SAMPLE STUDY MATERIAL

Postal Correspondence Course

GATE, IES & PSUs

Civil Engineering

CPM & CONSTRUCTION EQUIPMENT

ENGINEERS INSTITUTE OF INDIA
India's Best Institute for IES, GATE & PSUs
A Team of IES & GATE Toppers

CONTENT

CHAPTER-1

CPM & PERT

PROJECT:

- A project is made up of a group of interrelated work activities constrained by a specific scope, budget and schedule to achieve the specific goals of an agency.
- Projects are defined by their scope, budget and schedule.

Project Management:

Objective:

- To minimize the project cost while satisfactorily completing the task.
- Optimum use of available resources.
- Project cost involves (a) material cost (b) construction cost.

Various Phases of a Project:

- Resources includes (a) Men (b) Materials (c) Machineries (d) Money

1. **Planning**:
   - Efficient use of machineries, material, men etc. along with minimizing resource cost is the basic aim of this phase.
   - It involves proper sequencing of events.

2. **Scheduling** :
   - Scheduling is basically the allocation of resources.
   - Process of sequencing various events of a project within a timeframe.
   - Required for continuous tracking of project, resource mobilization etc.
   - Useful in minimizing the cost and optimal use of resources.
   - Assigning dates for start and completion of each activity in logical sequence in systematic manner.

3. **Controlling & Monitoring** :

- Execution of the project is monitored for its timely completion.
  As per requirement re-planning, rescheduling is done by applying suitable corrective measures, which is called updating of individual activities
- To monitor project cost, progress of construction, etc.

Note: The first method that was developed for planning a project is called project planning & scheduling (PPS). Critical path method (CPM) came later and are generally used these days for similar type of project and it has a deterministic approach.

TECHNIQUE USED FOR PROJECT MANAGEMENT:

(I) Bart chart: [Characteristic] [Developed by Gantt in 1900 As]

(i) It is simple & easy to understand.

(ii) A bar chart consist of two co – ordinate axes one representing the time elapsed and other represent the jobs or activities to be performed.

(iii) It is a pictorial representation.

(iv) The length of bar chart represents its time of completion. Whereas shaded width of bar represents the percentage completion of that particular of activity.

(v) It is used only for small scale project.

Short comings of bar chart:

i) Lack of details:

Only major actives are shown in a bar chart and sub activities cannot be separated out. It too many activities or tasks are shown separately it becomes clumsy.

ii) Review of project progress:

It cannot be used as a control device as it does not shows the progress of work

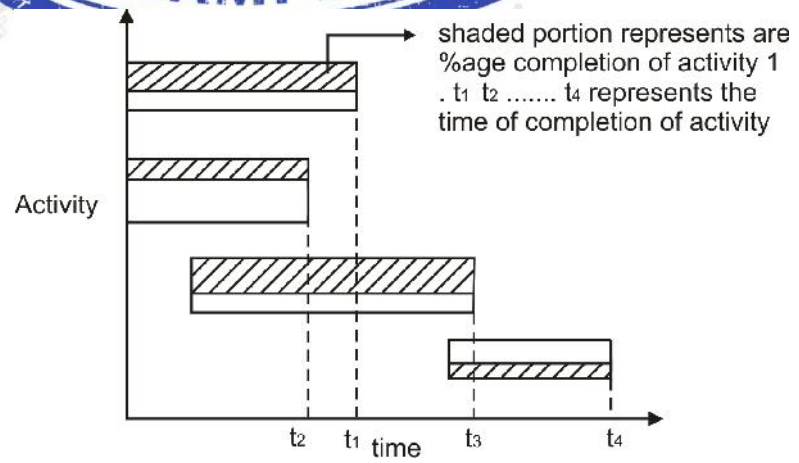
iii) Activity inter relationship:

In a project there can be several activities which may start concurrently, bar char cannot differentiate such activities.

iv) Time uncertainties:

Bar charts are not useful in the project where there are uncertainties in determination of estimation of time required for completion of various activities.

v) Bar chart cannot differentiate between critical and non – critical activities. Hence updating of individual activities of resources smoothing and resource leveling cannot be done.



