Construction Technology & Management

Syllabus :- Network Techniques – Bar charts, Milestone charts, Work Break Down Structure & preparation of networks. Application of network Technique like PERT, CPM, GERT, AON & AOA in construction management. Project monitoring, cost planning, resource allocation through network techniques, Line of balance techniques.

Definition of a Network :- A network is a graphical and logical model or plan which lists out the sequence of various operations which are required to be performed for the final achievement of the project objectives.

Objectives of Network Techniques :- The term Network Techniques refers to the method of planning, scheduling, & controlling the progress on various components of the projects, specially those projects which are complex in nature. It provides an integrated construction management of projects, determines project duration more accurately, identifies the effect of schedule delays well in advance for timely corrective action, facilitates optimisation of resources and provides a scientific method for progress reporting & control, enabling the management to take better decisions for effective monitoring of projects.

Important Definitions :-

1. Activity :- Any portion of a project which consumes time or resources and has a definite beginning and an end is called as an activity. An activity is denoted by an arrow. Length of the arrow has no significance.

Representation of an Activity

2. Event :- The beginning or completion of an activity is termed as an event. It indicates a particular instant of time but does not consume any time or resources by itself.

Representation of an event

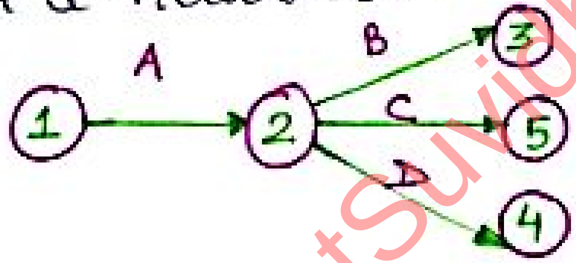
3. Network Logic :- This denotes the technical dependencies among the activities.
eg :- Activity A must be completed before Activity B can be started. i.e.

Network Logic

Also, when all activities & events in a project are connected logically & sequentially, they form a network.

4. Dummy :- A dummy is similar to an activity but it does not consume any resources. It is merely a method by which interdependence of activities or events can be clearly shown. A dummy is represented by a dashed arrow as shown below.

Types of Events :-
Consider a network :-



1. Tail Event :- An event which marks the begining of an activity is called a tail event.
eg :- Event 1 is said to be the tail event of activity 'A', as it indicates the beginning of an activity A.

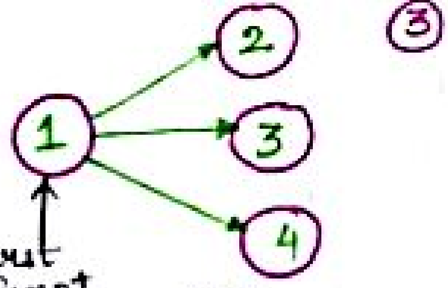
2. Head Event :- It is that event which marks the completion of an activity.
eg :- Event 2 is said to be the head event to Activity A.

3. Dual role Events :- If an event acts as the tail event for some activity & head event for some other activity or activities, it is called Dual role Events.
eg :- Event 2 acts as head event for activity A but also simultaneously as the tail event for activities B, C & D, so Event 2 is said to be a dual role event.

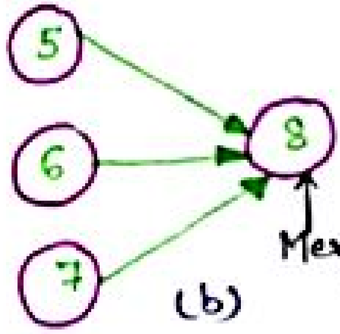
4. Burst and Merge Events :-

The nodes or events to which a no. of activities converge are called as Merge Events. (Fig b)

The nodes from which a no. of activities emerge are called Burst events or Burst nodes.



(a)

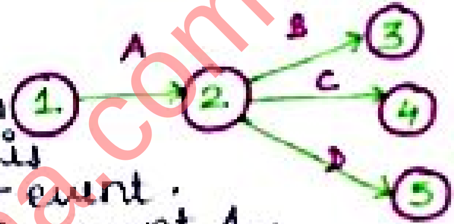


(b)

Interrelationship of Events :-

1. Succession Events :- The events that follow a particular event in the sequence of their completion is called a Successor event to that event.

eg → Event 2 is successor event to event 1.



Fig(c)

2. Predecessor Events :- The event that occurs before a particular event in the sequence of their completion are called predecessor events of that event.

eg, Event 1 is predecessor event to event 2 &
Event 2 is predecessor event to Events 3, 4 & 5.

Interrelationship of Activities

(1) Parallel Activities or Concurrent Activities :- They are the activities which can be carried out simultaneously and independent of each other.

eg In fig (c), Activities B, C & D are said to be parallel activities because they can be started simultaneously once Activity A is completed.

(2) Serial Activities :- These are activities which can be performed only in succession i.e one after the other sequentially.

