SSC-JE 2025

Staff Selection Commission

Junior Engineer Examination

Civil Engineering

Estimating, Costing and Valuation (CPM & PERT)

Well Illustrated **Theory** *with*
Solved Examples and **Practice Questions**

MADE EASY PUBLICATIONS

Estimating, Costing and Valuation (CPM & PERT)

Contents

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CHAPTER 1

Project Management and Network Theory

1.1 Introduction

Project is a temporary endeavour undertaken to provide a unique product, service or result. A project involves series of activities which consumes resource and time.

Objectives of a Project:

- It should be completed in minimum time with minimum capital investment.
- It should use available manpower and other resources optimally.

1.2 Phases of Project Management

Planning

Planning involves:

1. Defining objectives of the project.
2. Listing of jobs that have to be performed.
3. Determining gross requirements for materials, equipments and man power and preparing estimates of costs and duration for various jobs.
4. To bring about the satisfactory completion of project.

Planning is important because:

1. It provides direction and unifying frame work.
2. It helps to reveal future opportunities and provides performance standards.
3. It minimizes costs by utilizing available resources in best way.

Scheduling

Scheduling is the allocation of resources such as time, material, space, equipment and human and technological effort.

It involves:

1. Finalizing the planned functions mechanically.
2. Assigning starting and completion dates to each activity to proceed in a logical sequence and in a systematic manner.

Controlling

Controlling involves:

1. Determination of deviations from basic plan and their effects on the project.
2. Replanning and rescheduling of activities to compensate for the deviations which is called "updating".

It should be noted that planning and scheduling are accomplished before the actual project starts while controlling is operative during execution of the project.

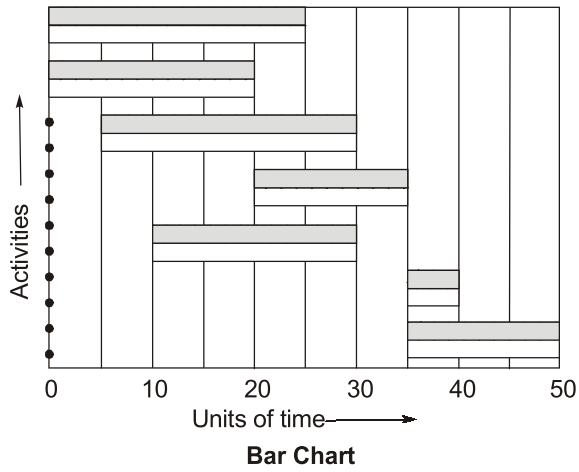
Do You Know?

The method of planning and controlling that was originally developed was called Project Planning and Scheduling (PPS). PPS was later on converted into Critical Path Method (CPM), so the CPM involves the deterministic approach and is used for the repetitive types of projects.

1.3 Techniques Used for Project Management

Bar Chart

Firstly introduced by Henry Gantt around 1900 AD.



Bar Chart

Features of bar chart are:

1. It is a pictorial chart
2. It has two coordinate axes, the horizontal coordinate represents the elapsed time and vertical coordinate represents the job or activity to be performed.
3. The beginning and end of each bar represents starting and finishing time of a particular activity respectively.
4. The length of bar shows the time required for completion.

Jobs can be concurrent or can be started one after other. So some bars can run parallel or overlap each other or may run serially.

Limitations of bar chart:

1. **Lack of degree of details:** Only major activities are shown in bar chart and sub-activities can not be separated out. Hence effective control over the activities in big projects can not be achieved.
2. A bar chart does not show progress of work and hence it can not be used as a control device.
3. A bar chart is unable to depict interdependencies of various activities clearly.
4. Bar charts are not useful in the projects where there are uncertainties in determination of estimation of time required for completion of various activities such as in R&D projects.
5. Bar chart can not distinguish between critical and noncritical activities and hence resource smoothening and resource levelling can not be done.