(II) Milestone chart:

i) It is an improvement over the original Gantt chart. Milestones are specific points in time which mark the completion of certain portions of the main activity.

ii) It gives idea about completion of sub activities.

iii) Controlling can be better achieved but still activity inters relationship and accountability of time uncertainly cannot be depicted.

This can be achieved by network method discussed further.

Network Methods

- CPM & PERT are two major network methods.
- Other network methods are like UNETICS, LESS, TOPS and SCANS. However PERT & CPM are major network method.

CPM: - Critical Path Method

- It involves deterministic approach.
- Used for repetitive project, e.g. construction of a building.

PERT: - Project / Programme Evaluation and Review Technique.

- It involves probabilistic approach.
- Used for research and development projects, e.g. Missile Programme.

Elements of a Network

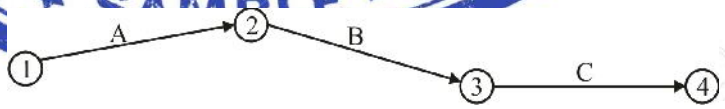
1. **Activity :**

- It represents execution of a specific job.
- It requires time and resources. For its completion.
- It is represented by an arrow.

e.g. - Brickwork, Plastering etc.

Brickwork → Plastering →

- Activities performed prior to an activity under consideration are called as predecessor activities to that activity.
- Activities performed after completion of an activity under consideration are called as successor activities to that activity.



"A" is predecessor activity of "B".

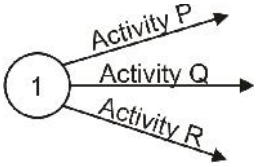
"C" is successor activity of "B".

AoA system (Activity on arrow system) is represented by arrow between events.

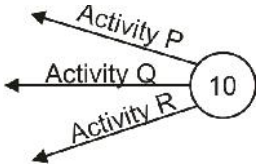
AoN system (Activity on Node) system is represented by activity on nodes. Events have no place in such system.

2. **Event** :

- It represents start or end of a task.
- It is generally represented by a circle.
- Beginning of an activity is called **tail event** and denoted by "i-node".



- Completion of an activity is called **head event** and denoted by "j-node". Add (8)



- Events which occurred prior to an event under consideration are called as **predecessor event** to that event.
- Events which occur after an event under consideration are called as **successor event** to that event.

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

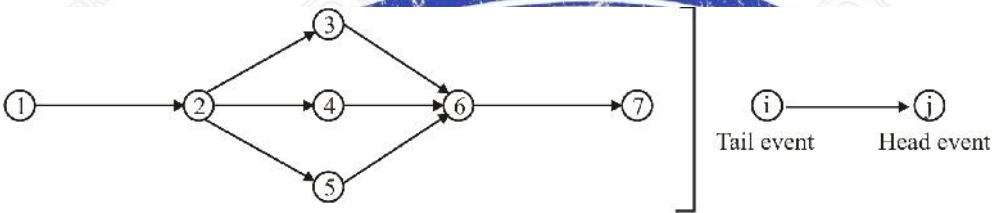
(a) Circular

(b) Rectangular

(c) Square

(d) Oval

There can only be one tail event and one head event in a project.



(1), (2) are predecessors event to (3).

(6), (7) are successor events to (3).

Event (2), (3), (4), (5) & (6) are dual role events.

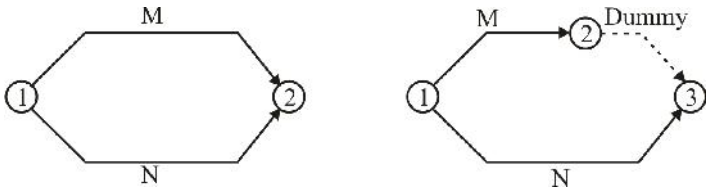
3. Dummy :

- It denotes an artificial activity.
- It is represented by a dotted arrow.
- It indicates that an activity following the dummy cannot be started until the activities preceding the dummy are not completed.
- It does not require time or resources.
- It denotes depending among the activities

Objective:

(a) To establish logical relationship between activities.

