Project orientated planning, scheduling and controlling technique

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In the past several years, there has been an explosive growth of management technique to be used for planning and controlling projects. Between 1957 *and* 1958 *such technique received special attention and as a result improved and developed further under various names (CPM, PERT, etc.). The technique is a method whereby the policy to be adopted in carrying out a project is represented by a graphical model in which the times necessary for the constituent parts are inserted. The model is analysed, the sequence (s) of times which determine the total project time extracted and the times available for all constituents calculated. Comparison of actual times with available times enables control to be exerted in the performance of the project.*

Introduction

There are several techniques used for project scheduling. The oldest and simplest which is still the most used is to set up a narrative list, more or less in chronological order, of the tasks to be accomplished showing the time required for each task and to work out on this basis the resources necessary to carry out the tasks. This elementary scheduling is, however, highly inefficient. The other way is to prepare a bar or Gantt chart and, although this is extremely simple in many cases, it does not show the interrelationship between the various activities.

In 1950, in Great Britain, the Operational Research Section of the Central Electricity Generating Board investigated the problems concerned with the overhauling of generating plants - a task of considerable complexity which was increasing in importance as new high-performance plants were being brought into service. By 1957, the Operation Research Section had devised a technique which consisted essentially of identifying the "Longest Irreducible Sequence of Events", and by employing this technique they were able to reduce performance time by 42% in 1958 and by additional 32% in 1960. The name of the technique. "Longest Irreducible Sequence of Events" was soon replaced by the name "Major Sequence".

Simultaneously, similar work was being undertaken in the U.S.A. In early 1958 the U.S. Navy Special Projects Office set up a team to devise a means of dealing with the planning and subsequent control of complex works. This investigation was known as the Programme Evaluation Research Task which gave rise to the code name PERT. After the successive imrovement of the technique the name has changed to **Programme Evaluation and Review Technique.** By October 1958 it was decided to apply **PERT** to the Fleet Ballistic Missiles Programme, where it was credited with saving two years in the development of the Polaris Missile.

The U.S. Air Force, under the code name PEP has undertaken similar development work. Also in 1958, the E.I. Du Pont de Nemours Company used a technique called the Critical Path Method (CPM) to schedule and control a very large project, and during the first complete year of its use CPM was credited with saving the company U.S. $1 million.

Since 1958 considerable work has been done to improve the technique which was referred to cover various names. Mr. K. G. Lockyer from the University of Loughborough in England prefers to call this technique Critical Path Analysis (CPA).

There is a general impression that CPA or CPM is a technique which is applicable only to large projects and that it is vital to use a computer to achieve worth-while results. This is not necessarily so; quite striking results can be obtained in small projects which can be computed by hand.

Fundamentals Of CPM- The Critical Path Analysis involves three distinct phases:-

Planning:- in the planning phase, the programme objectives are identified and the total job is broken down into events and activities. The events and activities which constitute a project are clearly defined and the time for the performance of each activity is estimated.

Experience of the people in the field is of importance in achieving this break-down. The project is represented graphically by circles (representing events) and arrows (representing activities which lead to or emerge from the circles).

Scheduling and Analysing:- Since all the works and activities cannot begin simultaneously due to technical constraints and resource limitations, they must be scheduled in some sequence. A network thus indicates the logical sequence and interdepedence between the various elements and provides a proper understanding of the details and the sequence of the components of the project. Every effort must be made to ensure that all activities which follow a particular event are depicted in the network.

The plans are translated into schedules with specific calendar dates which will govern the start and completion of work and authorize the expenditure of resources on each activity in the plan. A project schedule should provide at least the following:-

1. Starting date for the project.
2. Identification, in chronological order, of the important tasks to be performed with the starting and the completion dates of each task.
3. A completion date for the project.
4. Identification of resources such as equipment materials, special skills and man-power to be mobilized, within given spans of time, to perform each specific task.
5. A basis for planning the allocation of monies for carrying out each task.
6. A yard-stick for comparing physical progress and actual financial costs as they are incurred with those projected and provided for.