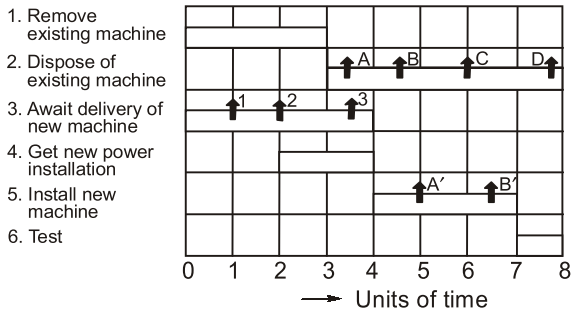
Bar chart diagrams are useful for only smaller and simpler conventional projects, especially construction and manufacturing projects, in which time estimates can be made with fair degree of certainty.

Mile-Stone Chart

- It is a modification over original Gantt chart. Milestones are key events of main activities represented by bar. Therefore they give idea about completion of sub-activities.

Linked Bar Chart

- It is an important our original bar chart or mile stone chart.
- In linked bar chart, auticities are linked with arrows and liners, indicating require and order of auticities.



Mile-stone chart

Do you know? Controlling can be better achieved with the help of milestone charts, but still activity interrelationship and accountability of time uncertainty can not be depicted which can be overcome in network technique.

Network Methods

- It is an outcome of the improvements in the milestone charts.
- They are called by various names such as PERT, CPM, UNETICS, LESS, TOPS and SCANS.
- However all these have emerged from the two major network systems viz.:
  1. PERT
  2. CPM

1.4 Network Techniques

Advantages of network method over bar chart and milestone chart:

1. Interrelationships between activities and events of a project are clearly shown.
2. The project can be treated as an integrated whole with all its sub-activities clearly related with each other. It helps in controlling the project.
3. Network method is useful for very complicated projects having large number of activities.
4. It indicates the time required in between two activities in which rescheduling of a project is possible.
5. Time uncertainty is accounted for and so it is also useful for research and development projects.

1.5 Elements of a Network

Event

- An event is either start or completion of an activity.
- Events are significant points in a project which act as control points of the project.
- An event is an instant of time and it does not require time or resources.

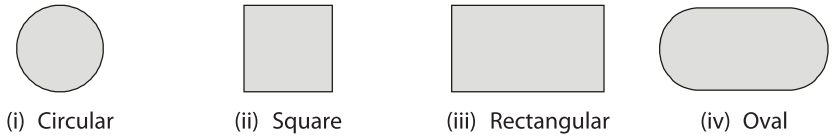
Following are examples of an event:

1. All parts assembled
2. A budget prepared
3. Construction completed

Following can not be events:

1. Prepare budget 2. Assemble parts 3. Excavate trench

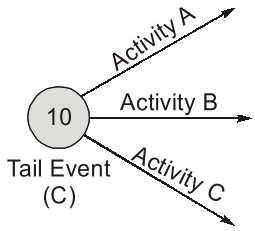
- Events are represented by nodes in a network. It may have any of the following shapes.



Different Shapes for Events

Most commonly adopted shape for events is circular shape.

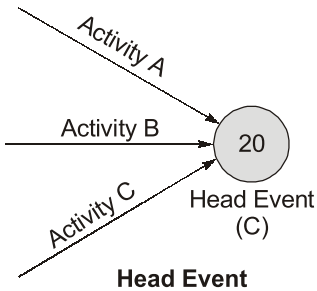
- **A tail event or a start event of a project:** It has only outgoing arrows.



Tail Event

Event 10 is a tail event. Arrows represent job or activity of a project.

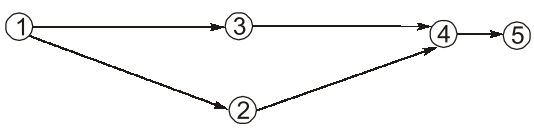
- **Head event or final event:** It is finish of a project having only incoming arrows.



Head Event

Event 20 is a head event

- **Dual role events:** All events except the first and the last event of a project are dual role events. They have both incoming and outgoing arrows.

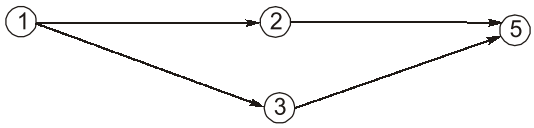


Dual Role Events

e.g.: Events 2, 3 and 4, are dual role events.

Events 2, 3, 4, are dual role events

- **Successor events :** The event or events that follow another event are called successor events to that event.



Successor Events

e.g.: Event 2 and 3 are successor events of event 1.

