

THREE Techniques of Network Analysis for Managers

Public managers periodically plan relatively complex projects. More often than not such plans must take into account the interdependence of the efforts of a variety of people and organizations and the trade-offs that inevitably must be made between the project's time requirement, cost, and performance. An understanding of and skills in network approaches to planning will prove quite valuable in these circumstances.

This chapter will provide an understanding of the basic concepts and procedures involved in network approaches to planning and control and should enable you to begin to employ network analysis with some confidence.

The techniques for network analysis presented here derive from applications of PERT (Program Evaluation Review Technique) and CPM (Critical Path Method) by public and private managers in carrying out their responsibilities for planning, monitoring, and controlling a wide variety of projects and programs. Experience with PERT, CPM, and Mark III planning and control systems is drawn upon to outline a relatively inexpensive, pragmatic scheme for employing the highly useful logic underlying network approaches to management.

Our intent is to "walk" the reader through the basic processes of doing network analysis while providing answers to the following questions:

What is network analysis?

How did it evolve?

- What are the basic concepts and formulas employed in PERT/CPM that can be used in low-cost applications of network analysis?
- What are the steps one must work through to generate a network plan?
- What procedures can be followed in assessing the merit of initial versions of network plans?
- How can managers monitor and control their projects using network plans?

What are the principal advantages of network analysis?

Network Analysis

Networks model the interrelated flows of work that must be accomplished to complete a project. They visually portray the events and activities that are planned for the project and show their sequential relationships and interdependencies. Networks generally flow from left to right and may or may not be drawn to scale on a time-based calendar.

Networks have inherent properties that are quite similar to those of most systems; that is, they are holistic and inclusive and their elements are interdependent and interconnect at one or more points. In doing a network analysis, you are taking a systems approach to producing a fully elaborated project plan that can subsequently be employed with confidence as a managerial tool.

There are four principal stages in network analysis. They will be briefly described here and discussed in more detail later.

1. Network Generation. This stage begins with specifications of the project's goal or objective. It moves from the conceptualization of what must be done to the precise specification of events and activities that are to be carried out in achieving the goal or objective. The network produced during this stage represents a graphic model of the project and incorporates time (and sometimes cost) estimates.

2. Network Evaluation. Once an initial network plan for a project is completed, it must be assessed by a manager to determine its soundness from the standpoint of its underlying logic.

3. Network Monitoring. Once adopted, the network plan becomes a valuable managerial tool for the life of the project. It can be employed

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to determine the extent to which the project is proceeding as planned and whether managerial interventions are required. Where such interventions are necessary, the network provides useful data for weighing possible alternative managerial actions.

4. Network Modification. Monitoring may indicate that the network plan will have to be altered to maintain necessary managerial control.

Evolution of Network Analysis

Contemporary network approaches to managerial planning and control have combined several evolving managerial technologies. These include (1) the systems approach to management with its emphasis upon holism and the effects of interdependencies; (2) the project form of organization, which is also grounded conceptually in systems thinking; (3) the use of computers—which have made it possible to rapidly process sizable numbers of calculations—for simulating the effects of alternative decisions and for generating network graphics in a timely manner; (4) flowcharting techniques for logically portraying complex sets of data economically; and (5) planning technologies such as Gantt, line of balance, and milestone charting.

The Critical Path Method (CPM) was developed by the Dupont Corporation with assistance from RAND in 1956. The Program Evaluation and Review Technique (PERT) was developed in 1957 by the Navy's Special Projects Office (with the assistance of Booz-Allen-Hamilton) to aid in managing the development of the Polaris weapon system. Subsequently, a multitude of similar planning and control systems flooded the market and a variety of "bells and whistles" were added.

PERT originally focused only upon time variables, but it was not long before it became possible to incorporate <u>cost variables</u> as well. Sophisticated computer programs became essential for full-blown applications of these planning technologies to handle the quantity of calculations required by periodic updating of network plans or for simulation analysis.

Some federal agencies such as the Navy Department moved toward policies of uniformly requiring the use of PERT on their principal projects and toward establishing standard report formats, computer programs, and so forth. For a while PERT was treated almost as a fad; everyone wanted it with the latest wrinkles. After several years a more realistic view developed as the economics of planning became evident. Some retrenchment in the use of PERT was then experienced for several reasons. First, making detailed and current planning information available to managers at higher echelons reduces the "cost" of their participating in great depth in the management of projects. This changes organizational influence patterns in ways that produce reasonably grounded resistance. Second, the effort to systematize planning and control systems began to produce a rigidity that was viewed as counterproductive. Third, and perhaps most importantly, computer-based planning and control systems can become extremely costly to employ. (Fortunately, there are less costly and simpler ways to use network analysis and derive its benefits without using computers.)