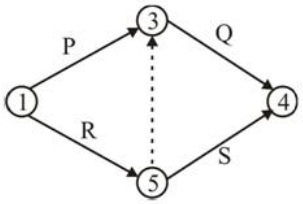
(b) To avoid grammatical mistake.



Type (a)

Use of "Dummy" here gives both activities a unique identification.

M → ①-②
M → ①-③

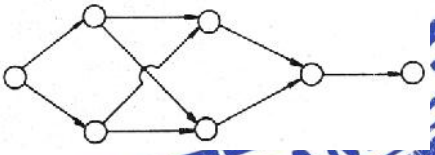


Type (b)

- Dummies are used to show predecessor relationship but if that relation is perfectly established inside the network, then such dummy is a redundant & should be removed.
- It dummy is only incoming arrow to a node then it can be removed provided there is no logical or grammatical error.

Rule of Network:

- In every project network, there should be only one initial and final event.
- Events occur in a particular order and any event cannot occur until all the predecessor events are not completed.
- Time flow is preferably assumed from left to right.
- Normally, arrows should not cross each other. If it is necessary to cross each other, the arrow should make a bridge over the other.



- Every activity should have its own "i-j" node, such that value of "j-node" should always be greater than "i-node".
- Number of arrows should be equal to the number of activities.
- An event cannot occur twice.

Fulkerson's rule for numbering the node of events:

- 1. The initial event is numbered as (1, 10 etc.)
- 2. Now all arrows coming out of initial event (1, 10 etc.) are removed.

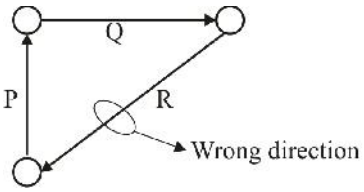
Thus one or more initial events are created which is numbered as (2, 3,4 etc…….or 20,30,40 etc…)

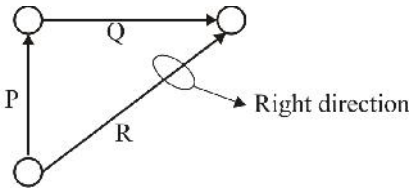
- 3. Step 2 is repeated until the final event of the network is not numbered.

Errors in Network:

1. Looping Error:

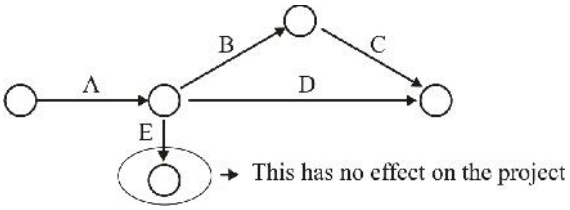
- It generates logical problem in the network.





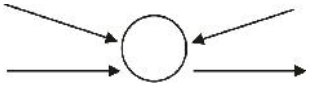
2. Dangling Error:

- Each network should contain only one initial event and one final event.



3. Wagon Wheel Error:

- It generates logical error in network.



CPM NETWORK:

Critical Path:

- It is defined as the path of longest project duration.
- The activities lying in critical path are called critical activities.
- Hence critical activities signify that any delay in critical activities will ultimately delay the overall project.
- All other activities which are not on critical path will not affect total duration of project.
- Alternatively, it can be stated that critical path is the shortest possible duration to complete the job/project.