Event 2, 3 are successor events of 1

- **Predecessor events :** The event or events that occur before another event are called predecessor event to that event.

  In above figure, events 2, 3 are predecessor to event 5.

Do you know? It should be noted there can be only one tail event and one head event in a project.

Activity

Activity is actual performance of a job. It requires time and resources for its completion.

Following are examples of an activity:

1. Excavate trench
2. Mix concrete
3. Prepare budget

Do You Know?

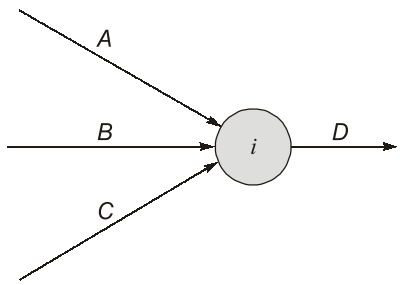
In A-O-A system (Activity On Arrow network system), activity is represented by arrows between events while in A-O-N (Activity On Node system), activities are represented by nodes. In A-O-N system, events have no places.

Here *A* and *B* activities are represented in two different systems.

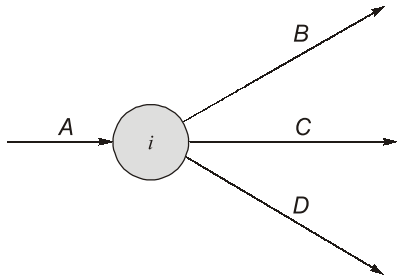
Type of Activity

1. **Parallel activities:** Parallel activities are those which can exist simultaneously or concurrently and are independent of each other.

   Ex:

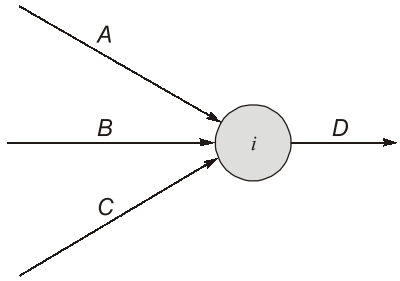


A, B, C are concurrent activities and terminates at same node '*i*' such activities are independent of each other.



As soon as event 'i' reached, activity B, C and D can be simultaneously started. Such activities (B, C, D) are also parallel activities.

2. **Serial activities:** The activities which can be started one after another and are dependent on each other are called as serial activities.



The set of activities A, B and C are in series with activity D.

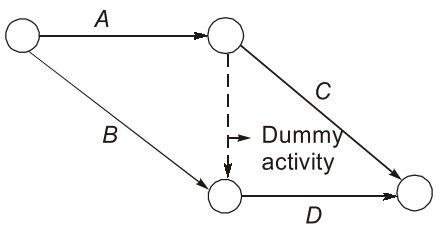
3. **Successor and precedessor activity:** The activity which exist after the occurrence of other activity is referred as successor activity. If this activity exist immediately after the occurrence of other activities it is referred as immediate successor activity.

   The activity which exist before the occurrence of other activity is referred as precedessor activity. If this activity exist immediately before the occurrence of the other activities is referred as immediate precedessor activity.

Dummy

- A dummy is a type of operation which neither requires time nor any resource, but it denotes dependency among the activities.
- It is represented by dashed arrow.

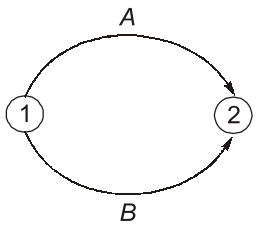
  In the figure shown below, a dummy activity is shown.



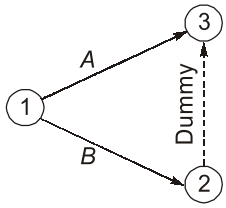
Dummy Activity

- Dummy is used to serve following purposes:

1. **Grammatical purpose:** To prevent two arrows having common beginning and common end.

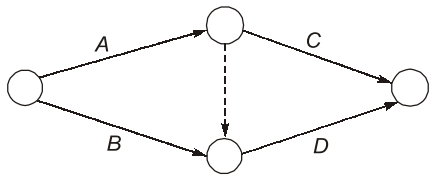


(a) Ambiguous Representation



(b) Grammatically Clean Representation

2. **Logical purpose:** To show relationship with other activities.
   Here dummy is required to show that activity *D* can start after completion activities of *A* & *B* both.



