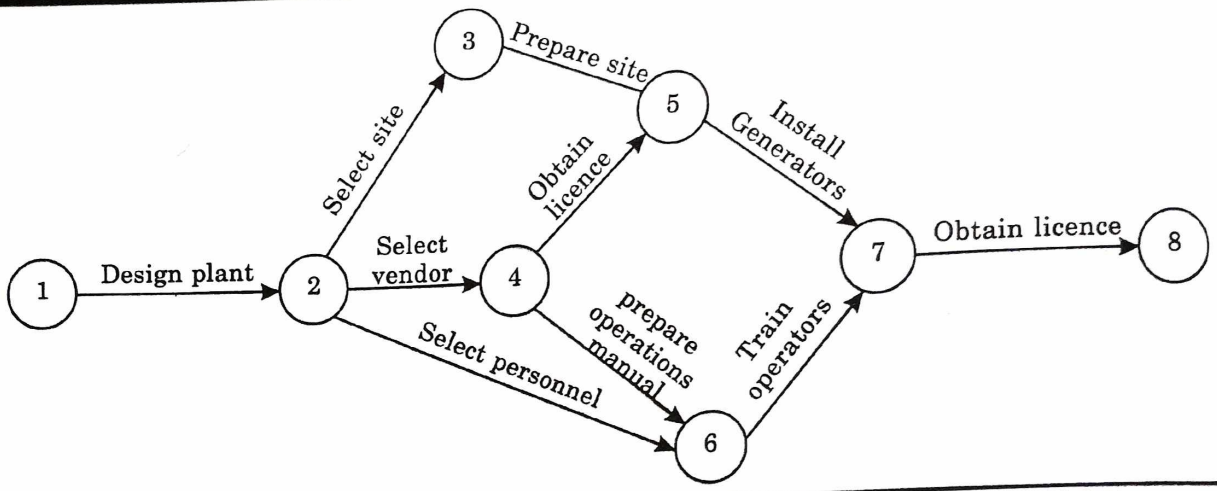
The critical path method (CPM) and program evaluation and review technique (PERT) are net work techniques for analysing a system in term of activities and events that must be completed in a specified sequence in order to achieve a goal. Some activities can be done concurrently whereas others have precedence requirements.

Exhibit 16.3 Shows a network diagram for power plant construction.

Exhibit 16.3 : Network Diagram for Power Plant Construction



Commonly used Network Symbols

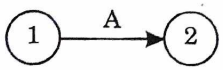
Exhibit 16.4 shows some of the commonly used network symbols.

Exhibit 16.4

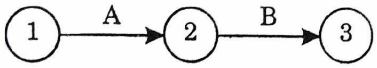
Symbol	Meaning
→	Activity
- - →	Dummy Activity
○	Event
1 —A→ 2 —B→ 3	Activity A must be completed before activity B can begin.
1 —A→ 3 —C→ 4; 2 —B→ 3	Activities A and B can occur concurrently, but both must be completed before activity C can begin.
1 —A→ 3 —C→ 4; 2 —B→ 3 —D→ 5	Activities A and B must be completed before activities C and D can begin, but C can begin independently of D and vice versa.
1 —A→ 3 —D→ 5; 3 —C→ 4; 2 —B→ 4 —E→ 6	Activities A and B can occur concurrently, but both must be completed before activity D can begin Activity E can occur only after activity B is completed. Activity C (dotted line with arrow head) is a dummy activity which shows a precedence relationship but has a zero time duration.

Terms used in Network Based Scheduling Techniques

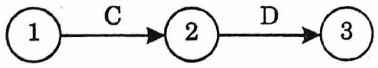
1. **Activity :** An effort that is required to complete a part of a project. (⟶)
2. **Event :** A beginning, completion point or milestone accomplishment within the project. An activity begins and ends with an event. (◯)

   E.g., 

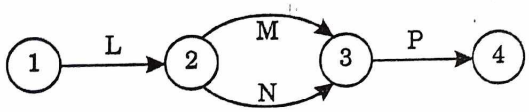
   1 & 2 – Events ; A - Activity
3. **Processor activity :** An activity that must occur before another activity.

