AN INTRODUCTION TO PERT . . . OR . . .

NOW THAT WE'VE ALL FINALLY AGREED ON WHERE WE WANT TO GO, HOW DO WE ARRANGE TO GET THERE FROM HERE.

Suppose you wake up on Saturday morning and decide to take the family on a picnic.

Going through your head is a jumble of activities and tasks that need doing in order to get the picnic organized. "Coffee. Is the thermos clean? Remember this time to take some fly-spray. Do we have any beer? What kind of sandwiches would everyone like?"

How to accomplish all the preparations? Obviously, you need the help of the rest of the family. But if everybody is involved in the task, how will it be coordinated? How avoid two people getting the napkins and nobody remembering to get the first-aid box? How to assign responsibility for the can-opener? And how to decide what must be done first, and what can be done at any time?

These kinds of questions *could* be all answered by one person, who would assign tasks and maintain supervision, settle disputes and respond to the inevitable complaints about work-loads, tasks neglected, and so forth.

Or there could be a non-directed kind of process in which the family periodically stops what it is doing to argue about everything from where we want to go down to which kind of olives to take.

But there is a planning method that permits a group to . . .

- Be mutually aware of the process and sub-goals. Contribute to and share in the decisions made about how, when and by whom activities are done
- Make more efficient use of resources by concentrating effort and time on the *critical tasks* rather than devoting time to sub-tasks while tasks of greater priority lack hands.
- Re-evaluate the project while it is underway, and re-allocate resources to cope with unexpected blocks to task accomplishment, or to take advantage of unanticipated success in meeting some sub-goal.

This planning method is called PERT, one of those acronyms to be sure, but no less valuable for that. It stands for Program Evaluation and Review Technique, and it has saved government and industry many millions of man-hours and dollars. A variation of PERT is known as CPM, or the Critical Path Method, a name that expresses something about how the thing is done. In this brief paper, we can only glimpse the bare outlines of PERT/CPM. Please consult the references for more detailed discussions.

PERT is a group analysis and flow-charting procedure that begins with identifying the sequences of dependent activities.

One begins, in true Lewis Carrol fashion, at the end.

Before we can arrive at the picnic grounds, we must travel there in the car. Before we can travel in the car, we must fill up with gas and check the oil. Before we can do that, we must have traveled to the service station. Before we can start out for the service station, we must have loaded all the supplies in the car . . . except ice, which we can get at the gas station.

The example we have given is thus seen to be trivial, indeed, but at the same time a paradigm of the planning process.

PERT is seen to be a tool of communication, and not just an abstract exercise performed only by the staff planners, thereafter executed under duress by the grumbling line.

PERT is a method that permits revision of the plan when things don't work out like the original plan said they should.

Plans never work out right.

But *the planning process is indispensable.*

The Psychological Corporation, 304 E. 45th Street, N.Y., N.Y. 10017.
Psychological Services, Inc., 4311 Wilshire Blvd., Los Angeles, Cal. 90005.
RBH, (Richardson, Bellows, Henry, and Company), 1140 Connecticut Avenue, N.W., Washington, D.C. 20036.
Science Research Associates, Inc., 259 E. Erie Street, Chicago, Ill. 60611.
Sheridan Supply Company, P.O. Box 837, Beverly Hills, Calif. 90213.
Stanford University Press, Stanford, Cal. 94305.
C.H. Stoelting Company, 424 North Homan Ave., Chicago, Ill. 60624.

Texts:

Buros, Oscar Krisen, ed., "The Seventh Mental Measurement Yearbook," Highland Park, N.J., Gryphon Press, 1972.
Stone, C. Harold and Kendall, William E., "Effective Personnel Selection Procedures," Englewood Cliffs, N.J., Prentice-Hall, 1956.