Fig(d)

In, fig (d), Activities A & B occur serially or one after the other

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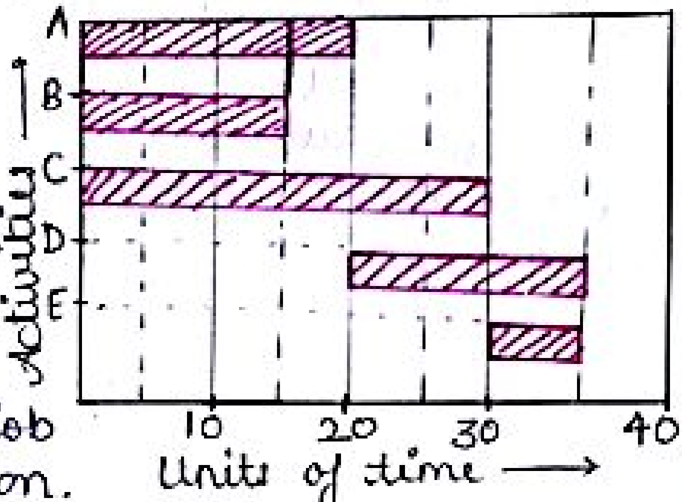
Network Techniques :-

(1) Bar charts or Gantt charts :-
Bar charts are the pictorial charts developed by Henry Gantt around 1900. It consist of 2 coordinate axes, one representing the time elapsed & the other jobs or activities performed. The jobs are represented in the form of bars.



The length of a bar indicates the duration of job or activity, takes for completion. Generally, in any project, some jobs can be taken up concurrently & some will have to be completed before others can begin. Hence, In a bar chart representing a project, some of the bars run parallel or overlap each other time wise & some run serially with one bar beginning after another bar ends. The following steps are necessary to prepare a bar chart :-

1) Analysis of Project.
2) Break the project down into activities.
3) Time required to finish each activity.
4) Place the activities in technical sequence.
5) Diagram is adjusted according to the target date.

- Advantage of Bar Charts :- The plan, schedule, progress of the project can all be depict graphically together.

- Limitations of Bar Charts :-

(1) Interdependencies of Activities :- In a program, where there are a large no. of activities that can be started with a certain degree of concurrency, the bar chart can't show clearly the interdependen-cies among the various efforts or activities. This is a serious deficiency.

(2) Project Progress :- A bar chart can't be used as a control device since it does not show the progress of work. A knowledge of the amount of

work in progress or jobs completed is absolutely necessary in a dynamic programme. Changes in the plan are a necessary part of a large project & a bar chart does not offer much assistance under such circumstances.

(3) Uncertainities :→ It does not reflect the uncertainity or tolerances in the duration times estimated for various activities. The completion of various stages or jobs can't be forecast with exactness. The uncertainity about a test becoming successful, or a sudden break through in technology or know how will always provide situations which will make rescheduling of various events a necessary part of the project & give it a dynamic character which is not reflected in a bar chart.

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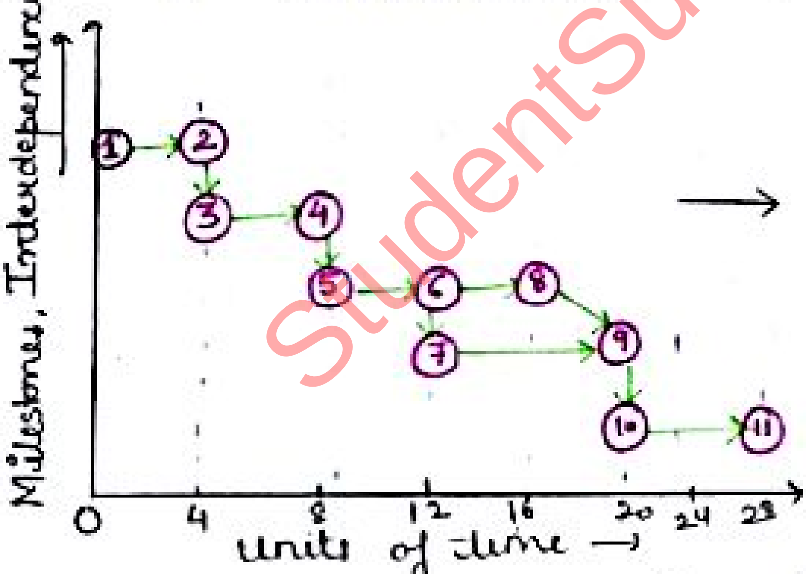
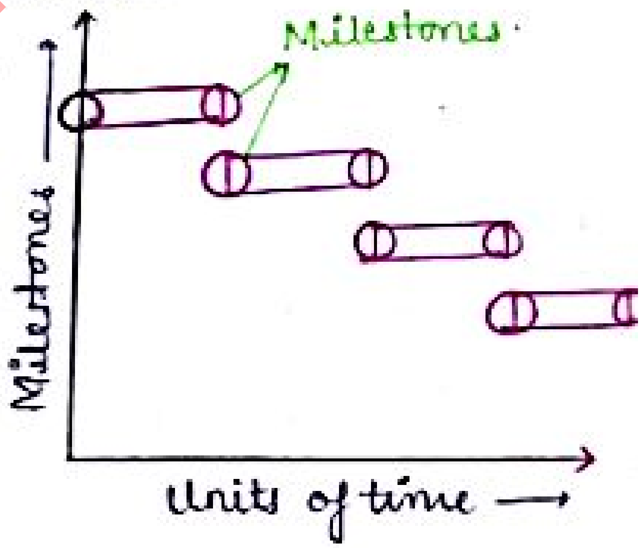
(2) Milestone charts :– The Milestone charts bring into picture the functional elements of a program & their inter relationship.