   E.g., 

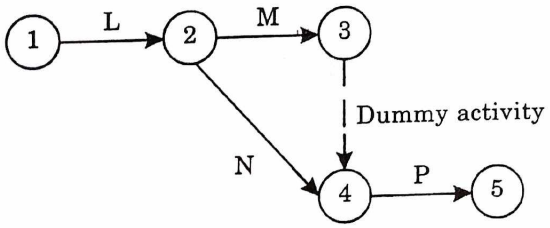
   Activity 'A' is a predecessor activity for activity B.
4. **Successor activity :** An activity that must occur after another activity.

   E.g., 

   Activity 'D' is a successor activity to activity 'C'
5. **Dummy activity :** An activity that consumes no time (zero time duration) but shows precedence between events.

   E.g., 

   The above network diagram shows that both activities M and N begin with event number 2 and end with event number 3. As a rule, no two activities can be represented by the same set of event numbers. This problem is solved by inserting a dummy activity as shown below:



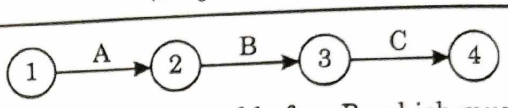
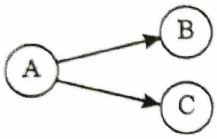
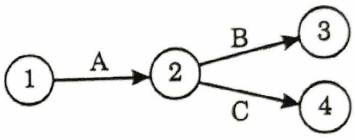
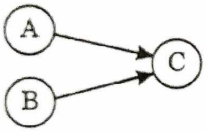
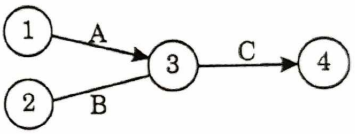
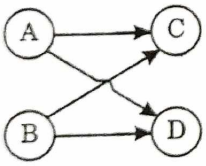
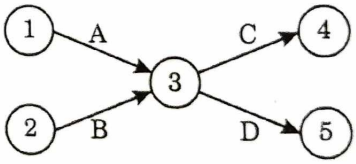
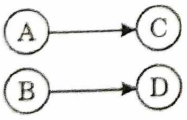
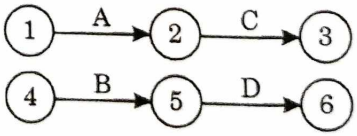
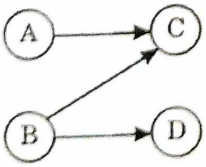
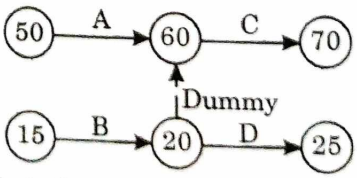
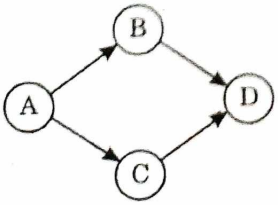
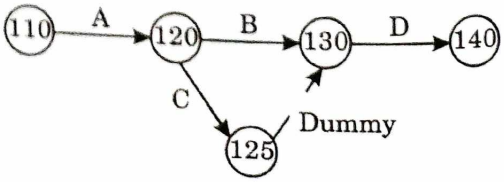
6. **Activity duration :** In CPM, the best estimate of the time to complete an activity. In PERT, the expected time or average time to complete an activity.
7. **Optimistic time (t_o) :** The time for completing an activity if all goes well, used in PERT.
8. **Pessimistic Time (t_p) :** The time for completing an activity if every thing goes wrong, used in PERT.
9. **Most likely time (t_m) :** The time for completing an activity that is the consensus best estimate, used in PERT.
10. **Expected time (t_e) :** The average time for completing an activity.
11. **Earliest start (ES) :** The earliest that an activity can start, from the beginning of the project.
12. **Earliest finish (EF) :** The earliest that an activity can finish, from the beginning of the project.
13. **Latest start (LS) :** The latest that an activity can start, from the beginning of the project, without causing a delay in the completion of the project.
14. **Latest finish (LF) :** The latest that an activity can finish, from the beginning of the project, without causing a delay in the completion of the project.

15. **Slack :** The amount of time that an activity or group of activities can slip without causing a delay in the completion of the project. It is also knows as "float".
16. **Critical activity :** An activity that has no room for schedule slippage, if it slips the entire project completion will slip. An activity with zero slack.
17. **Critical path :** The chain of critical activities for the project. The longest path through the network.