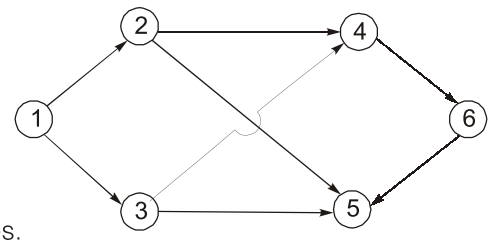
- Unnecessary dummies should be avoided.

Do You Know?

- Dummies are used to show predecessor relation but if that relation is already established in the network, then that dummy is redundant and has to be removed.
- If dummy is only incoming/outgoing arrow to/from a node then it can be remove provided there is no logical or grammatical error.

1.6 Rules of a Network

1. There can be only one initial and one final event.
2. An event can not occur unless all preceding activities are completed.
3. An event can not occur twice.
4. Number of arrows should be equal to number of activities.
5. Time should always flow from left to right.
6. Length of arrow does not show any magnitude. Straight arrows should be taken as far as possible.
7. Arrows should normally not cross each other. If it is necessary to cross, one should be bridged over the other.



Crossing Activities

1.7 Fulkersons's Rule for Numbering the Events

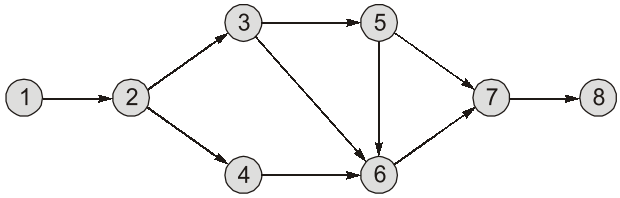
It states that through any path from initial event to final event, numbers must always be in increasing order.

Step 1: Number the initial event, generally 1.

Step 2: Remove all the activities originating from this initial event which results in the formation of one or more new initial events.

Step 3: Number the events sequentially.

Step 4: Repeat steps 2 and 3 until the whole network is numbered.

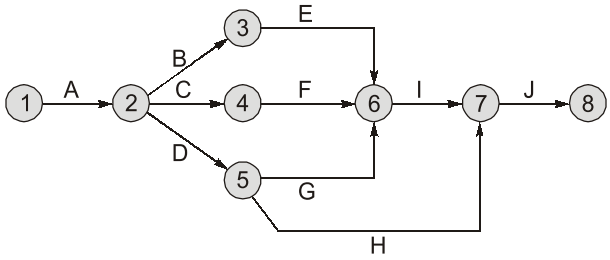


Example-1.1 A project consist of 10 activities as detailed below draw an arrow diagram representation of the project

Job activity	A	B	C	D	E	F	G	H	I	J
Immediate predecessor	–	A	A	A	B	C	D	D	E, F, G	H, I

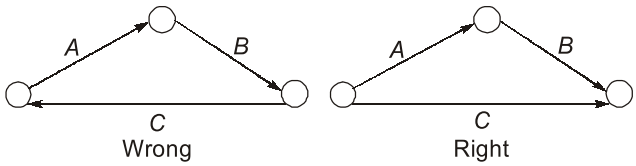
Solution:

The network:



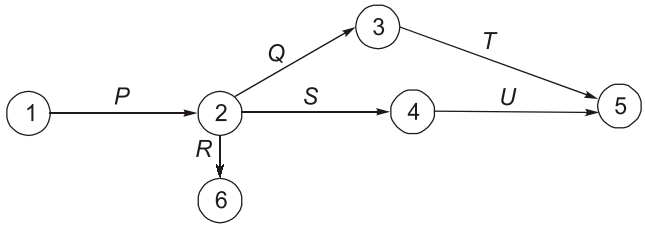
1.8 Errors in Network

1. **Looping error:** Loops should not be formed.



Looping Error

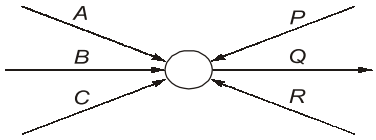
2. **Dangling error:** Project is complete only when all its activities are complete but the duration of activity '*R*' has no effect on the project time as shown in figure.