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Basic Concepts, Formulas, and Conventions

PERT concepts, formulas, and conventions will be drawn upon heavily in this section to identify the principal features of networks and elaborate some of their analytical advantages. A network consists of a series of circles (events) connected by arrows (activities) with time and/or cost data associated with each of the activities.

The Network

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The circles, or events, represent identifiable points in time at which an activity is begun or completed. These points of specific accomplishment are normally described in a summary way by placing a few key words within the appropriate circle, as below, for example.



No time- or resource-consuming effort is involved for events.

The arrows, or <u>activities</u>, represent tasks to be accomplished; that is, the time- and resource-consuming effort required in order to complete an event.



Networks are made up of events and activities that are interconnected in accordance with the logic underlying the actual work. That is, predecessor events must be completed before subsequent activities can be initiated. For example, activity B on p. 90 cannot be started prior to completion of event 2. Note also that the logic of the network indicates activity B is dependent directly on event 2 and only indirectly on event 1; if it were directly dependent on event 1 it would be charted differently as shown in the next network. Some work goes on in a sequential flow that is depicted by events and activities linked together in a "serial" manner.



Other work will be going on during the same period and will be charted as occurring in a "parallel" manner.



Activities with a predecessor-successor relationship take place in "sequence"; that is, the prior activities and associated events must be completed prior to the beginning of successor activities and events. Hence, there is an "interdependency" between them. Activities going on in "parallel" must be "independent" of one another, as is the case for activities E and F above.

Activity G above represents a <u>"dummy activity"</u>, or "constraint," which indicates that completion of event 4 must occur prior to completion of event 7 even though no resources or time are required as a result of the relationship between the two events. Dummy activities are represented by dotted lines on networks and are used to show dependency relationships that are important even though they do not require time or resources. For example, a building permit must be acquired prior to initiating construction but no resources are consumed as a result of this relationship.

Figure 3-1 depicts a typical network. Three separate <u>time estimates</u> are shown for each activity on the network—they represent the optimistic, "most likely," and pessimistic estimates of the time required for completion of an activity.

Just as time estimates associated with each activity may be shown on networks, resource estimates may also be used in networking. Total costs associated with an activity may be shown, or differing subsets may be depicted, such as manpower costs or man-weeks/man-months of effort.





Time Estimates

In a standard PERT network, three time estimates are acquired for each activity on the network. Acquisition of three time estimates provides a means of gauging the amount of uncertainty involved in the plan. More importantly, insight is acquired as to why there is uncertainty. Optimistic, pessimistic, and "most likely" time estimates are obtained, thus allowing the calculation of an "expected time" (t_e) and standard deviations reflecting the amount of uncertainty involved in the activity estimate.

The following are basic formulas for these calculations (for examples of some of these calculations, see Figure 3-2).

Expected time $|t_e| = \frac{a + 4m + b}{6}$ (an approximation for each activity),

Standard deviation $(\sigma) = \frac{b-a}{6}$,

Variance (σ^2) = standard deviation squared,

where

- a (optimistic time) = an estimate of the shortest time an activity will take; that is, it will not occur more quickly more than one time in one hundred;
- m (most likely time) = an estimate of the amount of time an activity would normally take;
- b (pessimistic time) = an estimate of the longest time an activity is likely to take; that is, it is not likely to be completed any more quickly than one time in one hundred.

Other basic concepts follow.

 T_{E_i} the "earliest expected time," is the time by which an *event* can be com-





pleted. This time estimate is obtained by accumulating the calculated time estimates $(t_e's)$ of each activity on the longest path prior to the event, as illustrated in Figure 3-2:

 T_E of a successor event = T_E of its predecessor event + the t_e of the activity between them.

 T_{L} , the "latest allowable time," is the time by which an *event* must be completed to prevent delaying the completion of the total project. This time estimate is obtained for an event by tracing back from the final event along the longest path to the event in question. Accumulate the expected times $(t_e's)$ for all activities along this path, and subtract this sum from the time of the critical path. The resulting number is the maximum time that can elapse from the beginning of the project to the completion of this event without compelling a delay in the completion of the project. (Sample calculations are provided in Figure 3-2.)