Networking Conventions

A network uses circles and arrows to represent the planned relationships among the activities required to complete a project. Either of two conventions can be used to develop a

Exhibit 16.5 : AON and AOA Methods of Indicating Activity Relationships on Network Diagrams

	Activity-on-node (AON) convention (Precedence notation)	Activity-on-arrow (AOA) convention (i – j notation)
(a)		
	A, B and C are activities and 1, 2, 3 and 4 are events. A must be performed before B, which must be performed before C.	
(b)		
	A must be completed before either B or C can begin.	
(c)		
	Both A and B must be completed before C can begin.	
(d)		
	Both A and B must precede both C and D.	
(e)		
	A must precede C and B must precede D, but the A - C path is independent of the B - D path.	
(f)		
	A and B must precede C and B must precede D but A is independent of D.	
(g)		
	A must precede both B and C. Both B and C must precede D.	

network. One convention uses circles to represent the project activities, with arrows linking them together to show the sequence in which they are performed. This is called *activity-on-node* (AON) diagram or convention.

Activity On Node (AON): Network diagram convention in which activities are designated on nodes.

Another convention shows the activities as arrows and use circles to connect predecessor and successor activities. This method is called the *activity-on-arrow* (AOA) diagram or convention. *Exhibit 16.5* shows the AON and AOA methods of indicating activity relationships on network diagrams.

Activity On Arrow: (AOA): Net work diagram in which activities are designated on arrows and events on nodes.

In AOA convention, the circles or nodes represents *events* which are points in time at which activities begin or end. An event consumes no resources, whereas an activity consumes time and other resources.

A network is drawn after all the activities and their relationships have been identified. After the activities are identified the questions to be asked for each activity are:

1. Which activity must immediately precede this one?
2. Which activity must immediately follow this one?
3. Can this activity be accomplished without dependence on some other activity?

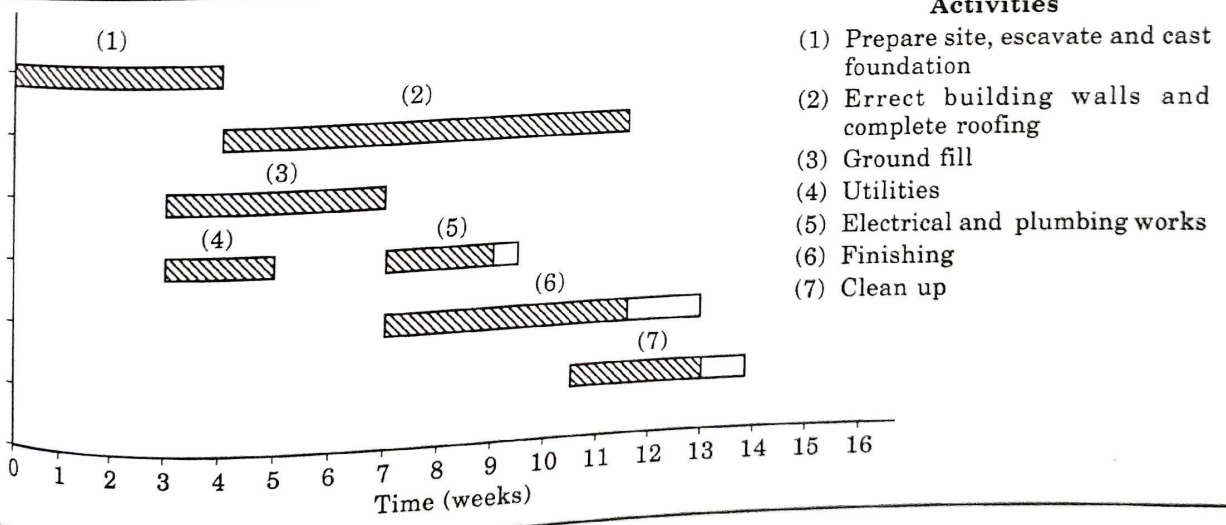
The activity that must be performed just before a particular activity is its *predecessor activity* and the one that follows is its *successor activity*.

PROJECT SCHEDULING TECHNIQUES

Scheduling Chart

(Gantt chart or horizontal bar chart) : This chart is the most frequently used tool to manage small projects. The chart indicates - *what must be done and when it must be done*. As the project progress, the chart is updated to indicate the amount of accomplishment toward the plan. In this way the project managers can compare actual project work accomplishment with planned project progress. This chart time phases activities. Every activity should have a start date and finish date. *Exhibit 16.6* shows a typical Gantt chart or Horizontal bar chart for a building construction project.

