically located throughout the world, thus creating a worldwide "working" environment, as shown in Figure 6.30. Further, when major suppliers are selected, particularly for the design and development of large system elements, there are likely to be a number of suppliers selected for the production and delivery of some of the smaller components that make up the various subsystems and items of an equivalent level and complexity. Thus, we sometimes find that we may be dealing with a *layering* of suppliers, as illustrated in Figure 6.31.

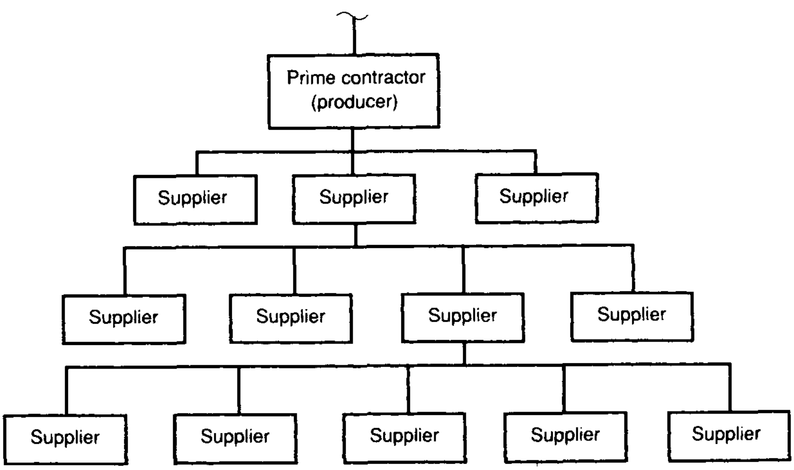

Figure 6.31 Typical structure involving the layering of suppliers.

With the involvement of many different suppliers in the design, development, manufacture, and support of systems, there is an ever-increasing need for the implementation of good system engineering practices and methods/techniques. Major suppliers, as key participants in the design process, must be involved from the beginning. The System Engineering Management Plan (SEMP) must include coverage of supplier functions and activities. The System Specification (Type "A") must provide a good functional baseline from which the various lower-level specifications can be developed. Of further significance, the *functional interfaces* (described in Section 2.7) must be well defined in the applicable specification. In essence, major suppliers must be brought into the design process early, must participate as members of the design team, and must be committed to the implementation of the system engineering process.

In regard to these requirements, the following sections discuss the identification of potential suppliers for a given program, the development of a *Request for Proposal* (RFP) soliciting supplier response, the review and evaluation of supplier proposals, the ultimate selection of suppliers, and the subsequent contracting for a defined level of activity. Supplier functions, organizational relationships, and responsibilities are covered further in Chapter 7.

6.3.1 Identification of Potential Suppliers

A review of the system engineering process described in Chapter 2 will illustrate a number of steps, commencing with the identification of a consumer need and extending through the definition of operational requirements, the maintenance concept, the identification of technical performance measures (TPMs), functional analysis and the allocation of requirements, and the preparation of the System Specification (Type "A"). These steps are represented by the first two blocks in Figure 6.32.

As indicated, the system is described in *functional* terms identifying the "WHATs," and each functional entity is evaluated and trade-off studies are conducted with the objective of determining "HOW" the function(s) can best be accomplished (refer to Section 2.7, Chapter 2). The basic question in each instance is, Should the function be accomplished through the application of equipment, software, facilities, data/information; the utilization of human resources; or a combination of these? The results of these trade-off studies are presented in the form of specific resource requirements.

The next step is to identify the possible sources of supply. Should the design and/or manufacture of an item of equipment, the development of a software package, or the completion of a process be accomplished in house by the producer or prime contractor, or should an external source of supply be selected? The objective is to establish the "WHERE" in determining the *source* in responding to resource requirements.