Dangling Error

To avoid dangling error, the network must be examined in such a manner that all events except initial and final events must have at least one activity entering and one activity leaving them.

3. **Wagon wheel error:** As shown in figure, each of the activities *P*, *Q* and *R* cannot start until all the three activities *A*, *B* and *C* are completed. But in reality, this may not be the situation. There is no error visible in the construction of diagram but logical error has crept into it.



Wagon Wheel Error

STUDENT'S ASSIGNMENTS

Q.1 In arriving at a resource based schedule bar-chart for a construction project, the following stages for planning of the work are involved.

1. Finalizing a network of activities.
2. Determining the optimal activity durations considering all the relevant parameters.
3. Computation of time and floats.
4. Developing the resource-based bar-chart and the corresponding histograms and mass curves of resources.
5. Identification of the critical constraining resource.
6. Deciding the criteria for optimization.

The correct sequence of these stages in the planning of the work will be

(a) 1, 6, 2, 3, 5, 4
(b) 6, 2, 1, 3, 4, 5
(c) 1, 2, 3, 6, 5, 4
(d) 2, 1, 3, 5, 6, 4

Q.2 Consider the following statements:

1. A dummy activity is artificially introduced in a network when necessary.
2. A dummy activity consumes some time.
3. A dummy activity is represented by a dotted arrow.
4. A dummy activity must necessarily be introduced in every network.

Which of the above statements are correct?

(a) 1, 2 and 3 (b) 1 and 3
(c) 2, 3 and 4 (d) 1 and 2

Q.3 Match **List-I** (Activity type) with **List-II** (Representation by) and select the correct answer:

List-I

A. Artificially introduced
B. Critical
C. Noncritical type
D. Dangler

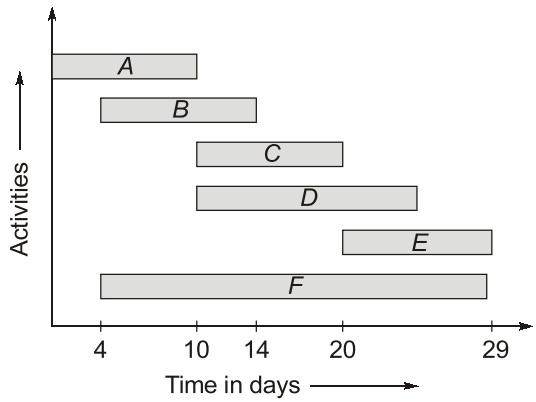
List-II

1. A single thick arrow
2. A single arrow
3. An arrow emerging from an event but not entering into any event
4. A dotted arrow

Codes:

	A	B	C	D
(a)	4	1	2	3
(b)	2	3	4	1
(c)	4	3	2	1
(d)	2	1	4	3

Q.4 Which of the following are critical activities of the bar chart shown below:



(a) Activities B and E
(b) Activities A, D and F
(c) Activities A, C and E
(d) Activities A and F

Q.5 Functional organisation system of working was given by
(a) F.W. Taylor
(b) Henry Gantt
(c) M.R. Walker
(d) J.E. Kelley

[ESE-1995]

Q.6 Grantt charts indicate
(a) comparison of actual progress with the reheduted progress
(b) balance of work to be done
(c) progressive cost of project
(d) inventory costs **[ESE-1997]**

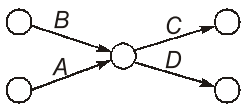
Q.7 A serious limitation of interdependencies between various activities is generally observed in
(a) Bar chart
(b) Milestone charts
(c) Network analysis
(d) Job layouts

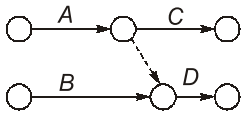
[ESE-2003]

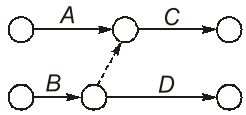
Q.8 A inked bar chart is an improvement our a conventional bar chart, because
1. Resources for individual activities can be planned.
2. Floats will be available for utilization as needed.
3. Milestone events need not be specially monitored.