Exhibit 16.6 : Gantt Chart for Construction of a House



Activities

(1) Prepare site, escavate and cast foundation
(2) Errect building walls and complete roofing
(3) Ground fill
(4) Utilities
(5) Electrical and plumbing works
(6) Finishing
(7) Clean up

The chart is prepared in advance of the project to plan and schedule the activities of the project. After the bar chart is initially prepared, managers can be assured that all the activities

of the project are planned for, the order in which the activities must be performed is taken into account, the time estimates for completing each activity are included and finally the overall estimated time for completing the project is developed. The horizontal bar chart becomes the overall plan for the project.

As the project progress and the activities are completed, actual progress is recorded by shading in the horizontal bars.

These charts are easy to understand, and to modify. They are of low cost. The draw back is that these charts do not adequately indicate the degree of interrelationships among the project's activities.

Programme Evaluation & Review Technique (PERT) and Critical Path Method (CPM)

PERT: (Programme Evaluation and Review technique): A networking approach to planning, monitoring, controlling and evaluation of complex projects.

PERT is the name given to a networking approach to planning, monitoring, controlling and evaluation of complex projects. It consists of a network diagram which is a two-dimensional schematic of the relationships between tasks in a project. PERT is used for non-repetitive projects that have been done before and will not be done again in precisely the same manner. PERT technique has been used for projects such as developing missiles, nuclear powered submarines and for the programme that landed the first man on the moon. It is a planning tool which enables the project manager to estimate the time required to complete a proposed project. It also provides a time schedule for various project activities and for checking of the scheduled time against the actual time taken for an activity. PERT helps to design a management control system for activities that are subject to a considerable degree of uncertainity in performance time. It is based on a statistical treatment of activity performance time.

PERT also minimises delays in various parts of the overall job and helps in expediting the completion of the projects. It is a method of budgeting resources to predetermine the job on schedule. Above all PERT is an outstanding approach for the timely completion of projects.

With PERT, projects can be better planned and controlled for cost when they are broken-down into their components. PERT tells how to set up network, how to calculate completion time and how to monitor and control work.

Critical Path Method (CPM)

CPM (Critical Path Method): A quantitative technique which is used for planning and coordinating large projects.

CPM refers to a quantitative technique which when applied to network planning, is helpful in calculating the minimum time and the sequence of tasks needed to complete a project. This technique is mostly used for construction projects such as bridges, building, dams, canals etc., where engineers and contractors try to complete the job at the earliest to avoid rising costs. In CPM technique the precedence, the relationships between activities and their mutual dependence are suggested, leading to the final objective of reducing the cost and completion time of the project.

Purpose of CPM :

1. To ensure logical discipline in planning, scheduling and controlling projects.
2. To encourage more long range and detailed planning of projects.
3. To provide management with periodic reports as the project progress.
4. To identify the most critical element of the plan.

Procedure for Drawing up a CPM Network

The general procedure has two major activities namely

(a) Structure analysis — (i) Draw up lists of activities
(ii) Draft of structure / Network
(iii) Numbering of events

(b) Time Analysis —
- (i) Assessment of the duration of the activities
- (ii) Progressive (and retrogressive) time calculation (also known as forward pass and backward pass)
- (iii) Assessment of the critical path
- (iv) Assessment of the float or slack

(a) CPM - Structure Analysis

(i) Preparing the list of activities : The list of activities is a catalogue of all activities and process in the project for example, *Table 16.2* shows the list of activities relating to a project.

Table 16.2 : List of Activities Relating to the Project

i	j	Task areas	Description of activity	Duration (days)
1	2	Design department	Design parts for sub-assembly A & B	25
2	3	Purchase department	Procure materials for sub-assembly 'A'	30
2	4	Purchase department	Procure materials for sub-assembly 'B'	10
3	5	Fabrication shop	Fabricate parts for sub-assembly 'A'	20
4	6	Fabrication shop	Fabricate parts for sub-assembly 'B'	40
5	7	Assembly line	Sub-assembly A	40
6	7	Assembly line	Sub-assembly B	5
7	8	Assembly line	Final assembly	6

(ii) The drafting of the network : While drafting the network, the insertion of every activity is to be carried out systematically by means of a technique to pose suitable questions. To obtain the correct sequences, the following questions should be answered for each activity.

(a) Which activities must be ended directly before the new one begins?

(b) Which activities can only begin directly afterwards?

(c) Which activities can take place autonomously and simultaneously?