In many industrial organizations, a "make-or-buy" committee, or an equivalent activity within the producer's organization, is established, with representation from program management, engineering, logistics, manufacturing, purchasing, quality assurance, and other supporting organizational activities as required. Participating engineering should include the system engineering organization and the appropriate design disciplines. Decisions are based on the evaluation of a combination of factors, such as the criticality of need (When is the item required?), item complexity, the

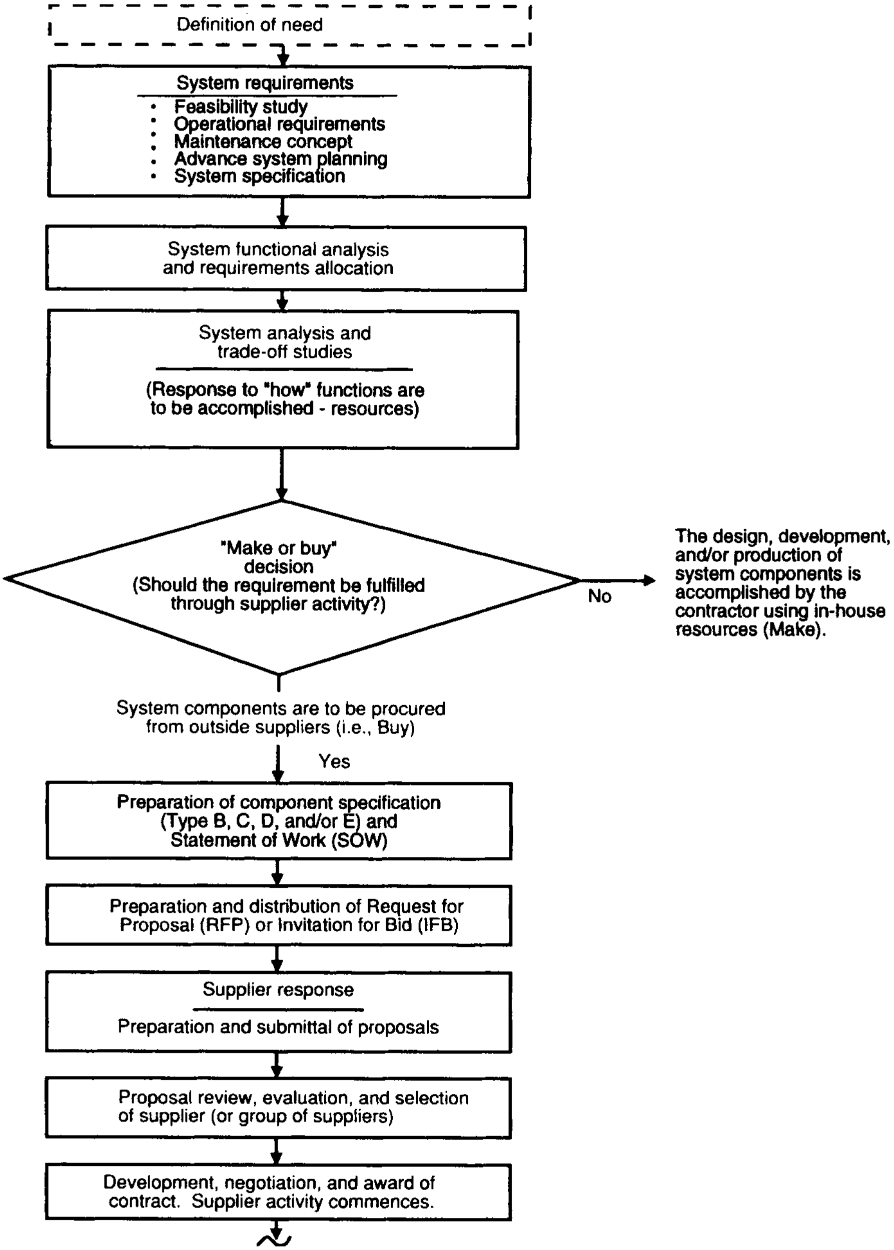

Figure 6.32 Supplier identification and procurrent process.

availability of internal technical capabilities and required resources versus the use of potential outside suppliers, related social and political factors, and cost.[16]

From a system engineering perspective, items that are relatively complex, involving the application of new technologies, and are critical to the overall system development effort, should be handled internally if at all possible. These activities will, in all likelihood, require frequent monitoring and the application of tight controls (both management and technical), which may be difficult to accomplish should a remotely located supplier be selected for the task.

As shown in Figure 6.32, the results from of the deliberations of the "make-or-buy" committee will lead to specific recommendations as to the potential sources of supply for the fulfillment of various functional requirements in a given system development effort. Potential external "candidate" suppliers are identified, which, in turn, will lead to the next step: the development of a formal Request for Proposal (RFP), Request for Quotation (RFQ), Invitation for Bid (IFB), or the equivalent.