Milestones are key events or points in time which can be identified when completed, as the project progresses. In the Gantt chart, a bar which represents a long term job is broken down to several pieces, each of which stands for an identifiable major events. While the milestone charts was definitely an improvement on the bar chart, it still had one great deficiency i.e it does not clearly show interdependencies between events.

In Mile stone charts, the events are in chronological, but not in a logical sequence.

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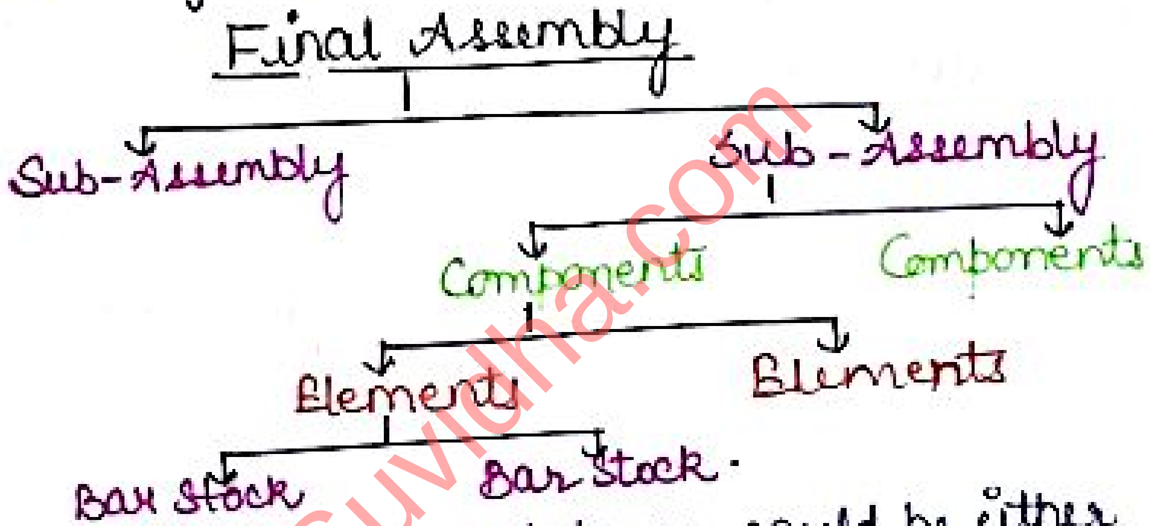
(3) <u>Work Break down Structure</u> :- Work Break down Structures are also known as Indenture level structure. Such a structure establishes the hierarchial order in a system. In a general case, a system is broken down to sub-systems & each sub-system to sub-sub-system until the assembly is reduced to elements or components representing the manageable units for planning & control.



The several units in the breakdown could be either end item oriented or product oriented. The end item oriented units are the ones which forms a necessary part of final item. The product oriented items include Organisational or service units which are also essential for the completion of the project.

Each unit must be definable segments of the work to be accomplished & should form key points, each with a time schedule for satisfactory completion of the entire project.

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Preparation of Networks :-

- Types of Networks
  1. Activity on Arrow (A-O-A) or Arrow diagrams.
  2. Activity on Node (A-O-N) or Precedence Diagrams.
  3. Event Oriented Networks (PERT type).

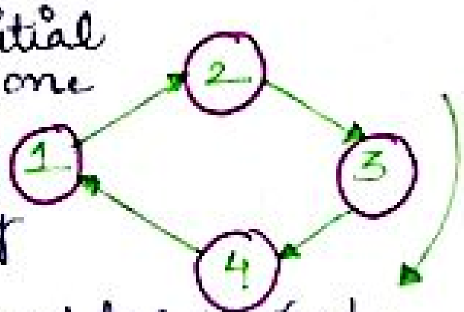
1. A-O-A Networks :- It is composed of arrows & nodes. The arrows represent the activities & nodes represent the events.

2. A-O-N Networks :- In A-O-N networks, the nodes represent the activities & the arrows, their interdependencies or precedence relationships.

- Basic Assumption for creating a Network schedule

1) The project can be broken down into a group of activities.
2) Each activity can be assigned a duration.
3) Logical relationship among activities are known & fixed in the network chains.

- Rules for Drawing a Network



1. A network will have only one initial node. Initial node will have only one outgoing arrows.
2. A network can have only one final node. Final node will have only incoming arrows.
3. No activity can start until its tail event has occurred.
4. An event can't occur until all the activities leading upto it are completed.
5. No event can occur twice. Hence, network looping is not permitted.
6. An arrow should represent a singular situation. Individuality and separate entity of each activity should be maintained.
7. The network should be drafted such that all activities are completed to reach the end objective.
8. All constraints & interdependencies should be shown properly on the network using dummies.
9. Network logic should always be maintained.
10. The time flow is usually shown from left to right.