Computation of project time:

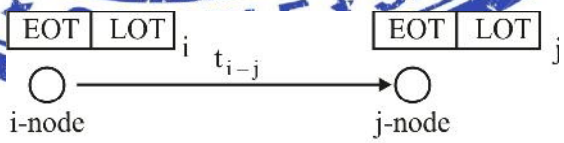
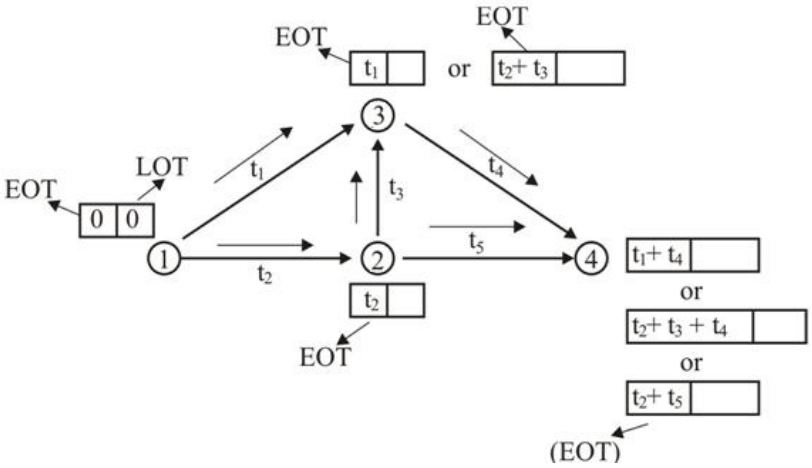


Figure (a)

- The box at the "i-node" contains two terms:
  - (i) EOT- Earliest occurrence time at i-node.
  - (ii) LOT- Latest occurrence time at i-node.
- "t_{i-j}" → Duration of Activity.

EOT :



- It is the earliest time when an event can occur.
- In general ,it can be written as:

$$\boxed{(EOT)_j = (EOT)_i + t_{i-j}} \quad \text{.....(i)}$$

- To compute the (EOT)at all the nodes:

i. Assume the value of $\boxed{\text{EOT} \mid \text{LOT}}$ at first node i.e. at 1 equal to

O	O

ii. Now, calculate the value at the other nodes using above equation

$\therefore \boxed{(EOT)_2 = 0 + t_2 = t_2}$ (at node only one activity merges)

$$\left.\begin{aligned} (EOT)_2 &= 0 + t_1 = t_1 \\ OR& \\ &= t_2 + t_3 = (t_2 + t_3) \end{aligned}\right\} \therefore (EOT)_3 = \text{Maximum of } (t_1, (t_2 + t_3))$$

- Then, proceed with maximum value of $(EOT)_2$

(for illustration both values is taken here for calculation at $(EOT)_4$)

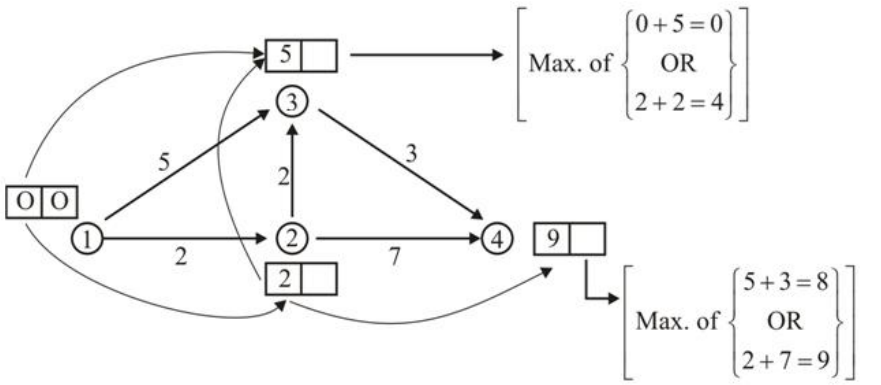
$$(EOT)_4 = \text{Maximum of } \begin{cases} (t_1) + (t_4) = t_1 + t_4 \\ (t_2 + t_3) + (t_4) = t_2 + t_3 + t_4 \\ (t_2) + (t_5) = t_2 + t_5 \end{cases}$$