Cross References: *Executive Selection; Industrial Psychology; Personnel Testing.*

PERT (PROGRAM EVALUATION AND REVIEW TECHNIQUE)

The advancing technology of the Space Age brought an explosive growth of a new family of planning and control techniques. Much of the development work was done in the defense industry, but the construction, chemical, and other industries have also played an important part. Perhaps the best known of all the new techniques is Program Evaluation and Review Technique, commonly referred to as PERT.

The new techniques have several distinguishing characteristics:

(1) They give management the ability to plan the best possible use of resources to achieve a given goal within overall time and cost limitations.

(2) They enable executives to manage "one-of-a-kind" programs, as opposed to repetitive production situations.

(3) They help management handle the uncertainties involved in programs where no standard time data of the Taylor-Gantt variety are available.

(4) They utilize a so-called "time network analysis" as a basic method of approach to determine manpower, material, and capital requirements.

Development of PERT. Project managers increasingly noted that the techniques of Frederick W. Taylor and Henry L. Gantt, introduced during the early part of the century for large-scale production operations, were inapplicable for a large portion of the industrial effort of the 1960s and 1970s, an era that has aptly been characterized as the "Age of Massive Engineering."

The Special Projects Office of the U.S. Navy, concerned with performance trends on large military development programs, introduced PERT on its Polaris Weapon System in 1958, after the technique had been developed with the aid of the management consulting firm of Booz, Allen & Hamilton. Since that time, PERT has spread rapidly throughout the U. S. defense and space industry. Currently almost every major government and military agency concerned with Space Age programs is utilizing the technique, as are large industrial contractors in the field. Small businesses wishing to participate in national defense programs have found it increasingly necessary to develop PERT capability.

At about the same time the Navy was developing PERT, the duPont company, concerned with the increasing costs and time required to bring new products from research to production, initiated a similar technique known as CRITICAL PATH METHOD (CPM) which has spread quite widely, and is particularly concentrated in the construction industry. (For an overview discussion of the various control techniques, see INTEGRATED PROJECT MANAGEMENT.)

What PERT Is. In the early 1960s, PERT was in practice restricted largely to the area of time. (Later extensions are described below.) The basic requirements of PERT/time as established by the Navy were as follows:

(1) All of the individual tasks to complete a given program must be visualized in a clear enough manner to be put down in a *network*, which is comprised of *events* and *activities*. An event represents a specified program accomplishment at a particular instant in time. An activity represents the time and resources which are necessary to progress from one event to the next. Emphasis is placed on defining events and activities with sufficient precision so that there is no difficulty in monitoring actual accomplishment as the program proceeds. Exhibit I shows a typical operating-level PERT network from the electronics industry. Events are shown by the circles in the network, and activities are designated by the arrows leading from one event to its successor event or events.

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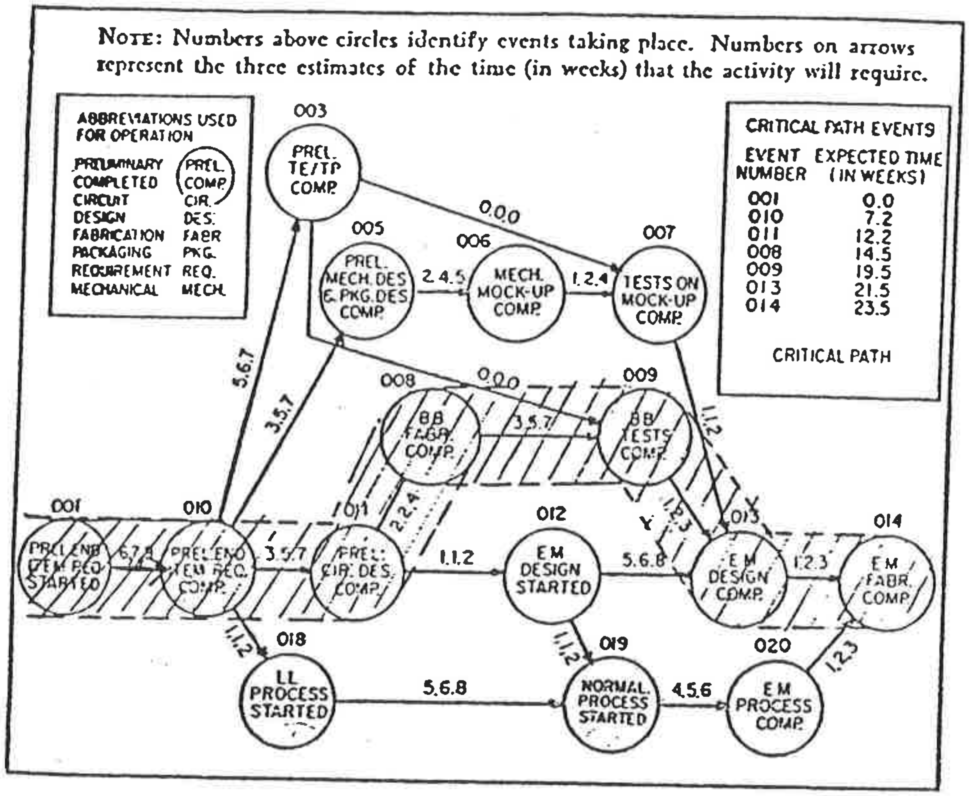
EXHIBIT I