Without a project schedule that provides at least the foregoing, it is difficult to ensure that a project would cost reasonably close to what is was estimated to cost. Equally important, without such a schedule it is very improbable that a project can be completed and can begin to produce revenues or benefits anywhere near the expected time.

By analysing the plans and schedules, the question "How long will the whole project take?" can be easily answered. All the series of activities can be analysed considering the duration and the sequence of events. The longest sequence of the series of activities can be determined. This sequence is critical to the performance of the project and is hence known as **the Critical Path.**

Controlling:- The project control programme is one of the important elements in the evaluation and appraisal of a project in the implementation stage. It gives reasonable guide lines for establishing the timing for capital outlays and also for evaluating the thoroughness of planning.

During the implementation of the project it is one of the important tools for measuring performance. Along with financial reporting it is also very helpful in spotting potential or actual trouble and taking steps to overcome it.

When the implementation of the project gets underway the project authorities must ensure that the progress of work is such that the project will be completed by its scheduled date. For this, it is necessary to adopt a correct reporting system to enable realistic assessment of the progress against the plan laid down in the project schedule.

The reporting system may consist of:-

1. **Mile-stone charts**:- These charts may be prepared for the total project displaying the scheduled dates of the major mile-stones in the project. The periodic reports should show whether these mile-stones have been accomplished by the scheduled dates or not.
2. **Status Reports**:- This report is a summary of the events which are critical to the project at the time of reporting.
3. **Cost Reporting**:- The project cost report is presented under the various heads used in the original project estimates and shows variations under each head. Periodical assessment of the status of the project through project cost reports would determine the funds required for the execution of the project.

Activity & Time Element

Once the plan of sequence and interrelationship between the various activities of the project has been established, the next step is to estimate the duration or each activity on the network, assuming a normal application of resources. This time estimate should be made by the people most familiar with the work and it normally represents the most likely time that the activity may take. Care must be taken to obtain sound estimates based on logical reasoning.

Terminology Used in Network Preparation

Activity:- is a work effort of a programme which is represented by an arrow. An activity cannot be started until the event preceding it has occurred and it may represent a process, task, waiting time, or simply represent a connection or interdependence between two events on the network.

Expected Elapsed Time (te):- is the elapsed time which an activity is estimated to require. The expected elapsed time is identical to a single time estimate for the work to be accomplished.

Earliest Expected Date (TE):- is the earliest calendar date on which an event can be expected to occur. The TE value for a given event is equal to the sum of the expected elapsed time (te) for the activities on the longest path from the beginning of the programme to the given event.

Event:- is a specific definable accomplishment in a programme, recognizable at a particular instant in time.

Beginning Event:- is an event which signifies the beginning of one or more activities.

Ending Event:- is the event which signifies the completion of one or more activities. The ending point is time of an activity.

Latest Allowable Date (TL):- is the latest calendar date on which an event can occur without delaying the completion of the programme. The TL value for a given event is calculated backward, by subtracting the sum of the expected elapsed time (te) for the activities on the longest path between the given event and the end event of the programme, from the latest date allowable for completing the programme. TL for the end event in a programme is equal to the directed date (TD) of the programme. If a directed date is not specified, TL - TE for the end event.

Critical Path:- is the sequence of activities which determines the total time i.e. the longest path which controls the time of completion of the project.

Float or Slack (a Property of Events) :- is the difference between the latest and earliest event times (TL - TE).

The foregoing elements have been noted, for illustration on the Critical Path Diagram. (Fig. 1) for a house building project.

Example - Building a House

A simple and familiar example should help to clarify the notion of Critical Path Scheduling and the process of constructing a graph. The project of building a house is readily analysed by the CPM technique and is typical of a large class of similar applications.