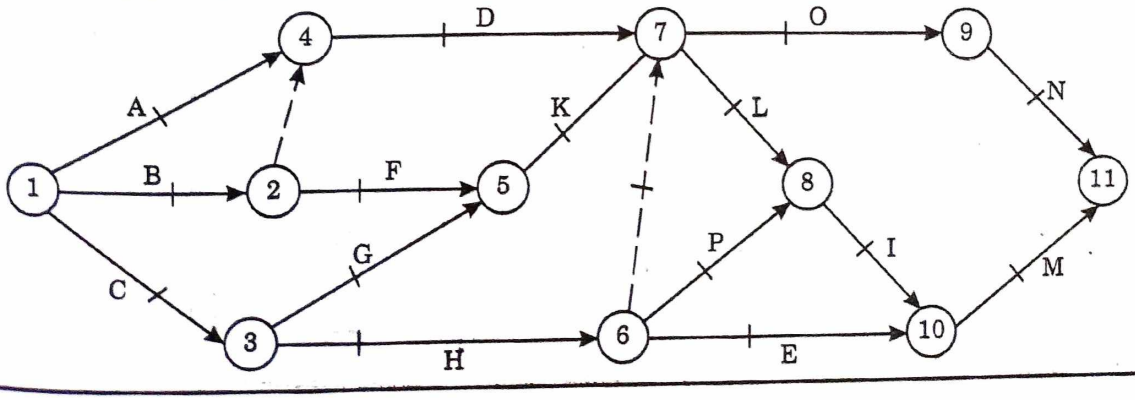
(d) Can this activity be subdivided into others?

In the structure analysis no time factors are considered but only the sequence and interrelation of the activities.

(iii) *Numbering of events :* Every activity in the network is defined by its start and end events. Events must be numbered by positive integers (say 1, 2, 3 etc.). The numbering must be done in the ascending order.

Exhibit 16.7 gives an example of numbering of events in a CPM network.

Exhibit 16.7 : Numbering of Events



The procedure is as follows:

The initial start event of the project is numbered by 1 and all arrows beginning in this event are crossed. Put the next higher numbers for particular events where only crossed arrows end. All arrows beginning at the newly numbered event are then crossed. This procedure is repeated in the same way until all the events are numbered.

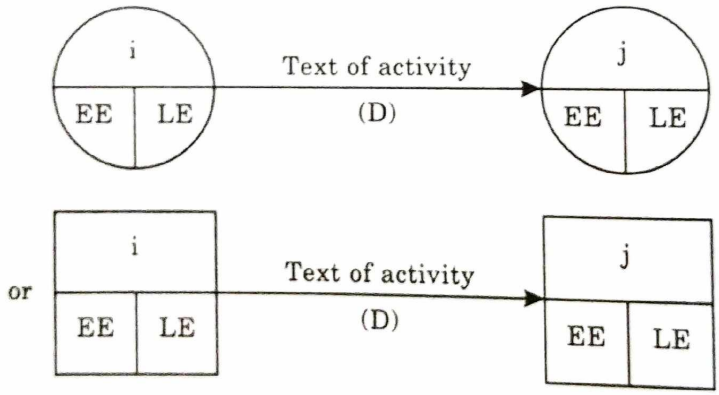
CPM - Time Analysis

The symbols used are

D = Duration of activity (hours or days or weeks or months)
ESA = Earliest (possible) starting time of the activity
LSA = Latest (permitted) starting time of the activity
EEA = Earliest (possible) ending time of activity
LEA = Latest (permitted) ending time of the activity
EE = Earliest (possible) time of the event
LE = Latest (possible) time of the event
TF = Total float of the activity
FF = Free float of the activity
IF = Independent float of the activity

Mode of representation : *Exhibit 16.8* shows how to represent the events and activates

Exhibit 16.8 : Representation of Events and Activities



(i) Determination of the Activity's Duration `D'

For each activity of the project, the duration must be indicated by means of a determinate unit of time and the same is entered in the list of activities.

(ii) Progressive and Retrogressive Computation of Time (or Forward pass and Backward pass)

(a)Progressive computation or Forward pass : The earliest start and earliest finish for each activity are found by calculations performed in sequence from the left to the right of the network. This series of calculation is called the forward pass we first assign a project day, usually zero to the start of the first activity, to represent the ES for that activity. Then we obtain the ES and EF *i.e.*, earliest start and earliest finish by making a forward pass through the network form left to right. The duration of activity 'D' is added to its ES to obtain its EF.

Exhibit 16.9 illustrates forward pass.