6.3.2 Development of a "Request for Proposal (RFP)"

Having evaluated the alternatives and come to the ultimate decision to "buy," the contractor (in this instance) must develop the necessary materials for incorporation into a Request for Proposal (RFP). The objective is to develop a data package that can be distributed to potential suppliers for the purposes of soliciting a proposal.

In general, the RFP is a formal mechanism by which the contractor specifies the requirements for a product, or for a service, in response to a designated need. The need for a system component has been identified, a decision has been made to procure the item from an outside source, and the contractor must translate the requirements for this item in a detailed and precise manner. These requirements are described in a data package, attached to a letter of invitation to bid, and sent to prospective suppliers interested in responding to the RFP. More specifically, the content of the data package should include the following:

1. A technical specification describing the product, its performance and effectiveness characteristics, physical features, logistics and quality provisions, and so on. This document, tailored to the application, may constitute a Type "B," "C," "D," or "E" Specification, depending on the particular requirement (refer to Figures 1.12, 3.2, and 6.15).

2. An abbreviated management plan describing overall program objectives, contractor organizational responsibilities and interfaces, the WBS, program tasks, task schedules, applicable policies and procedures, and so on. This information primarily relates to contractor activities; however, individual suppliers must understand their respective roles in the context of the overall program.

[16]On certain occasions, decisions may be based on social, economic, and/or political considerations, such as the identification of a need to improve the local economy by selecting a supplier in a given geographical area, the desire to increase the amount of subcontracting, the need to establish a manufacturing and/or support capability in a designated foreign nation, the need to respond to an existing unemployment crisis, the desire to support a given political position, and so on.

3. A Statement of Work (SOW) describing detailed tasks, task schedules, deliverable items, supporting data, and reports that are to be provided by the supplier. This information, derived from a combination of the specification and the management plan, constitutes a summary of the work to be performed and serves as the basis for the supplier's proposal.

Meeting the objectives of system engineering is highly dependent on initial supplier selection, applicable follow-on activities, and the ongoing evaluation and control efforts imposed by the contractor. As an input to this process, the technical specification (i.e., the Type "B," "C," "D," or "E" Specification, as applicable) must be *comprehensive* in covering *all* of the system-level requirements as they are allocated (or apportioned), down to the element of the system being procurred. A top-down approach is an important aspect of system engineering, and the technical specification must support system requirements to the extent applicable.

The degree of influence of the System Specification (Type "A") on the lower-tier specifications is, of course, dependent on the item being procured from the supplier. A large developmental effort will require a very comprehensive Type "B" Specification, whereas a standard commercial off-the-shelf component may be covered by a relatively short and simple Type "C" Specification. It is important to ensure that the appropriate "traceability" is maintained as one progresses down through the applicable specification tree (refer to Figure 6.15).

Although the top-down technical requirements are maintained through the "specification track," the appropriate management-oriented requirements must be imposed on the supplier through the management plan and the Statement of Work (SOW). Organizational continuity must be ensured from the top down, tasks specified for the supplier must directly support those tasks being accomplished by the contractor, schedules must be compatible, the WBS must show the relationships between the supplier and contractor activities, and so on. In other words, a close continuity must be ensured in the transition of work from the contractor to the supplier.

The RFP data package, prepared by the contractor to cover planned supplier activity, is extremely important in maintaining the necessary continuity from the top system-level requirements down to the lowest-level component of the system. One of the prime tasks in system engineering is that of *system integration,* and it is an objective in developing the RFP that the appropriate level of system integration be recognized and addressed. So often a document such as this is compiled in a "hurry-up" manner, proposals are generated, contracts are negotiated, and the necessary system integration requirements are put off until the end. This, of course, can be a costly practice. The RFP data package must be considered an extension of the System Type "A" Specification and the SEMP.

6.3.3 Review and Evaluation of Supplier Proposals

After the RFP data package has been developed and distributed to interested and qualified suppliers, each recipient must make a "bid/no-bid" decision. Those suppliers deciding to respond will establish a proposal team and will proceed with the preparation of a proposal. The results, of course, must be responsive to the instructions included in the RFP.

The nature of the supplier's proposal activity will depend on the type and scope of the effort described in the RFP. When the acquisition process is directed toward large elements of the system, involving some design and development (e.g., major subsystems), the supplier proposal activity can be rather extensive. A formal project-type organization may be established, specific project tasks are identified, and the level of effort may be somewhat similar in approach to the project configuration(s) described earlier.