TYPICAL OPERATING-LEVEL PERT NETWORK



(2) Events and activities must be sequenced on the network under a highly logical set of ground rules which allow the determination of important critical and subcritical *paths*. These ground rules include the fact that no successor event can be considered completed until all of its predecessor events have been completed, and no "looping" is allowed, i.e., no successor event can have an activity dependency which leads back to a predecessor event.

(3) Time estimates are made for each activity of the network on a three-way basis, i.e., *optimistic*, *most likely*, and *pessimistic* elapsed-time figures are estimated by the person or persons most familiar with the activity involved. The three time estimates are required as a gauge of the "measure of uncertainty" of the activity, and represent full recognition of the probabilistic nature of many of the tasks in development-oriented and nonstandard programs. It is important to note, however, that, for the purposes of computation and reporting, the three time estimates are reduced to a single expected time (t_e) and a statistical variance (σ^2).

(4) *Critical path* and *slack times* are computed. The critical path is that sequence of activities and events which will require the *greatest expected time to accomplish*. Slack time is the difference between the total expected activity time required for any specific path and the total for the critical path. Thus for any event it is a measure of the spare time that exists at the moment in each of its subsequent sequence of events.

If the size and complexity of the network call for them, computer routines are available to calculate the critical path, as well as the amount of slack for all events and activities not on the critical path. If total expected activity time along the critical path is greater than the time available to complete the project, the program is said to have *negative slack*. Negative slack time is a measure of how much acceleration is required to meet the schedule objective dates.

Time Estimates. Interpretation of the concepts of optimistic, most likely, and pessimistic elapsed times has varied. The definitions which represent a useful consensus are as follows.

Optimistic—An estimate of the *minimum* time an activity will take, if unusual good luck is experienced and everything "goes right the first time."

Most likely—An estimate of the *normal* time an activity will take, a result which would occur most often if the activity could be repeated a number of times under similar circumstances.

Pessimistic—An estimate of the *maximum* time an activity will take, if unusually bad luck is experienced. It should reflect the possibility of initial failure and fresh start, but should not be influenced by such factors as "catastrophic events"—strikes, fires, power failures, and so on—unless these hazards are inherent risks in the activity.

Averaging formulas have been developed by which the three time estimates are reduced to a single expected time (t_e), variance (σ^2), and standard deviation (σ). Thus (approximately):

$$t_e = \frac{a + 4m + b}{6}$$

$$\sigma = \frac{b - a}{6}$$

where a is the most optimistic time, b is the pessimistic time, and m is the most likely time. The choice of probability distribution and the approximations involved in these formulas are subject to some question, but they have been widely used and seem appropriate enough in view of the inherent lack of precision of estimating data. The variance data for an entire network make possible the determination of the *probability of meeting an established schedule date*, as shown in the Appendix at the end of this article.