- Hence, in general it can be stated that

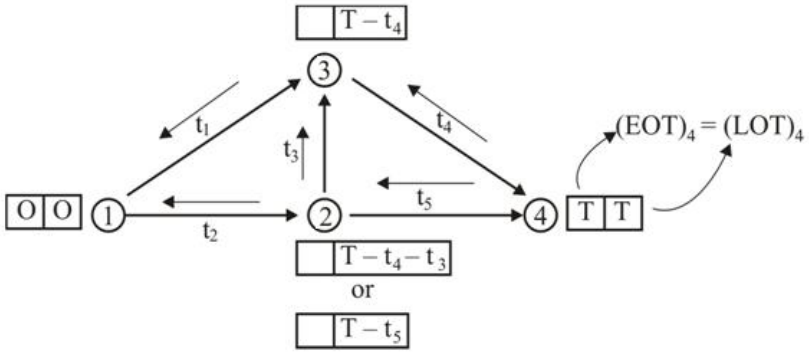
$\boxed{(EOT)_j = \left[(EOT)_i + t_{i-j}\right]_{\max.}}$ if more than one activities merge at an event.

- Total project time is given by $(EOT)_4$ or EOT of last event.
- Thus, it is calculated by forward method.

e.g.



➢ Proceed with previous figure



➢ It is defined as the latest possible time at which event may take place without affecting the total project duration which is calculated by forward pass method.

➢ Hence,(LOT) of last event is taken equal to (EOT) of last event.

Hence, $\boxed{(EOT)_4 = (LOT)_4 = T}$

➢ In general, $\boxed{(LOT)_i = (LOT)_j - t_{i-j}}$ ……..(ii)

➢ It is also known as backward pass method.

➢ Now calculate values at other nodes using above equation (ii)

$(LOT)_3 = T - t_4$ [only one activity meets at this event while tracing in backward direction]

$(LOT)_2$ =Minimum of

$$\begin{cases} T - t_5 = T - t_5 \\ (T - t_4) - t_3 = T - t_4 - t_3 \end{cases}$$

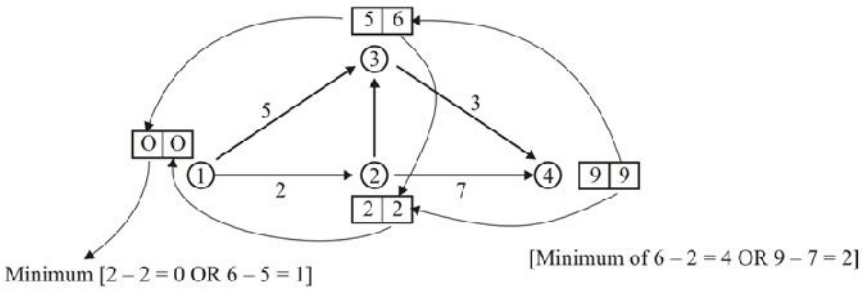
Similarly, $(LOT)_1$=Minimum of values calculated at 1

[since, it is initial event, hence it should be equal to $(EOT)_1=0$]

➢ Hence ,it can be stated as :

$\boxed{(LOT)_i = [\ (LOT)_j - t_{i-j}\ ]_{\text{min.}}}$ - Minimum of all the values, if more than one activity merges at an event.

e.g. using the previous example:



Notes:

I. Nodes having some values of EOT and LOT are called as critical nodes. And the paths connecting the critical nodes are called as critical path.