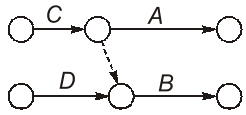
Which of these is/are correct?
(a) 1, 2 and 3 (b) 3 only
(c) 2 only (d) 1 only

Q.9 Activity 'C' follows activity 'A' and activity 'D' follows activities 'A' and 'B'. The correct network for the project is

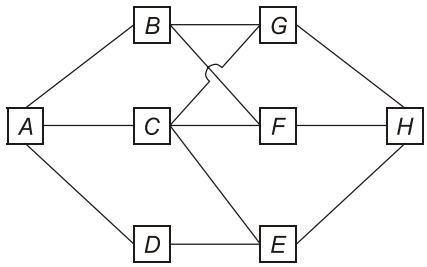
(a) 

(b) 

(c) 

(d) 

Q.10 Consider the AON diagram below:
What is the minimum number of dummy arrows required for conversion into AOA diagram?

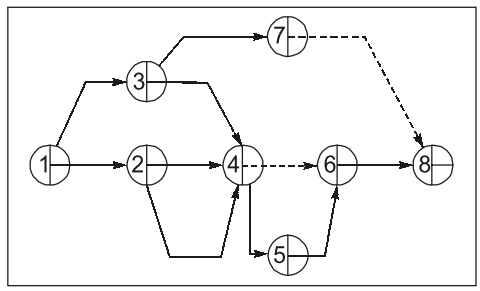


(a) 3 (b) 4
(c) 5 (d) 6

Q.11 Which of the following is the correct sequence to analyze a project for implementation?
(a) Time-cost study, Network, WBS, Scheduling with resource allocation
(b) Network, Time-cost study, Scheduling with resource allocation, WBS
(c) WBS, Network, Scheduling with resource allocation, Time-cost study
(d) WBS, Time-cost study, Network, Scheduling with resource allocation

[ESE-2004]

Q.12 The total number of errors in the given AOA network is



(a) 1 (b) 2
(c) 3 (d) 4

Q.13 Match **List-I** (Chart) with **List-II** (Precipitation) and select the correct answer:

List-I

A. Bar chart
B. Milestone bar chart
C. W.B.S.
D. Linked bar chart

List-II

1. Activity dependencies can be implied
2. Resources requirement can be depicted
3. Higher level of authority can effect monitoring and controlling
4. Trade base rite supercision can be assigned

Codes:

	A	B	C	D
(a)	4	3	2	1
(b)	2	1	4	3
(c)	4	1	2	3
(d)	2	3	4	1

Q.14 List the following processes in their correct sequence, from earliest to latest, in project implementation planning :

1. Project duration
2. Resource histogram
3. Standardized input/performance for each activity including alternatives
4. WBS
5. Resource optimization considering constraints
6. Activities and their inter-relationships

Select the correct answer using the code given below:

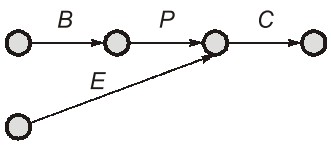
(a) 2, 1, 3, 5, 6 & 4 (b) 2, 6, 3, 5, 1 & 4
(c) 4, 1, 3, 5, 6 & 2 (d) 4, 6, 3, 5, 1 & 2

[ESE-2014]

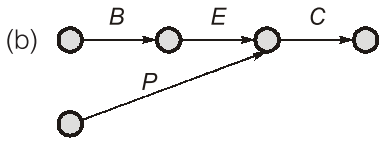
Q.15 Consider the following tasks:

1. Placing of reinforcement (*P*) for roof slab cannot start before bending of reinforcement (*B*) and erection of framework (*E*).
2. As soon as placing of reinforcement is finished correcting (*C*) will follow. The correct activity on arrow diagram representing the above task is

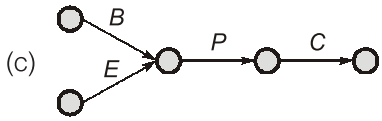
(a)



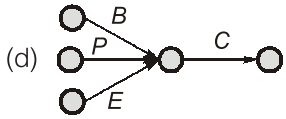
(b)



(c)



(d)



ANSWER KEY // STUDENT'S ASSIGNMENTS

1. (c)	**2.** (b)	**3.** (c)	**4.** (c)	**5.** (a)
6. (a)	**7.** (a)	**8.** (a)	**9.** (b)	**10.** (c)
11. (c)	**12.** (b)	**13.** (d)	**14.** (d)	**15.** (c)

HINTS & SOLUTIONS // STUDENT'S ASSIGNMENTS

5. (a)

The concept of functional organisation was given by F.W. Taylor, who recommended the appointment of specialists at important positions. Functional organisation allows decision to be decentralised since issues are assigned to specialists or units, giving them the responsibility of implementing, equating, or controlling the given procedures or goals.