Exhibit II contains data on the critical path and slack times for the sample network of Exhibit I. The data are shown in the form of a *slack order report* (lowest to highest slack), perhaps one of the most important of PERT reports. Other output reports, such as event order and calendar time order reports, are also available.

Review and action by responsible managers, generally on a biweekly basis, are required, concentrating on important critical path activities. Where required, valid means of shortening lead times along the critical path must be determined by applying new resources or additional funds, obtained from those activities that can "afford" them because of their slack. Alternatively, sequencing of activities along the critical path may be changed. A final alternative may be, perforce, a change in the scope of the work of the critical path to meet a given schedule.

PERT requires constant updating and reanalysis, since the outlook for the completion of activities in a complex program is in a constant state of flux. Highly systematized methods of handling this aspect of PERT have been developed.

Benefits Gained. A big advantage of PERT is the kind of planning required to create a major network. Network development and critical path analysis reveal interdependencies and problem areas which are either not obvious or not well defined by conventional planning methods.

Another advantage, especially where there is a significant amount of uncertainty, is the three-way estimate. If the decision maker is statistically sophisticated, he can examine the standard deviation and probability of accomplishment data. If there is a minimum of uncertainty, the single-time approach may, of course, be used, while retaining the advantages of network analysis.

Finally, PERT allows a large amount of data to be presented in a highly ordered fashion, bringing the management-by-exception prin-

EXHIBIT II
SLACK ORDER REPORT

PERT SYSTEM
Airborne Computer– Slack Order Report
Date 7/12/73 Week 0.0 Time in Weeks Page 1

Event	T_E	T_L	T_L-T_E	T_S	*pr*	
001	0.0	0.0	0			T_E = Expected event date
010	7.2	7.2	0			T_L = Latest allowable event date
011	12.2	12.2	0			
008	14.5	14.5	0			T_L-T_E = Event slack
009	19.5	19.5	0			T_S = Scheduled event date
013	21.5	21.5	0			
014	23.5	23.5	0	23.5	.50	P_r = Probability of achieving T_S date
020	20.6	21.5	+ .9			
019	15.6	16.5	+ .9			
012	14.4	15.3	+ .9			
018	9.4	10.3	+ .9			
007	18.2	20.3	+2.1			
006	16.0	18.1	+2.1			
005	13.2	14.3	+2.1			
003	14.2	19.5	+5.3			

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ciple to an area of planning and control not hitherto readily susceptible to it. Additionally, many individuals in different locations can easily determine the total task requirements of a large program.

Implementation Techniques. When a well-thought-through network is developed in sufficient detail, the first activity time estimates made are as accurate as any, and these should not be changed unless a new application of resources or a trade-off in goals is specifically determined. Further, the first time estimates should not be biased by some arbitrarily established schedule objective, or by the assumption that a particular activity does not appear to be on a critical path. Schedule biasing of this kind, while it obviously cannot be prevented, clearly atrophies some of the main benefits of the technique—although it is more quickly discovered with PERT than with any other method.

In the case of common resource centers, it is generally necessary to undertake a loading analysis, making priority assumptions and using the resulting data on either a three-time or single-time basis for those portions of the network which are affected. It should be pointed out that the process of network development forces more problems of resource constraint or loading analysis into the open for resolution than do other planning methods.

Application to Production. It is sometimes viewed as a disadvantage of the PERT technique that it is not applicable to all manufacturing effort. PERT deals in the time domain only and does not contain the quantity information required by most manufacturing operations. Nevertheless, PERT can be, and has been, used very effectively through the preliminary manufacturing phases of production prototype or pilot model construction, and in the assembly and test of final production equipments which are still "high on the learning curve." After these phases, established production control techniques which bring in the quantity factor are generally more applicable.