The <u>critical path</u> of a network is the longest path (in terms of time) through the network. Time delays on this path result in delays in accomplishing the total project.

<u>Slack</u> is the concept used to refer to the difference between the T_L (latest allowable time) and the T_E (earliest expected time) for the completion of a given event. The amount of slack available tells whether an event and its associated activities are on the critical path (longest path through the network). An event on the critical path has 0 slack. All other events have ascertainable amounts of slack, knowledge of which provides managers with an understanding of their available flexibility. Slack may be positive or negative; negative slack occurs when projects fall behind schedule.

Slack for an event = that event's T_L - its T_E .

The standard deviation of the critical path provides a measure of the extent of uncertainty involved in the plan's scheduled completion time (T_s) for the total project. It is obtained by summing the variances for each activity on the critical path and then taking the square root of the sum to obtain the desired standard deviation.

The probability of meeting the desired completion date can be estimated in a two-step calculation by first subtracting from the completion time $\{T_s\}$ the sum of the expected times $\{t_e's\}$ for the activities in the critical path, and then dividing this by the standard deviation of the initial path. This gives you the slack in the critical path expressed in terms of standard deviations of the initial path. The larger this quotient, the *less* likely it is that the scheduled completion date will be missed. The probability of not completing the network by the desired time can be calculated by considering this quotient equivalent to a z-score in a table of the standardized normal distribution. Such a table can be found in most basic statistics texts. In using such a table, you should calculate the probability associated with a z-score greater than the value of the quotient. For example, if the desired completion time is the same as the earliest completion time for the final event, this gives a quotient equal to zero and a probability of meeting the desired deadline of .5. If the quotient is one, then the probability of meeting the deadline is .8414 and of not meeting it is .1586.

The Process of Network Generation

This section offers one step-by-step approach to developing a network plan. It is not the only way, but this author has found it useful.

In the first step, specify as clearly as possible the project's goal or objective. What will the final event on the network be? In thinking about what effort has to be accomplished to reach that event, it is useful to work backward from the final event as well as forward from the initiation of the project.

Next, the manager responsible for the project should establish a set of working assumptions, specifically, rough estimates of the anticipated life of the project and the amount of funding available for it. There is a danger that these rough estimates will become unrealistic constraints or self-fulfilling prophecies. Nonetheless, a common set of working assumptions is needed to prevent different participants in the planning process from operating from premises with order-of-magnitude differences.

Development of a work breakdown structure or block diagram is the next step. This involves conceiving of the project as a system with subsystems, sub-subsystems, and so on. Such a conception allows the development of the skeletal structure around which a network can be generated. It establishes the various areas of effort for which events and activities will be developed.

Figure 3-3 depicts a sample work breakdown structure. Tier l represents the system as a whole; tier 2, the principal subsystems; tier 3, the sub-subsystems, and so forth.

The work breakdown structure becomes the basis for the next step—identification of those individuals who will be responsible for making required inputs to events and activities for each of the subsystems, which, when combined, make up the network plan. The individuals selected for each subsystem along with the project manager normally constitute the <u>project management team</u>. Each of these individuals will eventually develop a mini-network for his or her particular subsystem. This mini-network should be based on the individual's own knowledge and experience plus inputs the individual elicits from others who will be working with him or her on their subsystem effort.

Next, the project manager should meet with the project manage- $(\zeta$ ment team and provide them with more specific planning guidelines. For



Figure 3-3. Work Breakdown Structure: A Simplified Plan for an Annual Conference

example, how detailed should their subsystem plans be in terms of time intervals between events (a common guideline being from three to five weeks on the average); what cost guidelines and what overhead rates apply; and what is the desired format for planning inputs. A project manager will often supply a form that is to be made out for each event on the network and that asks for time and cost data plus a narrative explanation of the essence of the event. Such a narrative clarifies performance expectations and avoids differences in interpretations of the plan.

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It is now necessary to establish the events and activities that must be accomplished in order to complete the project. This normally is done first at the subsystem level. Occasionally, it is helpful to generate an initial list of events and activities at the system level. A chart can then be drawn that conveys the general outline of the project. At that point the necessity to go into more detail at the level of subsystems will become apparent. Often, the project manager or a member of the staff will work jointly with the individual responsible for each particular subsystem to identify essential events and activities and their logical relationships. Through this process, tentative subsystem networks are drawn and time and possibly cost—estimates are made for each of the activities. Also, an effort is made to identify points of interface between subsystems to aid in the subsequent drafting of a system-level network as well as to begin to recognize significant interdependencies.