- **Fulkerson's Rule for Numbering the Events :-**

It has following steps :-

(i) There will be a single initial event in a network which has only arrows coming out of it. The event is given number (1)

(ii) All the arrows coming out of event (1) are neglected. This provides us with one or more initial events. These events are numbered (2), (3), (4) - etc.

(iii) Again, neglect all arrows coming out of these events. A few more initial events will be created. Number them similarly.

(iv) This operation is continued until the last event is reached & numbered.

Problems

Q-1 In a small construction project, there are 6 activities identified from A to F. The relationships b/w them are :

(1) A is the first activity to be formed.

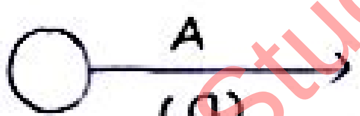
(2) B & C can be done concurrently & must follow A.

(3) B must precede D

(4) E must succeed 'C', but it can't start until B is completed.

(5) the last operation 'F' is dependent upon the completion of both 'D' & 'E'.

Sol :- The events must be numbered acc. to Fulkerson's rule. The step by step procedure is.



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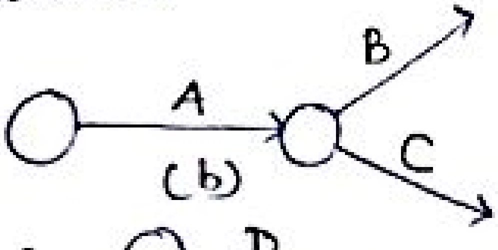

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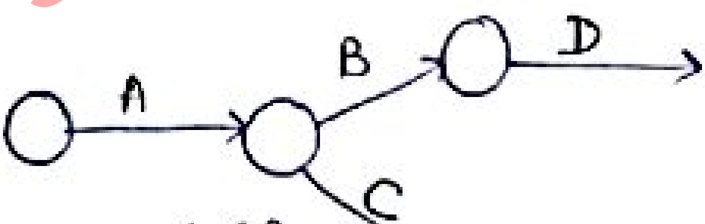

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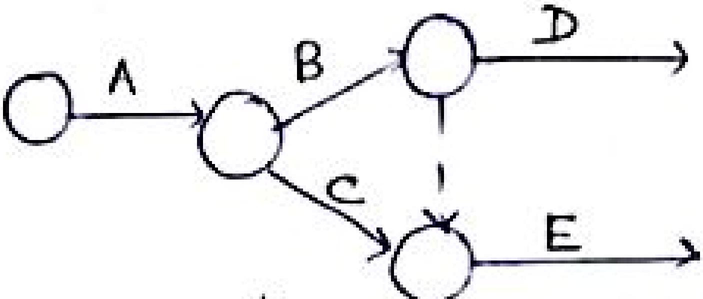
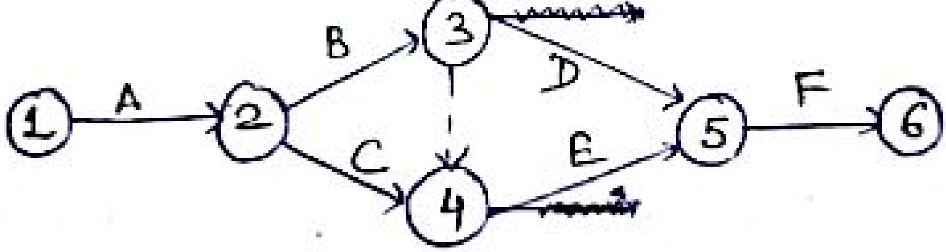


(d)