In chronological order the "events" can be written and the time (in days) required to accomplish each "activity" can be estimated and listed in Table 1.

Table 1

Example — building a house

EVENTS	DESCRIPTION OF JOBS	ACTIVITIES	DURATION TIME IN DAYS (te)
1	Start	-	0
2	Excavate & pour footers	1-2	4
3	Pour concrete foundation	2-3	2
4	Erect wooden frame including rough roof	3-4	4
5	Lay brickwork	4-5	6
6	Install basement-drains & plumbing	3-6	1
7	Pour basement floor	6-7	2
8	Install rough Plumbing	6-8	3
9	Install rough wiring	4-9	2
10	Install heating and ventilating	4,7-10	4
11	Fasten plaster board and plaster (including drying)	8,9,10-11	10
12	Lay finish flooring	11-12	3
13	Install kitchen fixtures	12-13	1
14	Install finish plumbing	12-14	2
15	Finish carpentry	12-15	3
16	Finish roofing and flashing	5-16	2
17	Fasten gutters and down spouts	16-17	1
18	Lay storm drains for rain water	3-18	1
19	Sand and varnish flooring	15-19	2
20	Paint	13, 14-20	3
21	Finish electrical work	20 21	1
22	Finish grading	17, 18-22	2
23	Pour walks and complete land-scaping	22-23	5
24	Finish	19,21,22-24	0

These events and activities are presented in the diagram (fig. 1) following the CPM technique.