It should be noted, however, that many programs of the Space Age never leave the preliminary manufacturing stage, or at least never enter into mass production. Therefore, a considerable effort is going forward to integrate the techniques of PERT within some of the established methods of production control, such as LINE-OF-BALANCE or similar techniques that bring in the quantity factor.

PERT and Computers. There is a common impression that the technique is only applicable when large-scale data-processing equipment is available. This is certainly true for large networks, or aggregations of networks, where critical path and slack computations are involved for several hundred or more events.

However, several ingenious manual methods have been developed, ranging from simple inspection on small networks to more organized but clerically oriented routines for determination of critical path, subcritical path, and slack times on networks ranging from fifty to several hundred events. Exhibit I shows the network for a relatively small electronics program. Developed in less than a day, the whole network required only two hours for manual computation.

PERT Extensions. A considerable amount of research has been put into the extension of PERT into the areas of manpower, cost, and capital requirements. The ultimate objective is the determination of "trade-off" relationships between time, cost, and product or equipment performance objectives.

PERT/Cost. Most job-costing structures in industry on complex development programs need a great deal of interpretation to relate *actual costs* to *actual progress*. They are rarely, if ever, related in any explicit manner to the details of the scheduling plan. Yet cost constraints either in the form of manpower shortages or funding restrictions have a great deal to do with the program's success. For this reason, an approach called basic PERT/cost was developed. This involves establishing job cost estimates *directly from an activity or group of activities on a time network* [1]. The networks themselves are based upon the framework of a *work breakdown structure* for the complete program.

Regarding development of actual cost figures in basic PERT/cost, an estimate of manpower requirements, segregated by classification, is usually the easiest place to start, since these requirements were presumably known at the time the network was established. A single-valued scheduled time figure generally replaces t_e in the basic PERT/cost approach, as a matter of convenience in developing manpower leveling data. The summation of such data often reveals a manpower or funding restriction problem, and forces a replanning cycle if no alternatives are available.