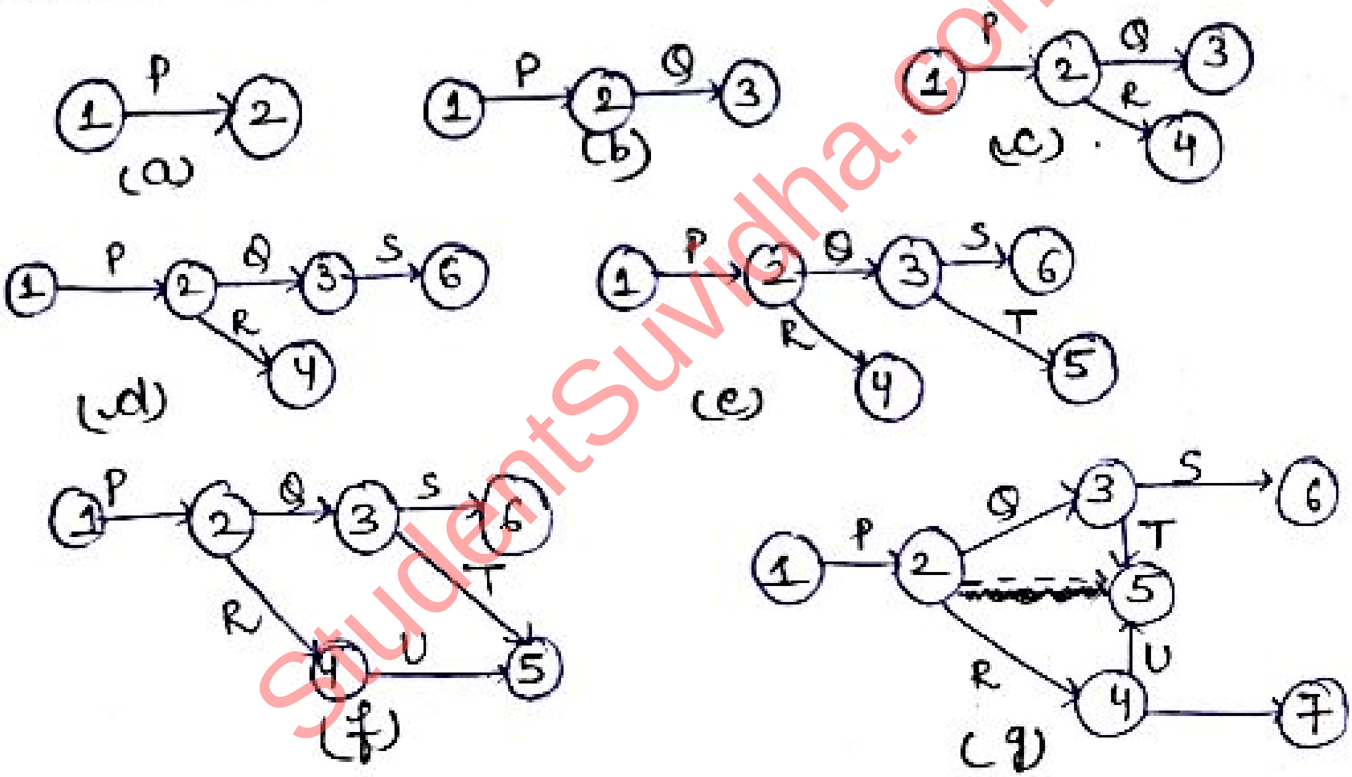


(c) Final Network

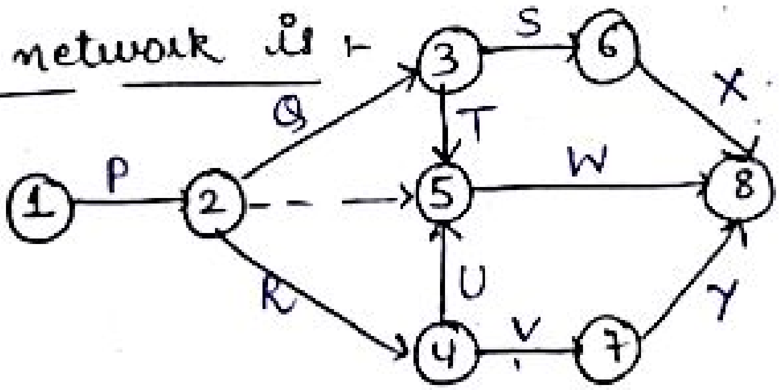
Question-2:- The maintenance project of a building consist of 10 activities. Draw the network diagram.

Activity	P	Q	R	S	T	U	V	W	X	Y
Identification	(1,2)	(2,3)	(2,4)	(3,6)	(3,5)	(4,5)	(4,7)	(5,8)	(6,8)	(7,8)

Solution . the network will be as follows:-



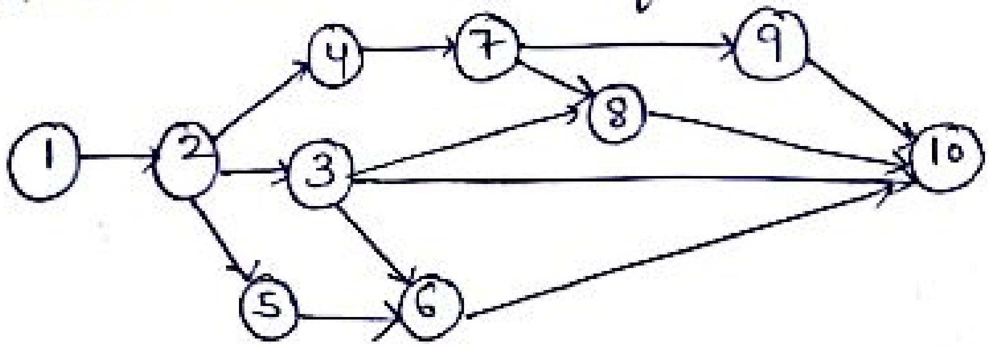
Final network is:-



Question-3 A project consist of 10 events. Draw the network

Event	1	2	3	4	5	6	7	8	9	10
Immediate Predecessor	–	1	2	2	2	3,5	3,4	3,7	7	3,6,8,9

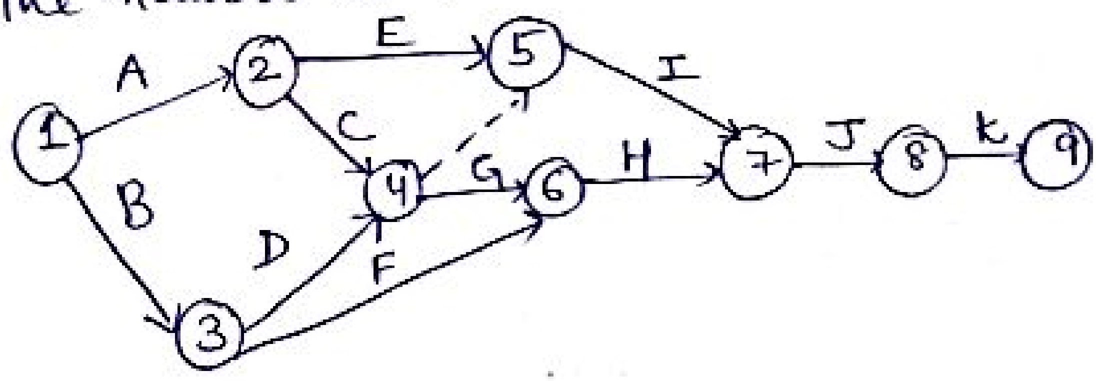
Sol. The network is as follows.