II. A project may have more than one critical paths, but the time taken by each critical paths will be same.

Activity time in CPM:

1. EST: Earliest Start Time:

➢ It is the earliest possible time at which an activity may start.

$$(EST)_{i-j} = (EOT)_i$$

2. EFT: Earliest Finish Time:

➢ It is the earliest possible time at which an activity may finish

$$(EFT)_{i-j} = (EOT)_i + t_{ij}$$

3. LST : Latest Start Time:

➢ It is the latest possible time at which an activity may start without any delay in project duration.

$$(LST)_{i-j} = (LOT)_j - t_{ij}$$

4. LFT : Latest Finish Time:

➢ It is the latest possible time at which an activity may finish without any delay in project duration.

$$(LFT)_{i-j} = (LOT)_j$$

Float:

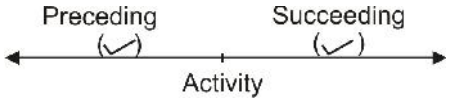
- The range within which the start time or finish time of any activity may vary such that it doesn't affect the completion of project.
- It is of four types:

1. Total Float (F_t):

- It is given by the difference of maximum available time of an activity and the activity duration.

$$\therefore \boxed{F_t = \left((LOT)_j - (EOT)_i\right) - t_{ij}}$$

- It affects the total float of succeeding and preceding activities.

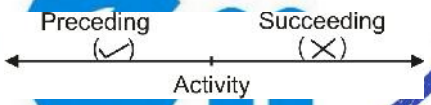


2. Free Float (F_f) :

- It is given by the difference of available time when all events start as early as possible and the activity duration.

$$\boxed{F_f = \left((EOT)_j - (EOT)_i\right) - t_{ij}}$$

- It does not affect the succeeding activities.

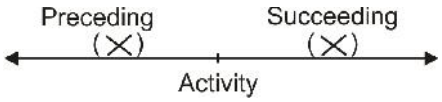


3. Independent Float ($F_{ind.}$):

- It is given by the difference of minimum available time .i.e. activity starts as latest as possible $[(LOT)_i]$ and finishes as early as possible $(EOT)_j$ and the activity duration.

- $$\boxed{F_{ind.} = \left((EOT)_j - (LOT)_i\right) - t_{ij}}$$

- In some cases, it does not affect succeeding activity or preceding activity.
- If the value of it comes to be negative, it is taken as zero.



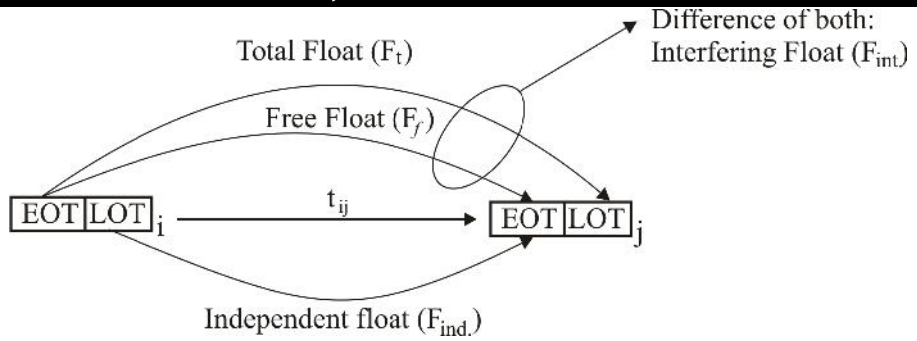
4. Interfering Float ($F_{int.}$):

- It is the difference of total float and free float.

$$\boxed{F_{\text{int.}} = F_t - F_f}$$

- It is equal to head event slack.

Notes:



- Here, floats indicated on arrow can be obtained by difference of value at head and tail of arrow and activity duration (t_{ij})
- All the four floats of each activity on critical path are zero.

Slack (s):

- It denotes the range within which an event can occur.

- i.e. $s_i = (LOT - EOT)_i$

$s_j = (LOT - EOT)_j$

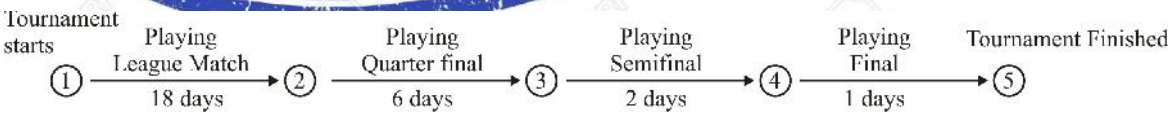
- The minimum value of slack is zero i.e.it indicates about critical event.