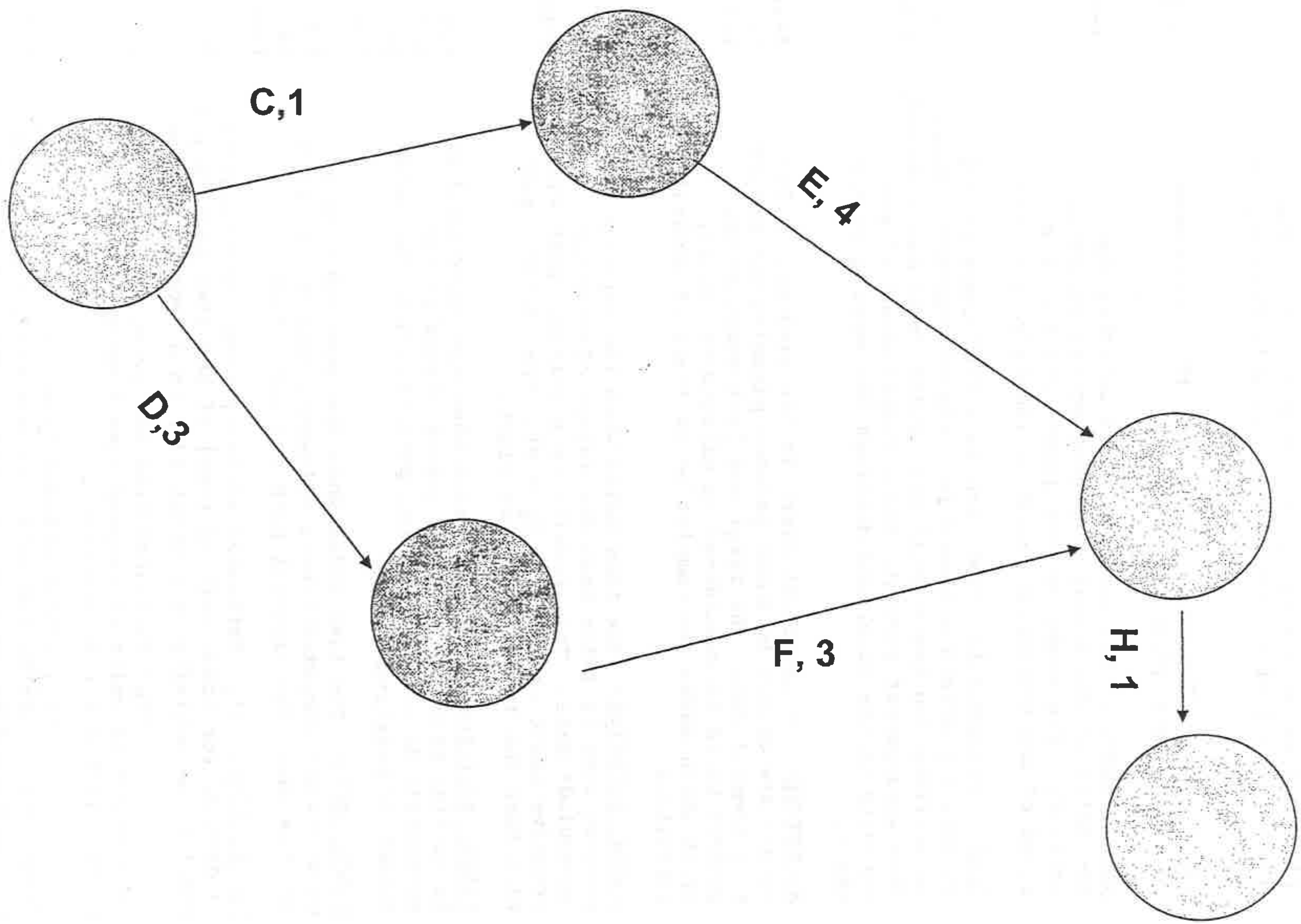
SECTION 8

GLOSSARY OF PERT TERMS WITH PAGE REFERENCES

	Text Pages
ACTIVITY: A time-consuming element of a project which is represented on a chart as an arrow between two events. An activity cannot be started until the event leading it has been accomplished. A follower event cannot be accomplished until all activities leading it are complete. The arrowhead points toward the follower event.	1-3 to 1-9
ACTIVITY, DUMMY: A zero-time activity which constrains its follower event by requiring its leader be completed first. The dummy activity is represented on the chart by a dash-line arrow.	4-1 to 4-7
CHAINING, BACKWARD: The predicting and listing of a sequence of activities in reverse order. Generally used to prevent inadvertent ommission of necessary steps or requirements.	1-1 to 1-5
CHART, PERT: A visual representation showing the logical sequence and relationships among the various activities and events in a project.	1-15 to 1-19
CONSTRAINT: The relationship of activities to their follower events showing that an event cannot occur until all the activities leading it have been completed. Also, the term is used to indicate the relationship of an event to following activities wherein the activities may not start until their leader event has occurred.	4-3
CRITICAL PATH: The sequence of activities in a project that forms the longest time path from the first to the last event. If the project has a scheduled completion date, the critical path will be that path which has the greatest amount of negative slack, least amount of positive slack, or zero slack.	3-25 to 3-28
EVENT: A specific definable accomplishment in the project plan, which is recognizable as a particular instant in time when activities start or finish. Events do not consume time or resources and are represented in the chart by numbered circles.	1-5 to 1-13
EVENT FIRST: The start of all activities leading to the achievement of the project's goals.	1-10