6. (a)

Bar chart gives comparison of actual progress to the scheduled progress.

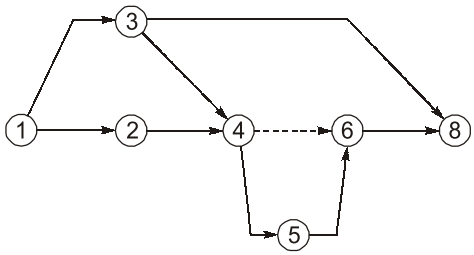
9. (b)

As per the question activity *C* is only dependent on activity *A* and activity *D* is depending on activity *A* and *B* both. Therefore,
Option (a) is wrong because according to network shown, *C* is also dependent on *B* which is not correct.

Option (c) is wrong because head of the arrow is towards left of activity *A*.
Option (d) is wrong because according to network given in option, *C* is dependent on *A* and *B* and *D* depends only on *B*.
Option (b) is correct as it follows the instructions of questions.

12. (b)

There is an extra dummy between events (7) and (8).
There are two arrows joining events (2) and (4).
The correct diagram will be



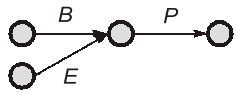
So there are two errors.

13. (d)

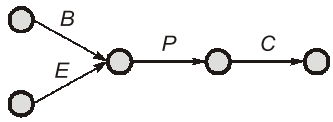
W.B.S. (Work Brendum Structure) is the process of breaking the project into easily idenfiable major systems, their subsystems and discrete activities.

15. (c)

Task *P* can only be started after completion of tasks *B* and *E*.

Thus, 

and task *C* will start after task *P*
∴ Network will be like as given below:



CHAPTER 2

PERT and CPM

2.1 Programme Evaluation and Review Technique (PERT)

- PERT stands for "Project/Programme Evaluation and Review Technique".
- PERT involves uncertainty into the project completion time.
- It is a numerical technique used in the projects in which time can not be estimated accurately such as research and development projects. It is an event **oriented network**. Cost is assumed to be directly proportional to time.
- PERT was developed by U.S. Navy for the development of Polaris missile along with lock head martin.

Three time estimates are made in PERT:

1. **Optimistic time (t_o):** This is the minimum possible time in which an activity can be completed under the most ideal conditions
2. **Pessimistic time (t_p):** This is the maximum time required to complete an activity under the worst possible conditions.
3. **Most likely time (t_m):** This is the time required to complete an activity under normal working conditions. Its value lies between t_o and t_P. It is near to the expected time.

Do You Know?

The most likely time (t_m) is based on experience and judgement being based on the time required if the activity is repeated a number of times under essentially the same conditions. This time signifies the most frequently occurring time. It reflects a situation "things are as usual, nothing exciting".

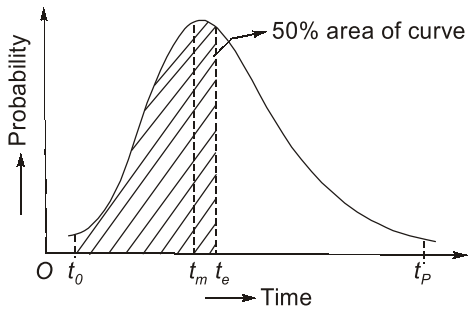
Mean Time, Standard Deviation and Variance of an Activity

Mean Time or Expected Time or Average Time

This is calculated from β - distribution curve of time at which probability of activity is just 50% Time taken by activities follow β-distribution.

Hence value of expected time is calculated by weighted average as,

$$t_e = \frac{t_o + 4t_m + t_p}{6}$$



β-curve with skewness to the left

Standard Deviation of An activity (σ)

This is the measurement of uncertainty, which is approximately one sixth of range.

$$\sigma = \frac{t_P - t_o}{6}$$

Do You Know?