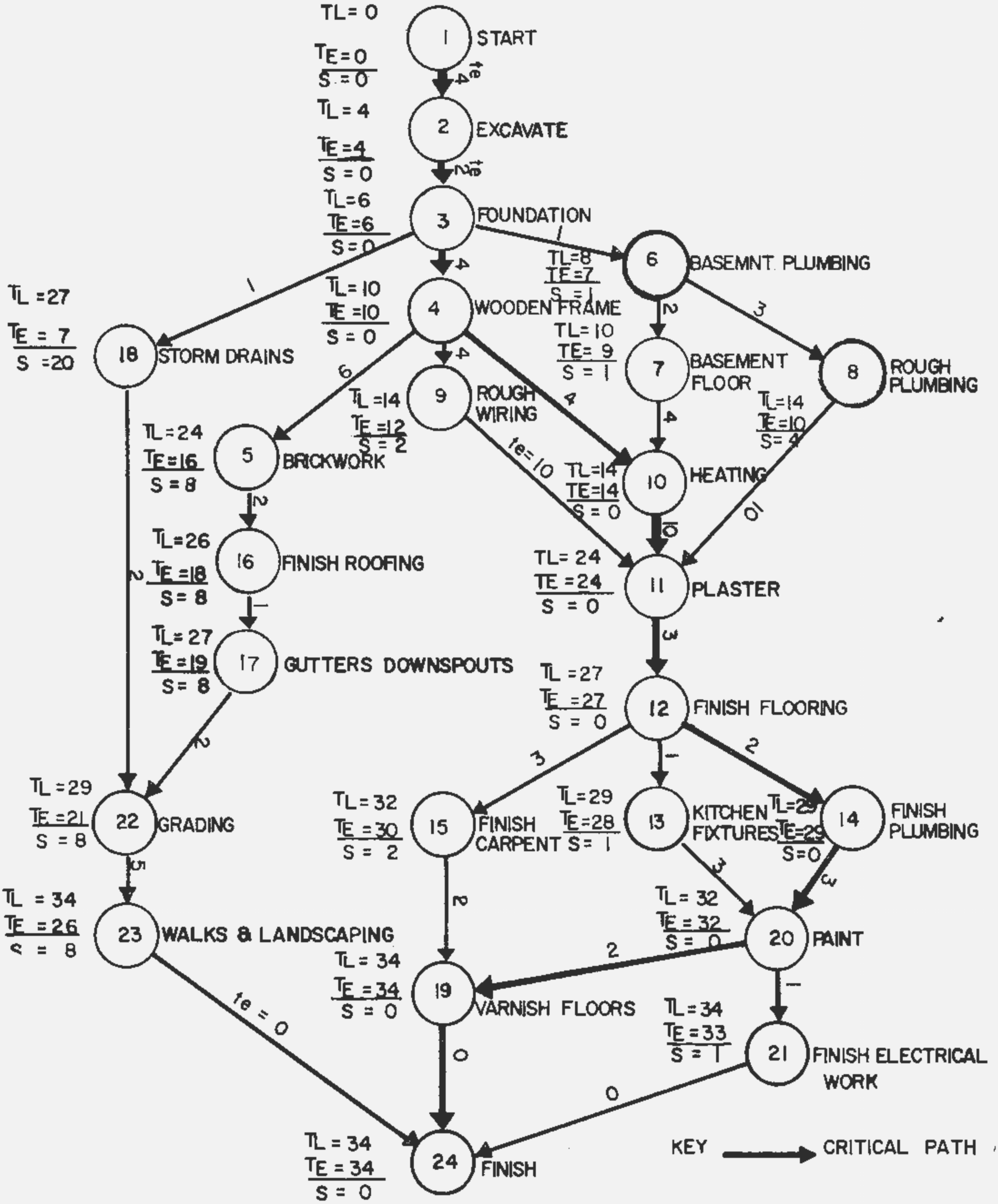


Fig. 1 CRITICAL PATH DIAGRAM

From the analysis of the Critical path diagram fig. 1 it can be seen that:

a) The Critical Path is 1-2-3-4-10-11-12-14-20-19-24.

b) The total time required for the completion of the activities and events along the Critical Path, as well as the whole project, is 34 days.

c) Along the Critical Path there is no slack (no time to spare), which means that the activities and events along the Critical Path have to be accomplished as scheduled, in order to complete the whole project in 34 days.

d) Activities not falling on the Critical Path can absorb some delay in the starting and completion time without affecting the completion date for the project.

Cost Calculations:- The cost of carrying out a project can be readily calculated from the job data if the cost of doing each job is included in the data. If jobs are done by crews and the speed with which the job is done depends on the crew size, it is possible to shorten or lengthen the project time by adding or removing men from crews. Any speed-up may involve