	Text Pages
EVENT, FOLLOWER: The event which denotes the accomplishment of an activity. The number of this event is the second of the two numbers used to identify an activity.	1-8
EVENT, LAST: The event which marks the achievement of the project goals.	1-10
EVENT, LEADER: The event which establishes the beginning of the actual work that occurs during an activity. The number of the leader event is the first of the two numbers used to identify an activity.	1-8
LOOP: An impossible condition in a PERT chart formed by activity arrows arranged in a closed sequence. Since no activity can begin until its leader event has occurred, this arrangement prevents the accomplishment of any activity in the loop, and destroys the meaning of the chart.	2-21 to 2-22
MILESTONE: An important event in the project. Milestones are chosen by those persons planning the project. As a general rule, the first and last event of the project would be considered as milestones, or any event which marks the completion or start of several activities.	1-12 to 1-13
SLACK, NEGATIVE: The time value when the expected completion date is later than the latest allowed (or scheduled) date. This results in a critical path with negative slack value ($T_L - T_E = S$). The critical path will have the largest negative slack.	5-9 to 5-19
SLACK, POSITIVE: The time value when the expected date is earlier than the computed latest allowable (or scheduled) date. The critical path will have the least amount of positive slack.	4-9 to 4-30 and 5-13 to 5-17
SLACK, ZERO: The time value when the expected date is equal to the computed latest allowable date for an event. In this case, the critical path has zero slack.	4-9 to 4-30
TIMES, PERT: (t_e) Estimated activity time. The estimate in days or (or other unit of time) of the time necessary to complete an activity or a chart path in a specified manner.	3-1
(T_E) Estimated time for event to occur. It is measured in units of elapsed time from any event back to the first event or milestone.	3-23
(T_L) Latest allowed time for event to occur which will not delay completion of the project beyond the time indicated by the critical path. Latest allowed time (T_L) minus estimated time (T_E) equals slack time (S).	4-15

PERT CHART



From the Master List, you transfer the activities to your workload for the day, the next day, the next week, and the next month. Psychologically, the Master List lets you know everything that you know of that you must do and that there's an end to it—at least until you add more items the next day! The Master List becomes a storage facility for all your ideas until you can distribute them to your daily, weekly, and monthly planners, or until you can delegate them to other appropriate staff members.

Milestone chart. The Milestone Chart graphically displays the relationship of the steps in a project (Figure 18). When you create this type of chart, you first list all the steps required to finish the project and estimate the time required for each step. The steps are listed down the left side of the chart, with dates shown along the top. A line is drawn across the chart for each step, starting at the planned beginning date and ending on the completion date of that step. Once you complete the Milestone Chart, you can see the flow of the action steps and their sequence. Several steps can overlap and be in progress at the same time. As the project progresses, you can chart the progress by drawing lines in another color beneath the original target lines. These new lines will indicate to you the "actual" as opposed to "targeted dates" of completion for each step in the project.