CPM Network

(a) A-O-A System (Activity on Arrow)

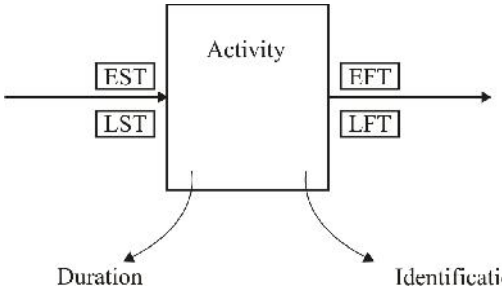
(b) A-O-N System (Activity on Node)

(a) A-O-A System



- In this system generally activity is written on one side of arrow and activity duration on other side of arrow.
- Dummies are also used as per network requirement. Also number of dummies should be kept minimum.
- Nodes represent events.

(b) A-O-N System :



- Activity along with its duration and its identification number are written in a rectangular box as shown above.
- EST, LST, EFT & LFT of an activity is written as shown above.
- It eliminates uses of dummies.
- It eliminated events.

PERT NETWORK:

- PERT: Project/Programme Evaluation and Review Technique.
- It is used in the cases of Research and Development Projects, projects which involve uncertainty in time estimation**.**
- It involves three types of activity duration:
- PERT is event oriented programming technique in which time cannot be estimated accurately.

(a) Optimistic Time (T_o):

- It is the minimum time required for an activity assuming ideal conditions during execution.

(b) Pessimistic Time (T_p):

- It is the maximum time required for an activity if unfavorable conditions exist during execution**.**

(c) Most Likely Time (T_m):

- It signifies most frequent occurrence time of an activity.
- It is generally estimated based on past experience of executing the same activity many a times.

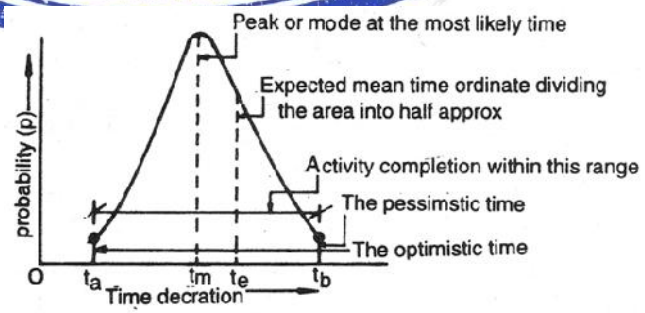


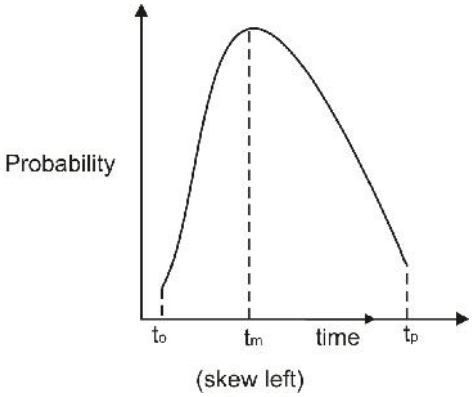
Figure: Probability distribution curve for activity duration

- It represents a situation in which things are as usual and none of the activities is non-scheduled.
- In PERT network analysis, “ (beta)-distribution” curve is used, because this curve yields good result for most of the activities.
- **Elements of (beta)-distribution**:

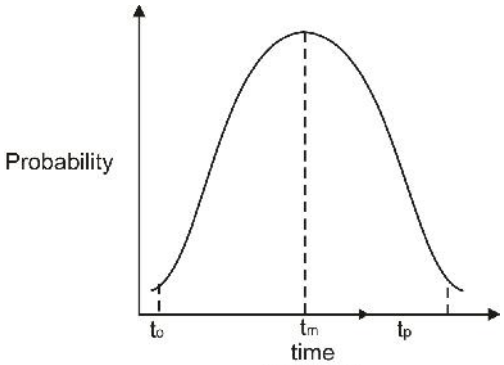
B distribution is of two types.