In situations in which large proposals require extensive effort, there is usually a requirement for some design and development activity. If the RFP (through a Type "B" Development Specification) dictates the need for the design of a major system element, the supplier will often attempt to design and construct a prototype model of the item as part of the proposal effort. A mini-project is organized, design and development tasks are completed expeditiously, and a physical model is delivered to the contractor along with the written proposal. Design decisions are consummated early, with the objective of impressing the contractor (i.e., the customer in this instance) relative to both design approach and the capabilities of the supplier. Should the supplier be successful and be selected in this case, the constructed prototype may well be considered as the baseline configuration leading into follow-on detailed design.

In the preceding scenario, subsystem requirements were specified as part of the RFP, design and development activities were completed during the proposal phase, a formal design review occurred through the contractor's review and evaluation of the supplier's proposal, and the resultant configuration became somewhat fixed relative to the possibility of incorporating any design changes. This scenario can be related to the development process described in Chapter 2, except that the time element is compressed significantly. Because of this type of scenario, the preparation of the RFP assumes a great degree of importance from the system engineering viewpoint (as indicated in Section 6.3.2). Further, the ongoing design activity accomplished during the proposal phase must consider the necessary design characteristics supportive of system engineering objectives (e.g., reliability characteristics and maintainability characteristics). Finally, the formal evaluation of supplier proposals must serve as a final check for compliance with system engineering requirements as they apply to the item, or the service, being procured.

On receipt of all proposals (solicited and unsolicited) from prospective suppliers, the contractor proceeds with the review and evaluation process. When competitive bidding occurs, the contractor generally establishes an evaluation procedure directed toward selecting the best proposed approach. Initially, each supplier proposal is reviewed in terms of *compliance* with the requirements specified in the Request for Proposal (RFP). Noncompliance may result in automatic disqualification, or the contractor may approach the potential supplier and recommend a proposal revision and/or addition.

When two or more suppliers meet the basic RFP requirements, an evaluation of each proposal is then completed, employing certain preestablished criteria. One may commence with the the preparation of a supplier checklist such as presented in Figure 6.33.

Supplier Evaluation Checklist

Refer to Appendix E for supporting questions.
E.1 General criteria
E.2 Product design characteristics
    E.2.1 Technical performance parameters
    E.2.2 Technical applications
    E.2.3 Physical characteristics
    E.2.4 Effectiveness factors
        1. Reliability
        2. Maintainability
        3. Human factors
        4. Safety factors
        5. Supportability/ serviceability
        6. Quality factors
    E.2.5 Producibility factors
    E.2.6 Disposability factors
    E.2.7 Environmental factors
    E.2.8 Economic factors
E.3 Product maintenance and support infrastructure
    E.3.1 Maintenance and support requirements
    E.3.2 Data/documentation
    E.3.3 Warranty/guarantee provisions
    E.3.4 Customer service
    E.3.5 Economic factors
E.4 Supplier qualifications
    E.4.1 Planning/procedures
    E.4.2 Organizational factors
    E.4.3 Available personal and resources
    E.4.4 Design approach
    E.4.5 Manufacturing capability
    E.4.6 Test and evaluation approach
    E.4.7 Management controls
    E.4 8 Experience factors
    E.4.9 Past performance
    E.4.10 Maturity
    E.4.11 Economic factors

Figure 6.33 Supplier evaluation checklist.

The items identified cover some general criteria, design characteristics of the subsystem or product being considered for procurement, the supplier's proposed maintenance and support infrastructure for the subsystem/product, and the qualifications of the supplier. The items in Figure 6.33 are supported by the questions presented in Appendix E and are weighted relative to degrees of importance based on the requirements for the system overall.[17]

[17]The questions in Appendix E are similar to the design review questions in Appendix D, except that a "supplier orientation" has been provided. However, a checklist tailored to the system and supplier requirements is preferred when possible.