a price increase. A job could be assigned a "normal time" and "crash time" and associated costs can be calculated in each case. If the project time is to be cut down some of the critical jobs could be put on "crash time" and the corresponding direct costs calculated. In this way it is possible to calculate the cost of completing the project in various total times, with the direct costs increasing as the overall time decreases.

Added to direct costs are certain overhead expenses which are usually allocated on the basis of total project time. Fixed cost per project thus decreases as project time is shortened. In ordinary circumstances, a combination of fixed and direct costs, as a function of total project time, would probably fall into the pattern shown in fig. 2. The minimum total cost (point A) is likely to fall to the left of the minimum point on the direct cost curve (point B) indicating that the optimum project time is somewhat shorter than an analysis of direct cost only would indicate.

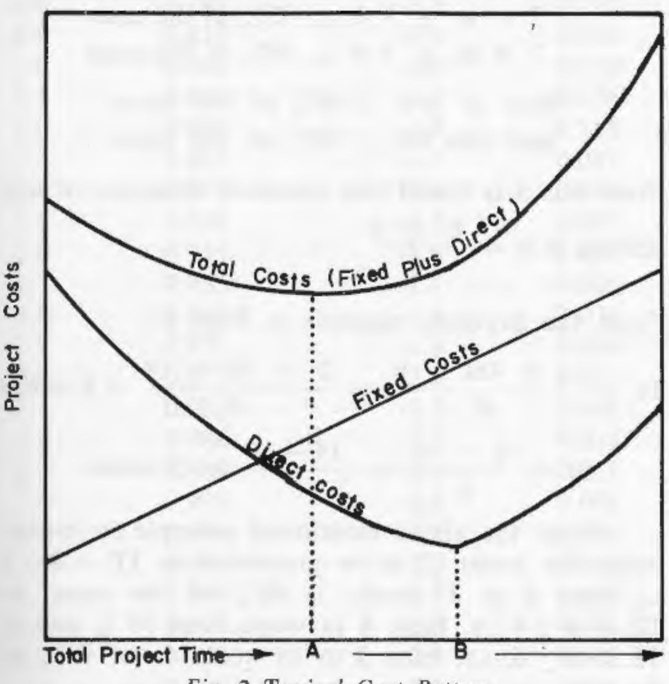
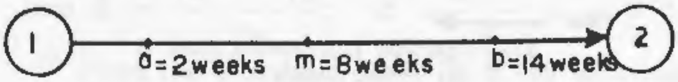