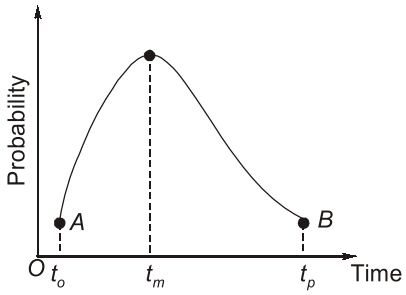
In a limiting case, certainty of an activity duration occurs only when the three time estimates coincide, so that the standard deviation and the variance both vanish. Consequently the activity duration becomes certain which is the case of CPM. Hence, a PERT is a general case whereas CPM is the particular case of PERT.

Variance of an Activity (σ^2)

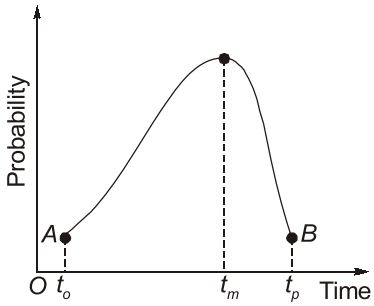
Square of standard deviation is variance of an activity. It is to be noted that higher the uncertainty about a process, greater is the standard deviation and hence greater is the variance of a project.

Do You Know?

A beta distribution is the one which is not symmetrical about its apex. Figure below shows two beta distribution curves, one having skew to the left (Beta distribution for optimistic estimator) and other having skew to the right (Beta distribution curve for the pessimistic estimator).



(a) Optimistic Estimation

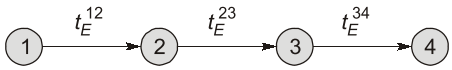


(b) Pessimistic Estimation

Central Limit Theorem

According to central limit theorem, if there are '*n*' activities in series each having its own β-distribution, t_E and σ then

(i) Expected completion time for the path along these activities will be



Expected completion time for path 1 – 2 – 3 – 4

$$= t_E^{12} + t_E^{23} + t_E^{34}$$

$$= \frac{\Sigma t_o + 4\Sigma t_m + \Sigma t_p}{6}$$

(ii) Standard deviation for path

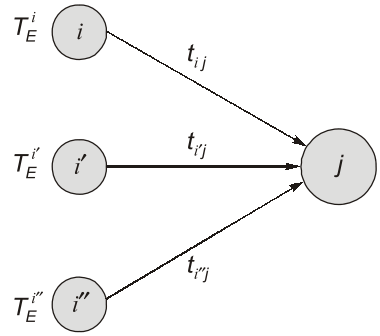
$$\sigma_{1-2-3-4} = \sqrt{\sigma_{12}^2 + \sigma_{23}^2 + \sigma_{34}^2}$$

(iii) If *n* is a fairly large number then project completion time for path as a whole will follow normal probability distribution.

Event Time

Earliest Expected Event Occurrence Time (T_E)

It is the earliest time in which an event may be expected to occur in the project an event is said to occur if all the activities leading to it are complete. It is computed by forward pass method.



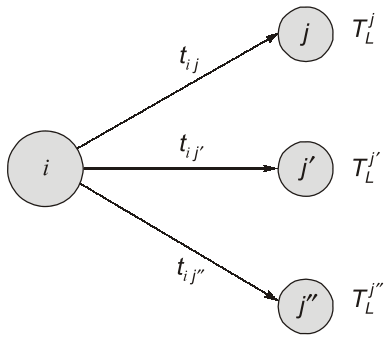
$$T_E^j = \text{maximum} \begin{cases} T_E^i + t_{ij} \\ T_E^{i'} + t_{i'j} \\ T_E^{i''} + t_{i''j} \end{cases}$$

NOTE:
- T_E of initial event is usually taken as zero.
- If T_E of the initial event is zero, T_E of the final event gives the project duration.

Latest Allowable Occurrence Time (T_L)

It is the latest time in which an event is allowed to occur without affecting the completion time of the project.

- It is computed using backward pass method.
- $(T_E)_{\text{final event}} = (T_L)_{\text{final event}}$ to avoid any further delay in the project.



$$T_{L_i} = \text{maximum} \begin{cases} T_L^j - t_{ij} \\ T_L^{j'} - t_{ij'} \\ T_L^{j''} - t_{ij''} \end{cases}$$