Evaluation Criteria	Weighting Factor (%)	Proposal "A"		Proposal "B"		Proposal "C"	
		Rating	Score	Rating	Score	Rating	Score
A. General Criteria	10	7	70	5	50	6	60
B. Product Design Characteristics	30						
1. Performance factors	6	3	18	5	30	4	24
2. Technology applications	3	7	21	8	24	6	18
3. Physical characteristics	2	3	6	4	8	5	10
4. Effectiveness factors	7	7	49	7	49	8	56
5. Producibility factors	2	4	8	6	12	5	10
6. Disposability factors	3	5	15	4	12	8	24
7. Environmental factors	2	2	4	3	6	5	10
8. Economic factors	5	4	20	4	20	6	30
C. Product Maintenance and Support Infrastructure	20						
1. Maintenance and support requirements	7	6	42	8	56	7	49
2. Data/documentation	3	3	9	4	12	6	18
3. Warranties/guarantees	3	2	6	3	9	5	15
4. Customer service	5	5	25	8	40	30	30
5. Economic factors	2	4	8	3	6	6	6
D. Supplier Qualifications	34						
1. Planning/procedures	3	5	15	4	12	5	15
2. Organizational factors	2	6	12	5	10	5	10
3. Personnel and resources	2	4	8	3	6	2	4
4. Design approach	4	6	24	4	16	3	12
5. Manufacturing capability	3	7	21	5	15	4	12
6. Test and evaluation	2	6	12	5	10	4	8
7. Management controls	6	7	42	6	36	4	24
8. Experience factors	4	6	24	4	16	4	16
9. Past performance	5	6	30	5	25	7	35
10. Maturity	3	7	21	7	21	6	18
E. Life-Cycle Cost	12	5	60	7	84	4	48
Grand Total	100		570		595		562

Figure 6.34 Proposal evaluation results.

The contractor develops a list of topic areas considered to be relevant in the evaluation and assigns weighting factors as shown in Figure 6.34. Note that *supplier qualifications, product design characteristics, product maintenance and support infrastructure,* and *general criteria* have been identified in order of precedence.

Through a review of each supplier proposal, using the questions in Appendix E as a guide, the analyst can assess the degree to which the supplier's proposal responds to the desired features conveyed through the questions. From Figure 6.34, the topics listed under *evaluation criteria,* taken from Figure 6.33, are weighted on the basis of level of importance, an assessment is made, and a *rating* is given in each area. A more

Refer to Figure 6.34, Item E

Rating (Points)	Evaluation Criteria—Life-Cycle Cost
10–12	The supplier has justified his design on the basis of life-cycle cost, and has included a complete life-cycle cost analysis in his proposal (i.e., cost breakdown structure, cost profile, etc.).
8–9	The supplier has justified his design on the basis of life-cycle cost, but did not include a complete life-cycle cost analysis in his proposal.
6–7	The supplier's design has not been based on life-cycle cost; however, he plans to accomplish a complete life-cycle cost analysis and has described the approach, model, etc., that he proposes to use in the analysis process.
3–5	The supplier's design has not been based on life-cycle cost, but he intends to accomplish a life-cycle cost analysis in the future. No description of approach, model, etc., was included in his proposal.
0–2	The subject of life-cycle cost (and its application) was not addressed at all in the supplier's proposal.

Figure 6.35 Sample checklist of evaluation criteria for supplier proposals.

detailed checklist for each topic may be developed to support the designated rating factor. Figure 6.35 shows an example covering item E in Figure 6.34.

In Figure 6.34, the assigned ratings are multiplied by the weighting factors to provide a score for each item. The individual scores are then added, and the highest score indicates the supplier with the best overall approach. In this instance, Supplier B appears to be the preferred alternative.[18]

In the evaluation of supplier proposals from the system engineering perspective, the following general questions, as they apply to the subsystem or product being procured, are appropriate.

1. Is the supplier's proposal responsive to the contractor's needs as specified in the Request for Proposal (RFP)?
2. Is the supplier's proposal directly supportive of the system requirements specified in the System Type "A" Specification and the System Engineering Management Plan (SEMP)?
3. Have the performance characteristics been adequately specified for the item(s) proposed? Are they meaningful, measurable, and traceable according to system-level requirements?
4. Have effectiveness factors been specified (e.g., reliability, maintainability, supportability, and availability)? Are they meaningful, measurable, and traceable according to system-level requirements?
5. In the event that new design is required, has the design process within the supplier's organization been adequately defined? Does the process incorporate the

[18]Refer to Case Study B.6, Appendix B, for the results of a similar evaluation.

utilization of computer-aided design (CAD)/computer-aided manufacturing (CAM)/computer-aided support (CAS) technologies where appropriate? Have reliability, maintainability, human factors, supportability, life-cycle cost, and related characteristics been properly integrated into the design where appropriate? Have design change procedures been developed, and are changes properly controlled through good configuration management practices?