Once each of these individual subsystem plans is developed, the



Figure 3-4. Work Breakdown Structure Turned on Side

project manager or the staff assistant should combine them into a first-cut system-level network. A useful way to facilitate this step mechanically is simply to think of turning the work breakdown structure on its side as illustrated in Figure 3-4. The network diagram would then closely parallel this skeleton as shown in Figure 3-5. It is helpful to locate the subsystems that interface with one another most frequently adjacent to one another on the network diagram. This facilitates the mechanics of drafting the plan.

Figure 3-5. Work Breakdown Structure Converted to Network



When this initial system-level network is available, the project manager should hold a project-level review of the plan at a meeting that includes all individuals with subsystem responsibilities. At this stage it is quite normal to find many inconsistencies existing in the plan. Events may have been left out or improperly sequenced; important interfaces may not be identified; some individuals may have been unduly optimistic or pessimistic in their time estimating. Examination of the network plan in this open-meeting format usually produces useful information for purposes of producing a revised plan. At the same time, it provides most team members with an improved comprehension of how their subsystem interacts with others and of the mutual importance of interfaces. Communication among team members is frequently improved qualitatively at this point. Often, after this review meeting, each of the subsystem plans is modified and a second system-level plan is prepared reflecting those revisions.

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Once the above revision is completed, the initial network plan for the project is available. It is time for a careful, analytical evaluation of its logic by the project manager and his or her staff.

First, a "forward pass" through the network is made by tracing through the various paths, calculating the T_E (earliest completion time) for each of the events and penciling them onto the network. Next, a "backward pass" through the network is made, and T_L (latest allowable time) is calculated for each event and penciled onto the network. At this point the project manager is in a position to assess the following questions.

1. Does the t_e for the final event in the network (expected completion date of the project) satisfy needs? Is the project manager willing to adopt that date as the T_s (scheduled completion time) for the project, or will the manager have to "adjust" the plan by trading-off project performance or cost variables to attain a different completion time? (While not always possible, there is normally room for shifting the completion time forward by spending more money or lowering the specifications for the performance of a project; for example, a smaller building or a less elaborate management information system.) Similarly, a manager may wish to shift the point of project completion backward in time to achieve cost savings or higher performance specifications.

2. A second point for analysis is to ascertain whether any particular subsystems within the plan appear out of line in terms of their time and cost estimates. In addition to drawing upon his or her own experience for this analysis, the project manager would be wise also to seek the judgments of other individuals who are knowledgeable in the particular area in question. A good format for this review is to hold a joint meeting with the individuals responsible for the subsystems, the project manager, and other knowledgeable individuals to review the logic of the flow of events and the time estimates.

3. A third focus for analysis is the interfaces between the subsystems of the network. In this case the project manager may wish to meet with the individuals responsible for the subsystems that are interfacing to discuss whether the timing of events on their respective plans is likely to cause one or the other problems. For example, the manager may ask how serious it would be to one subsystem's efforts if the other subsystem experienced slippage in completing its work. Or conversely, the manager may wish to explore the potential benefits for one subsystem of accelerating the efforts and schedule of the other subsystem. Through this process the significance of the interdependencies should become quite evident to all parties.

4. Next, the project manager would be wise to scrutinize carefully the critical path in the network. Any delays along this path will delay the project's completion. Are there reasonable ways to shorten the length (time) of the path? Are certain activities and events along the path particularly worrisome in terms of uncertainties involved in their time or cost estimates? Where is the manager going to have to be particularly concerned and carefully monitor progress?

5. On many projects a major source of delays is the slippages that result from not having necessary equipment and materials available in a timely way. A useful analysis is to separate out those network events that involve purchases, procurements, contracts, and so forth for careful monitoring. The manager should first feel assured that these events are planned to be initiated at points in time that are reasonable, and that the expected delivery/completion dates are realistic in terms of prior experience. Then the manager can develop a "control list" for these events and review it weekly to assure that the activities have in fact been initiated on time.