Fig. 2 Typical Cost Pattern

Basic Difference Between "CPM" and "PERT" Techniques:-

In CPM analysis, the expected elapsed time (te) is a single best time estimate for the work to be accomplished while in PERT it is derived from the calculation of a statistically weighted average time estimate in corporating the optimistic (a) most likely (m) and pessimistic (b) estimates for the work to be accomplished. This means that PERT involves the probabilistic concept.

For example, assume three time estimates for the occurence of event (2) below:



If the foregoing task is repeated many times under identical conditions the following types of probability distributions for "te" may be found:-

Normal Probability Distribution

In this case te=m would be the mean which divides the distribution curve in two equal parts. The elapse of time between *a* and *m* and between *m* and *b* would be equal.

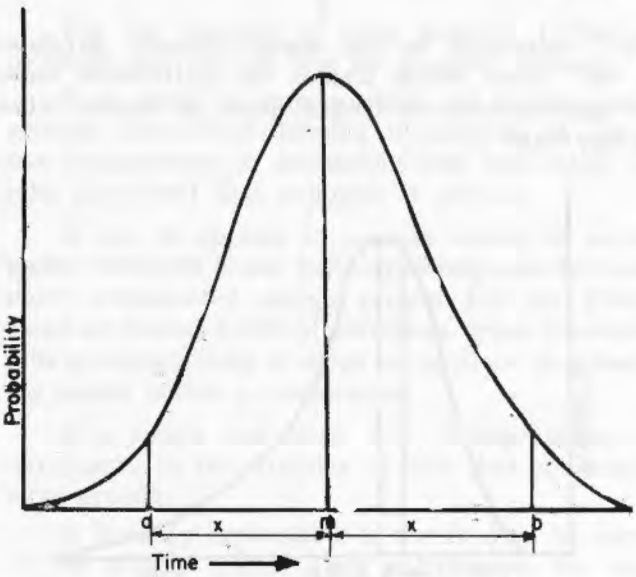


Fig. 3 Normal Distributions

Beta (Skewed) Probability Distribution

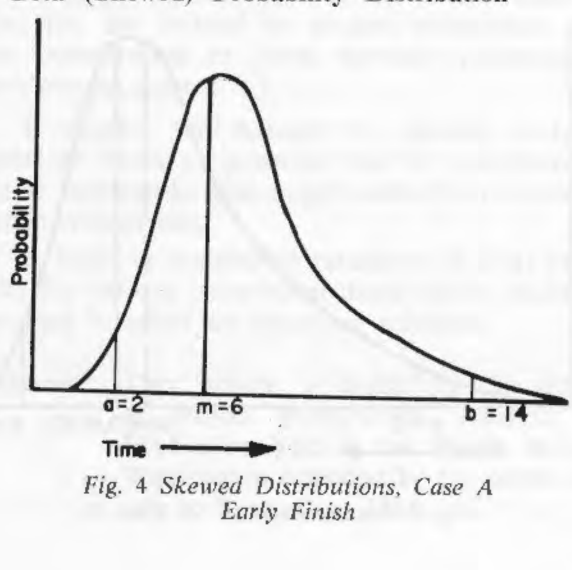


Fig. 4 Skewed Distributions, Case A Early Finish

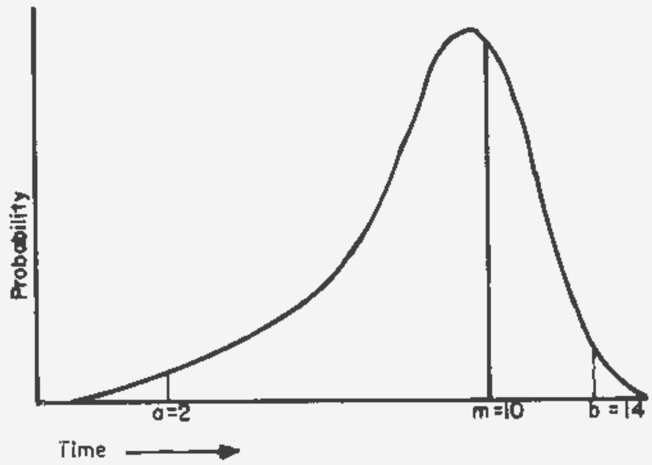


Fig. 5 Skewed Distribution. Case B
Late Finish

When the probability distribution is skewed the mean "te" would be computed employing the following empirical formula:-

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

In Case A, te $= \frac{2 + 24 - 14}{6} = 6.6$ weeks.

In Case B, te $= \frac{2 + 40 + 14}{6} = 9.3$ weeks.

"te", calculated by the above formula produces a "te" value which divides the distribution curve in approximately two equal parts as shown below in figs 6 and 7.

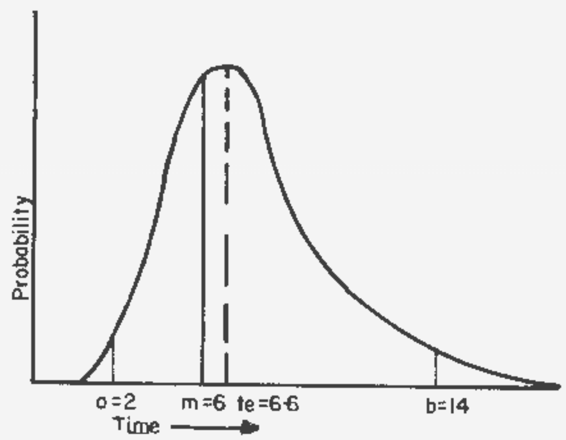


Fig. 6 Location of "te" in Case A.

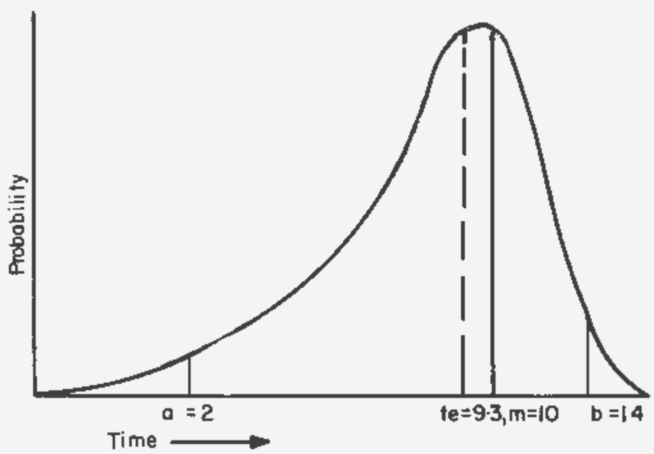


Fig. 7 Location of "te" in Case B.

Dispersion around the Average Value

Standard deviation (σ) is calculated by the following formula:-

$$\sigma = \left[\frac{1}{n} \sum (X - \bar{X})^2 \right]^{1/2}$$

It has been found that, in a normal distribution, the percentage of the cases (area under the curve) included within any number of standard deviations, measured from the mean, can be determined from specially prepared tables of areas of the normal curve and such tables can be found in any statistics book.