Question-4 Draw a network for simple project-erection of steel works for a shed. The various elements are :-

Activity	Description	Prerequisites
A	Erection of site workshop	–
B	Fence site	A
C	Bend reinforcement	B
D	Dig foundation	A, C
E	Fabricate steel works	B
F	Install concrete plant	C, D
G	Place reinforcement	G, F
H	Concrete foundation	E
I	Paint steel work	H, I
J	Erect steel work	J
K	Give finishing touch	

Sol:- The network is :-



Application of Network Techniques

(1) PERT (Program Evaluation & Review Technique) :-

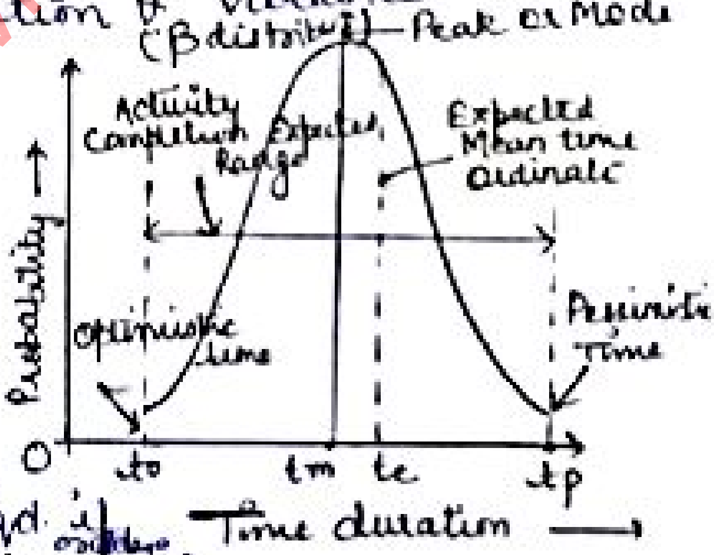
PERT is a management tool used for planning, controlling & scheduling a project. It was developed by the U.S. Navy along with the management consultancy firm for its Polaris Missile Program in 1958. It was recognized that something better was needed in the form of an integrated planning & controlling system for the Polaris weapon system program. To face this challenge, a research team was assembled consisting of various experts. This research project was designated as PERT (Program Evaluation & Research Task) & later on Program Evaluation & Review Technique.

PERT is an event oriented method & follows the probabilistic approach towards time durations. PERT introduces uncertainity into time estimates for activity & project durations. In PERT, 3 engineering time estimates are made & embedded within the theoretical curve. These 3 estimates enable the expected mean time, standard variation & variance.

- Time Estimates

Here,

t_o = optimistic time. It is an estimate of the min. time required for an activity if everything goes as per ideal conditions.



t_p = Pessimistic Time is an estimate of max. time reqd. if unusually bad luck i.e. failure, or ordinary experienced.

t_m – Most likely time is based on experience & judgement, being the time required if normal condition prevail. It lies between t_o & t_p.

A Probability distribution curve that can represent these estimates is called β (Beta) distribution.

The expected mean time (t_e) is :-

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

Standard deviation is :-

$$\sigma_t = \frac{t_p - t_o}{6}$$

Variance is $(\text{Standard deviaⁿ})^2$

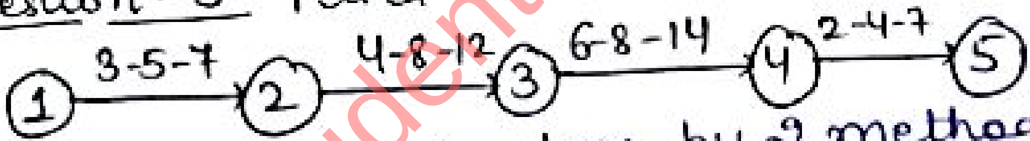
So, $V_t = (\sigma_t)^2 = \frac{(t_p - t_o)^2}{36}$

i.e $$V_t = \frac{(t_p - t_o)^2}{36}$$

• **Expected Time of Activities in Series** :- In a network, if no. of activities are in series, the expected time of the path along the activities is the sum of the expected time (t_e) of the activities.

Problems

Question - 5 Find t_e.



Solution :- It can be done by 2 methods :-

Method - 1 t_e of each activity is found & added together to get t_e of the network.