6. Cost estimates for the project need to be analyzed for their reasonableness at the overall project level and for each subsystem. One useful way to examine the total project's manpower "cost plan" is to divide the network plan into monthly intervals and calculate the amount of dollars to be expended on manpower during each month. These data can be overlaid upon the network chart itself or drawn in the form of a histogram as shown in Figure 3-6. The shape of the histogram is an important input. Experience with larger projects indicates that they tend to follow certain patterns in terms of their growth in manpower from initiation of the project through completion. Typically, they tend to approximate a logistic curve as depicted in Figure 3-7. A project manager who finds that the projected costs of manpower for his or her project will fluctuate irregularly month by month should probe further to ascertain whether those estimates are well reasoned.









Network Monitoring

Once the network evaluation is completed and any resultant revisions are made, much of the value of this approach to project planning and control will have been realized. In some instances managers may wish to revert to Gantt charts for control purposes. However, the network plan can be quite useful to the manager as a project monitoring device without much additional cost or effort. Some useful monitoring techniques are described below.

In monitoring the status of the project, one of the questions the manager will be addressing is whether the work is progressing according to plan. Network plans can be employed to answer this question providing they are drawn in such a way that the position of the events and the length of the activity lines are tied to a scale based on time. This is easily done by drawing a horizontal line along the base of the chart and creating a scaled calendar; for example, each week is equal to one inch.*

Given this time-based network chart a string can be hung from the top of the chart to the bottom at the appropriate point in time and then moved to the right each week. The presumption is that if the work is on schedule, events to the left of the line would have been completed and those to the right remain to be accomplished. Then, by simply shading in each event as it is actually completed, an easily read visual display will exist. Unshaded events to the left of the line are behind schedule. Shaded events to the right of the line are ahead of schedule. Another simple charting convention is to create a double line or colored line along the critical path of the network to make it stand out.

A second question of prime concern to the managers of projects is how their rate of expenditure compares to their planned expenditure rate? It is equally disconcerting to managers to be underexpending as it is to be overexpending in that it is likely that the underexpending project is also falling behind schedule in its work. Figure 3–8 illustrates one very useful monitoring aid. The straight-line extrapolation presents a uniform salary expenditure pattern for each month for the life of the project, given the targeted total cost figure. The curved dash line indicates the expenditure pattern that is "planned," based on the inputs in the network analysis and evaluation process. The dot-dash line indicates actual salary expenditures as they occur month by month. As is apparent, the significance of the pattern formed by the dot-dash line can easily be interpreted in light of the other two reference lines.

Another simple but useful display that ties project progress and expenditures together is presented in Figure 3-9. The means of ascertaining

*Networks may be drawn on "fade out" blue-line graphing paper---10x10 to the inch. This greatly facilitates time-based graphing; and when reproduction is done, the lines disappear leaving a "clear" chart suited for photographic reduction if desired.



Figure 3-8. Expenditure Analysis Chart (Salaries)

the percentage of available funds that has been expended is readily apparent. A suggested method for gauging the amount of project progress is to relate the distance in time that the project has progressed in terms of accomplishment along the critical path to the total length of that path. For instance, if the total length of the critical path through the original net-





Plan completed as of this week according to current critical path (measured by 100 x weeks remaining in current critical path ÷ total number of weeks in original critical path) work plan (recognizing the path will subsequently vary) produced a T_s of eighty weeks and the project team has just completed an event that still leaves forty weeks of effort to be accomplished on the rest of the current critical path, then the progress to date has been 50 percent, even though the project may have varied from its original schedule and plan in terms of time.

Network Modification

Once a network has been thoroughly evaluated and revised and you have entered the monitoring of progress phase, questions arise as to how often the network should be updated and in what manner. Let me express a caveat: My experience indicates that there is a definite hazard that you might expend more of the project's resources and the manager's time in modification efforts than are warranted! Some suggestions to avoid that possibility are offered in this section.

First, <u>drop the use of three time estimates bace you have completed</u> the initial evaluation of the network. The necessity for and value of most of the formulas and calculations diminish rapidly once the plan is well developed.

Second, use your network chart as a working document rather than a showpiece; be satisfied with penciled-in corrections and revisions, and only redraft the chart when it is clearly necessary.

Third, make use of project team meetings to acquire updating information from subsystem personnel. Only in the event of major changes in the goals, resources, or time requirements for the project should it be necessary to spend significant amounts of time in network revisions.

Advantages of Network Planning

What benefits are acquired by the manager who employs a network method of planning and control? Outlined below are some of the more important advantages.

1. Networking has an underlying logic that forces disciplined thinking in planning a project; if followed, that logic will increase managers' confidence that they are aware of the important elements of their programs.