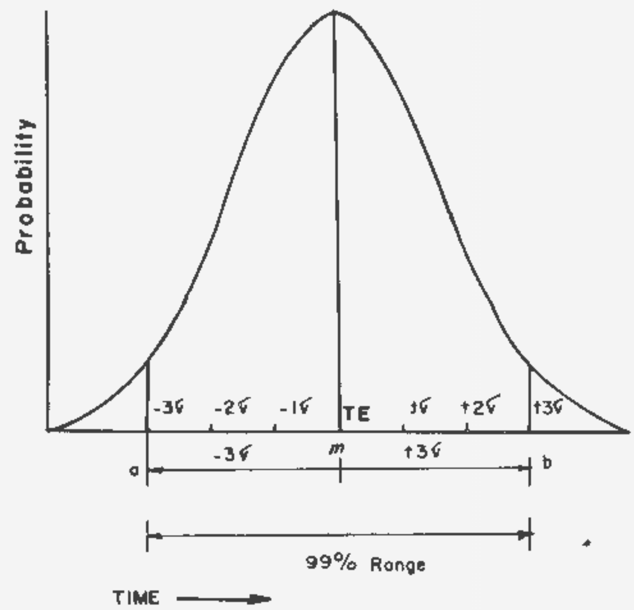


Fig. 8 Standard Deviation — Probability Relation in a normal distribution

If a distance equal to one standard deviation is measured in both directions from the mean it will include approximately 68% of the cases, two standard deviations will equal 95% and three deviations 99% of the cases.

-1σ to $+1\sigma$ = 68% of the cases
-2σ to $+3\sigma$ = 95% of the cases
-3σ to $+3\sigma$ = 99% of the cases

that is b-a = 99% of the cases
and also 6σ = 99% of the cases

From this it is found that standard deviation of any activity is $\sigma = \frac{b - a}{6}$.

From the previous example in Page 15:

$$Te = \frac{a + 4m + b}{6} = \frac{2 + 32 + 14}{6} = 8 \text{ weeks}$$

$$\sigma = \frac{b - a}{6} = \frac{14 - 2}{6} = 2 \text{ weeks}$$

From the above mentioned example the probability for event (2) to be completed in TE = 8 ± 2 i.e. from 6 to 10 weeks is 68% of the cases; in TE = 8 ± 4 i.e. from 4 to weeks is of 95 % and in TE = 8 ± 6, i.e. from 2 to 14 weeks is of 99 % of the cases.

In effect, the horizontal width of the probability curve, extending from -3σ to $+3\sigma$, measures the uncertainty of the TE value. As σ becomes smaller, the horizontal width narrows and the more certain does TE become; as σ becomes larger, TE becomes less certain.

From the Critical Path Diagram (fig. 1) of event (6) TE = 7 weeks and let it be assumed that the event standard deviation (σ_{TE}) for this event equals 1 week. When an event is constituted by a series of activities, the square root of the sum of the squares of activity standard deviation gives the standard deviation of the event which terminates the series of activities. This is called **"event standard deviation"**, (σ_{TE}).

$$\sigma_{TE} = (\sigma_{1\text{-}2}{}^2 + \sigma_{2\text{-}3}{}^2 + \sigma_{3\text{-}6}{}^2)^{1/2}$$

Then there is a small probability that the event either may be completed in as little a time as 4 weeks (i.e. $-3\sigma_{TE}$) or may require as long as 10 weeks (i.e. $+3\sigma_{TE}$). However, if σ_{TE} equals 2 weeks it is possible for the network to be completed in 1 week or to require as long as 13 weeks.