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

i.e

Activity	t_o	t_m	t_p	t_e
1-2	3	5	7	5
2-3	4	8	12	8
3-4	6	8	14	8.666
4-5	2	4	7	4.166

$\Sigma t_e = 25.83$ Ans

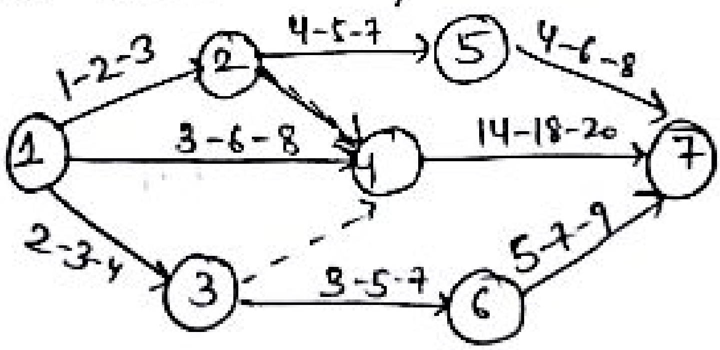
Method - 2 All, t_o, t_m & t_p are added together to get t_e

i.e $\Sigma t_o = 3 + 4 + 6 + 2 = 15$

$\Sigma t_m = 25$, $\Sigma t_p = 40$

$$\Sigma t_e = \frac{15 + 4 \times 25 + 40}{6} = 25.83 \text{ units Ans.}$$

Question-6 From the network given below, find the expected time for each of the path also find the critical path as well as expected time of project completion.



Sol The network has 5 paths.

1. 1-2-4-7
2. 1-2-5-7
3. 1-4-7
4. 1-3-4-7
5. 1-3-6-7

(a) To find te of each activity.

Activity	to	tm	tp	te
1-2	1	2	3	2
1-3	2	3	4	3
1-4	3	6	8	5.83
2-4	4	6	8	6
2-5	4	5	7	5.16
3-4	2	4	6	4
3-6	3	5	7	5
4-7	14	18	20	17.66
5-7	4	6	8	6
6-7	5	7	9	7

(b) Σte of path:

(1) 1-2-4-7 = 2+6+17.66 = 25.66

(2) 1-2-5-7 = 2+5.16+6 = 13.16

(3) 1-4-7 = 5.83+17.66 = 23.5

(4) 1-3-4-7 = 3+4+17.66 = 24.66

(5) 1-3-6-7 = 3+5+7 = 15

Critical path is the path which has max. te.

So, Here, Critical Path is → 1-2-4-7.

& duration of project = 25.66 units.

Estimates of PERT :-

1. Earliest Expected Time (T_E)
2. Latest allowable occurrence time (T_L).

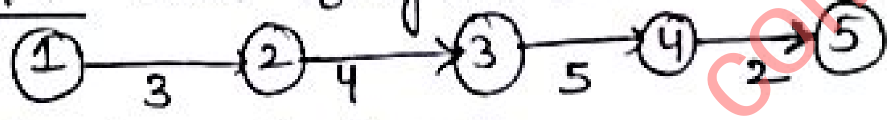
- **Earliest Expected Time (T_E)**

It is the time when an event can be expected to occur. It is usually put above or below that particular node.

It can be calculated by adding the expected time (t_e) of all activities along the path leading to that activity event.

Problems

Question-7 Find T_E of all events in the network.



Sol:- T_E of event 1 = 0

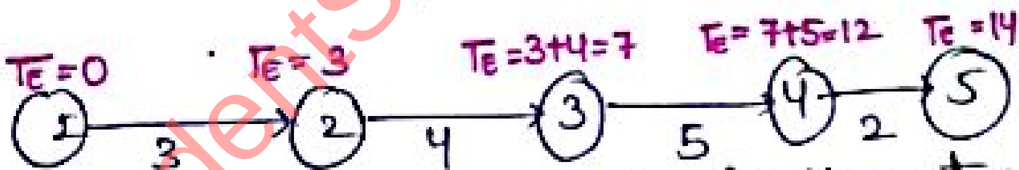
" 2 = 0+3 = 3

" 3 = 3+4 = 7.

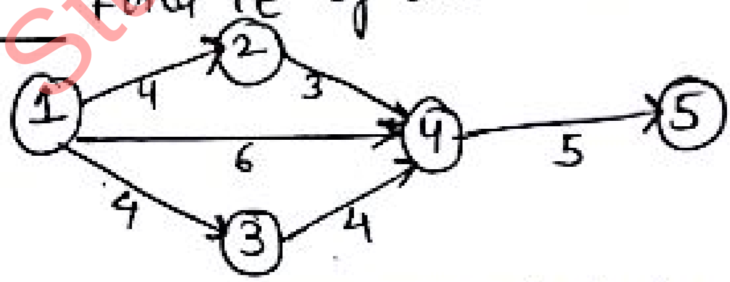
" 4 = 7+5 = 12

" 5 = 12+2 = 14

i.e



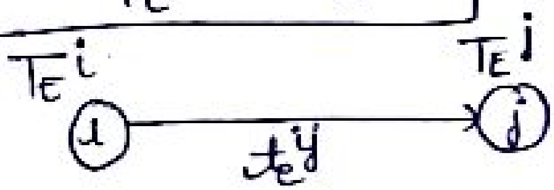
Question-8 Find T_E of all events in the network.