6. Is the design adequately defined through good documentation; that is, drawings, parts lists, reports, software, tapes, disks, and databases? Are the required data available? Have the data rights been specified?
7. Has the supplier addressed the requirement for the test and evaluation of the proposed system element or component? If testing has been accomplished in the past, are the test results documented and available? Have the plans for future testing been properly integrated into the system Test and Evaluation Master Plan (TEMP)?
8. Have the life-cycle support requirements been identified for the item being proposed; that is, maintenance resource requirements, spare/repair parts, test and support equipment, personnel quantities and skill levels, training, facilities, data, maintenance software, and so on? Have these requirements been minimized to the extent possible through good design?
9. Does the design configuration reflect good growth potential? reconfigurability?
10. Has the supplier developed a comprehensive production/construction plan? Are key manufacturing processes identified, along with their characteristics?
11. Does the supplier have a good quality assurance program? Are statistical quality control methods utilized where appropriate? Does the supplier have a good rework plan to handle rejected items as necessary?
12. Does the supplier's proposal include a good comprehensive management plan? Does the plan cover program tasks, organization structure and responsibilities, a WBS, task schedules, program monitoring and control procedures, and so on? Has the responsibility for system engineering tasks (as applicable) been defined?
13. Does the supplier's proposal address all aspects of *total cost;* that is, acquisition cost, operation and support cost, and life-cycle cost?
14. Does the supplier have previous experience in the design, development, and production of system elements/components that are similar in nature to the item proposed? Was that experience favorable in terms of delivering high-quality products in a timely manner and within cost?

Although these questions may be helpful in the evaluation of a supplier's proposal, there are some additional factors that must be considered before recommending a specific procurement approach:

1. Should a single supplier be selected (i.e., sole source), or should two or more suppliers be selected to fulfill the requirements as stated in the RFP? If the level of effort specified covers a relatively large element of the system and involves some design and development activity, the selection of two (or more) suppliers to perform the

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same tasks may be rather costly. On the other hand, for smaller standard off-the-shelf components, it may be appropriate to establish several sources of supply. The objective is to ensure a source of supply that will meet the need as long as required, with a minimum of risk associated with the possibility of the supplier "going out of business."

2. Will the supplier be able to provide the necessary support for the proposed item, both during and after production, throughout the planned life cycle of that item? Of particular interest is the source for spare/repair parts to support sustaining maintenance requirements after the initial production has been completed and the capability for producing additional spares no longer exists;—that is, postproduction support. If such support will not be available, then the procurement policy may dictate that enough spare/repair parts be purchased initially to support maintenance operations for the entire life cycle.

3. Should a supplier be selected on the basis of political, social, and/or economic factors? In this era of international involvement (or globalization), there may be certain political pressures encouraging the procurement of components, or services, from a particular foreign source. On the other hand, it may be feasible to select a prospective supplier on the basis of geographic location and economic need. On occasion, it may be specified that at least $x\%$ of the total volume of system development effort must be subcontracted. In any event, supplier selection is sometimes influenced by political, social, and/or economic factors.

The evaluation of supplier proposals may be accomplished using the approach conveyed in Figure 6.34, modified to take into consideration these additional factors; that is, single versus multiple suppliers, postproduction support requirements, and the influence of political and economic factors on supplier selection. This evaluation activity usually includes not only a review of the written proposal itself, but one or more on-site, inspection-type visits to the supplier facility. A recommendation is made, and contract negotiations between the contractor and the supplier are initiated.

As the results of the supplier evaluation and selection process have a significant impact on program success and meeting the objectives of system engineering, it is important that the system engineering organization be represented throughout this process. The proper coordination and integration of supplier activity into the total engineering design and development effort are essential.

6.3.4 Selection of Suppliers and Contract Negotiation

Having identified prospective suppliers through the evaluation and selection process, it is now incumbent on the contractor to develop a formal contractual arrangement with the supplier. A Request for Proposal (RFP) was initiated, proposals from potential suppliers were generated and evaluated, and a contractual structure (in some form) needs to be established. The type of contractual agreement negotiated can have a significant impact on supplier performance, particularly in the procurement of large system components involving design and development activity.

The objective of contract negotiation is to achieve the most advantageous contractual agreement from the standpoint of technical requirements, deliverables, pricing, the type of contract imposed, and payment schedule. Obviously, the contractor