(i) Skew right (less time ie optimistic estimation)

(ii) Skew right (more time ie pessimistic estimation)



(skew left)



(skew left)

1. Expected mean time of an activity(T_e):

$$T_e = \frac{T_o + 4T_m + T_p}{6}$$

2. Standard Deviation of an activity($\pm$):

$$\pm = \frac{T_p - T_o}{6}$$

3. Variance of an activity(^{3}):

$$^3 = \pm^2 = \left(\frac{T_p - T_0}{6}\right)^2 \quad or, \pm = \sqrt{^3}$$

Critical Path:

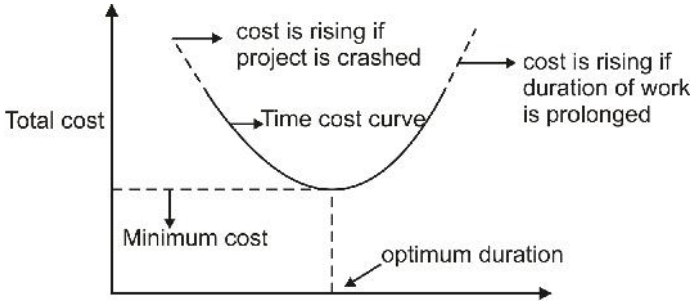
- The definition of critical path in PERT Network is same as that for CPM Network**.**
- For calculation purpose all the three time ,T_o, T_p & T_m are converted into expected time (T_e) [it will be used in place of activity time $t_{i\text{-}j}$]
- Hence,

$$T_e = \frac{T_0 + 4T_m + T_p}{6}$$

(i) ⟶ (j)

Note: When all the time co-ordinates i.e. T_p , T_m & T_0 coincides such that variance is O then the duration of the activity becomes certain and deterministic i.e. it changes into CPM. Hence it can

be concluded that PERT is a general case where as CPM is the particular case of PERT.



Earliest expected occurrence time (T_E):

- It is same as that of earliest occurrence time (EOT) of CPM. Hence it is given as :

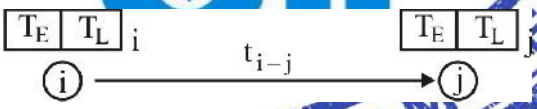
$$\boxed{(T_E)_j = \left[(T_E)_i + t_{i-j}\right]_{\max.}}$$ When more than one activity merges at an event.

Latest Allowable occurrence time (T_L):

- It is same as that of latest occurrence time (LOT) of CPM.
- Hence it is given as:

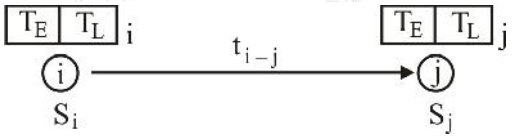
$$\boxed{(T_L)_i = \left[(T_L)_j - t_{i-j}\right]_{\min.}}$$ When more than one activity merges at an event.

- Scheduled completion time (T_s) of project is taken equal to "T_L" of the last event.



SLACK(s):

- It denotes the range within which an event can occur, same as that of CPM Network:



- i.e. $\boxed{S_i = (T_L - T_E)_i}$ & $\boxed{S_j = (T_L - T_E)_j}$
- Unlike the value of slack in CPM Network, in PERT network, the value of slack may be positive, zero, negative.

1. Positive Slack (s) > 0; i.e. Project is ahead of schedule, hence excess resources are available.
2. Zero Slack (s) = 0; i.e. Project is running as per schedule, hence resources are adequately available.
3. Negative Slack (s) < 0; i.e. Project is behind schedule; hence resources are not adequately available.

Notes:

Events which have least value of slack are treated as critical event. And the path joining critical events is called critical path.