2. Networking serves as an analytic aid to managers, helping them to recognize and understand the complex relationships that are present among different parts of their projects. Networking elicits essential facts from the outset; that is, what needs to be done, by whom, how long it will take, what it will cost, and what needs to be closely coordinated and monitored. iqu Nei Nei Ariants foi hage

3. Networks provide a basis for systematic evaluation of project management decisions. For example, is the planned approach to the project reasonable in terms of anticipated time and cost? Are there activities envisioned for subsystem efforts that can be combined or eliminated? What will be the effect of a proposed change or delay in one subsystem on other subsystems and the project as a whole?

4. Network generation efforts and the resultant network plans can be major aids in improving communications on projects. Communication that goes on about the project during the generation of a network contributes greatly to the development of an effective project team. The network itself represents a visual aid to communication about the project—what it is to accomplish, how, and its present status. The network can be usefully employed in orienting new project team members, reporting progress and/or problems, public relations efforts, and so forth.

5. Networks provide managers with a useful tool for carrying out their responsibilities for controlling projects and taking actions to ensure, to the extent possible, that projects are proceeding according to plan. Responsibility for specific events and activities is fixed in advance and there is less chance of things "falling through the cracks."

6. Finally, network plans that are carefully monitored provide timely warnings of impending problems and help managers to focus their attention where it will do the most good.

Conclusion

Network analysis can be a valuable technique for managers confronted with responsibilities for planning and controlling their projects. The benefits are many and will far outweigh costs associated with networking, providing that one is judicious in deciding upon the scope of effort appropriate for a particular project.

When engaging in network planning, it is important that advantage be taken of less costly methods for generating, analyzing, monitoring, and updating plans. Hopefully, this chapter has provided some insights and suggestions that will enable the reader to do just that. In closing, it seems important to note that the "how to" approach described here is in no way intended to discourage those who do make use of its suggestions from being experimental in their own approaches to network analysis in the light of their own particular situations. There is no "one best way" for planning all projects. Be willing to innovate wrinkles that seem appropriate to your unique needs without worrying about whether you are unorthodox.

Exercises

1. Recognizing predecessor/successor relationships between events requires logical reasoning. The events listed below are carried out "serially" in a single path. Place them in a logical sequence and be prepared to explain your reasoning.

Project appraised Project plan prepared Feasibility study completed Follow-up of project begun Project selected Project implemented Project funded

2. Please explain narratively the logic of the following network. For example, what is necessary for event 5 to be completed? Event 6?



3. What problem do you see with the following network?



- Techniques of Network Analysis for Managers
 - 4. Diagram and find the critical path for the following project.

Activity	Time in Weeks				
a-b curts a \$ b	4.0				
а-с	7.5				
b-d	3.6				
с-е	7.2				
d-f	4.4				
d-g	8.0				
d-h	4.2				
e-h	7.4				
e-i	5.8				
f-i	3.9				
8-i	4.2				
h-k	2.4				
i-k	5.0				
j-1	2.8				
k-1	3.0				
<i>l</i> -m	4.0				

Identify the critical path. How long is it? If your supervisor insisted that the project can be completed in thirty weeks, what alternatives would you consider to reduce the critical path?

5. Determine the expected activity time for activities that have the following estimates.

· · · · · · · · · · · · · · · · · · ·	A	В	С	D	E
a (optimistic)	8.6	5.4	11.6	1.3	8.4
m (most likely)	10.2	9.1	14.1	2.4	12.0
b (pessimistic)	16.4	15.0	20.5	5.9	18.2

6. Referring to Figure 3-2, the sample network in this chapter, determine the following:

- a. The T_E (earliest expected time) that the preliminary program plan will be approved;
- b. The T_L (latest allowable time) to complete the final program plan;
- c. The amount of slack for completion of the publicity plan.

7. What is the standard deviation for each estimated activity time calculated in exercise 5? If those five activities were a path, what would be its standard deviation?

8. What is the standard deviation for the critical path of the network depicted in Figures 3-1 and 3-2? 9. You have decided to pursue a master's degree at a nearby university. Prepare a network plan of the events and activities it will be necessary for you to complete, from the point of your decision until the day you receive your diploma.

Selected Bibliography

10. Congratulations, your city has just been selected by the International Olympics Committee to host the 1988 games. Please prepare a work breakdown structure that will provide the "skeleton" for constructing a network plan for holding the games.

11. Is positive slack in a particular portion of a network plan a positive situation, or may it have both positive and negative implications? Support your argument with examples if possible.

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