Te becomes more certain as σ_{TE} becomes smaller. σ_{TE} is the square root of the sum of the σ^2 values. This sum decreases as the activity standard deviation (σ) takes smaller values. Since each value equals (b-a) /6 it can be seen that only small values of (b-a) will result in the desired small value of σ_{TE}.

TABLE 2
NORMAL PROBABILITY DISTRIBUTION

Positive Values of $Z=\frac{TL-TE}{\sigma_{TE}}$		Negative Value of $Z=\frac{TL-TE}{\sigma_{TE}}$	
Z	PROBABILITY	Z	PROBABILITY
0.0	0.500	-0.0	0.500
0.1	0.540	-0.1	0.460
0.2	0.579	-0.2	0.421
0.3	0.618	-0.3	0.382
0 4	0.655	-0.4	0.345
0 5	0.692	-0.5	0.309
0 6	0.726	-0 6	0.274
0.7	0.758	-0.7	0.242
0.8	0.788	-0.8	0.212
0.9	0.816	-0.9	0.184
1.0	0.841	-1.0	0.159
1.1	0.865	-1.1	0.136
1.2	0.885	-1.2	0.115
1.3	0 903	-1.3	0.097
1.4	0.919	-1.4	0.081
1.5	0.933	-1.5	0.067
1.6	0 945	-1.6	0.055
1.7	0.955	-1.7	0.045
1.8	0.964	-1.8	0 036
1.9	0.971	-1.9	0.029
2.0	0.977	-2.0	0.023
2.1	0.982	-2.1	0.018
2.2	0 986	-2.2	0 014
2.3	0.989	-2.3	0 011
2.4	0.992	-2.4	0.008
2.5	0 994	-2.5	0.006
2.6	0.995	-2.6	0.005
2.7	0 996	-2.7	0.004
2.8	0.997	-2.8	0.003
2.9	0.998	-2.9	0.002
3.0	0.999	-3.0	0.001

From the above mentioned event (6) of the Critical Path Diagram (fig. 1) TE = 8 weeks, TL = 7 weeks and let σ_{TE} =2 weeks, and then the probability that the event will occur by its latest allowable date (TL) can be calculated from the following expression used in the determination of probability.

$$Z = \pm \frac{TL - TE}{\sigma_{TE}} = \pm \frac{S}{\sigma_{TE}}$$

Where Z refers to the probability of meeting or doing better than the scheduled date, and S is the slack or float (time to spare)

$$\text{then } Z = \frac{TL - TE}{\sigma_{TE}}; \quad Z = \frac{8-7}{2} = +0.50$$

From the probability table (2) it can be found that the value of Z = + 0.50 corresponds to 0.692. This means that the probability that the event will be accomplished within 8 weeks after the actual beginning event takes place is about 69%.

In PERT, TE and TL are calculated by involving three estimates of time and the probabilistic concepts and hence this technique offers itself for the use of computers.

Conclusions

For the manager of large projects, CPM is a powerful and flexible tool for decision making:

It is useful at various stages of project management, form initial planning or analysing of alternative programmes to scheduling and controlling the jobs (activities) that compreis a project.

It can be applied to a great variety of project types - from the house building example to the vastly more complicated design project for the Polaris - and at various levels of planning - from scheduling jobs in a single shop or shops in the plant, to scheduling plants within a corporation.

In a simple and direct way, it displays the interrelations in the complex of jobs that comprise a large project.

It is easily explainable to the layman by means of the project graph. Data calculations for large projects, while tedious, are not difficult, and can readily be handled by a computer.

It pinpoints attention to the small subset of jobs that are critical to project completion time, thus contributing to more accurate planning and more precise control.

It enables the manager to quickly study the effects of crash programmes and to anticipate potential bottlenecks that might result from shortening certain critical jobs.

It leads to reasonable estimates of total project costs for various completion dates which enable the manager to select an optimum schedule.

Reference: This Article is based on the seminar in project preparation, Analysis and Evaluation held in the World Bank in Washington attended by the writer from july to September 1968.