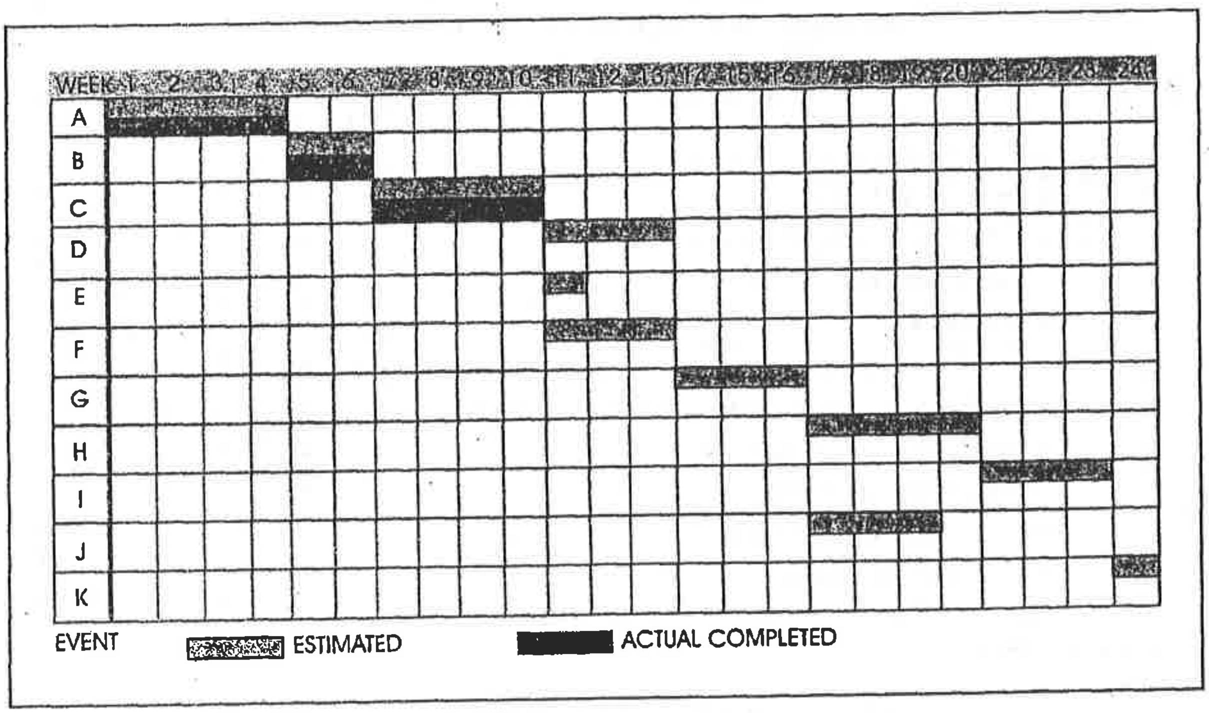
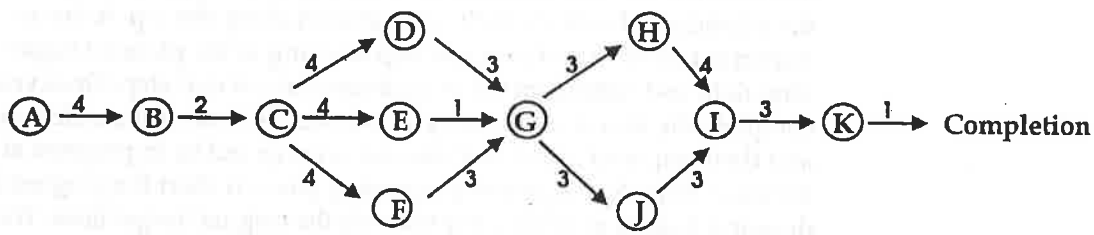


FIGURE 18—A Milestone Chart

PERT chart. PERT stands for Program Evaluation and Review Technique. It's a more sophisticated way of depicting the various steps in a project (Figure 19). These events (A–K) correspond with the steps listed in Figure 18. To formulate a PERT Chart, you list the steps required to finish a project and estimate the time required to complete each step. Then, you draw a network of relationships among the steps. The number of the step is shown in a circle, and the time to complete the step is shown on the line leading to the next circle. Steps that must be completed in order are shown on one path to clarify proper sequencing. Steps that can be underway at the same time are shown on different paths.



The critical path is ABCDGHIK. It will take 24 weeks from event A to event K.

EXAMPLE OF A PERT CHART TO BUILD A HOUSE			
Event	**Description**	**Time (in weeks)**	**Preceding Event**
A	Approve design and obtain permit	4	None
B	Dig and prepare footers	2	A
C	Put up frame and siding/stucco, or brick	4	B
D	Put in floors, tubs, showers	3	C
E	Put in windows	1	C
F	Put on roof and shingles	3	C
G	Put in wiring, plumbing, gas lines, phone lines, security system	3	D, E, F
H	Put in walls and paint, carpet	4	G
I	Install doors, trim, appliances, carpet	3	H
J	Grade and landscape, sidewalks	3	G
K	Turn over house to owners	1	I

FIGURE 19—A PERT Chart

A PERT Chart shows the relationship among various steps in a project. It also serves as an easy way to calculate what's called the "critical path." The critical path is the longest time path through the network of steps. It identifies essential steps that must be completed on time in order to not delay completion of the total project.