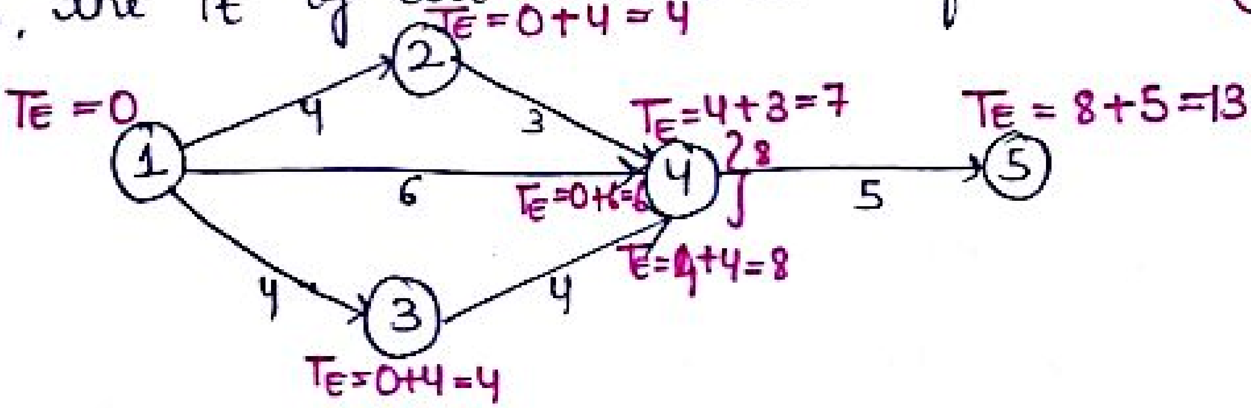
This method can be computed by a formula, i.e

$$T_E^j = T_E^i + t_e^{ij}$$

where

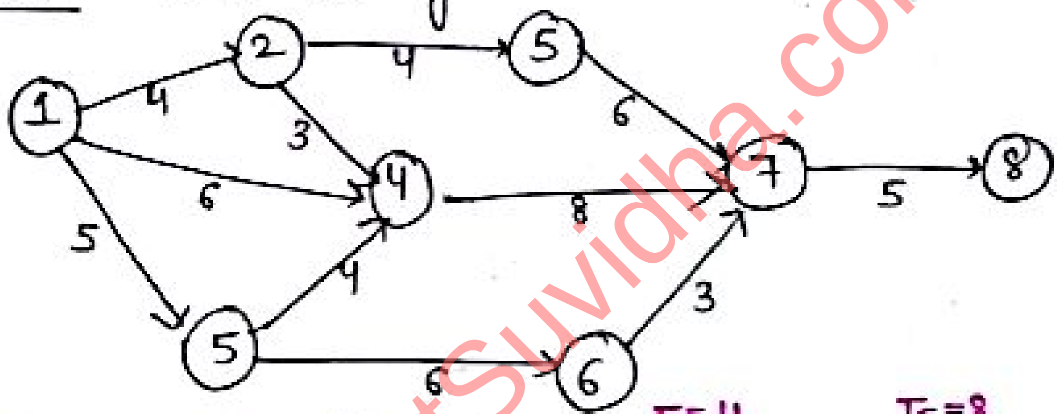


So, the T_E of all events are as follows :-



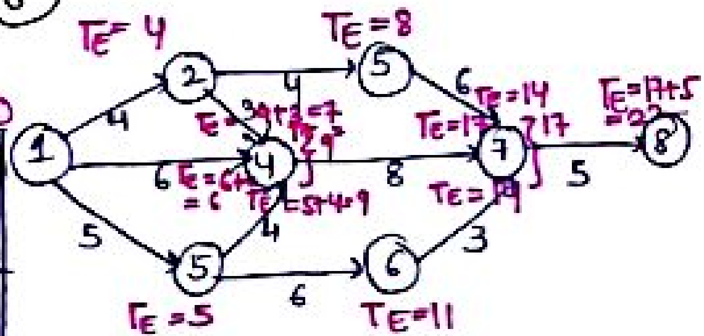
T_E for node 4 has 3 paths,
So, we will take the T_E which is largest.
So, T_E for (4) is 8.

<u>Question-9</u> Find T_E of all events.



<u>Sol</u>

<u>Computation of T_E is</u>



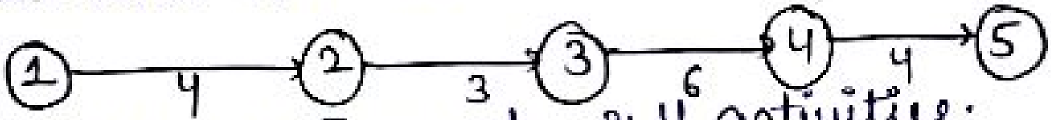
Event (1)	Predecessor Event (2)	Activity ij (3)	t_e^{ij} (4)	T_E^i (5)	T_E^j (6)
1	—	—	—	—	0
2	1	1-2	4	0	4
3	1	1-3	5	0	5
4	1	1-4	6	0	6
	2	2-4	3	4	7
	3	3-4	4	5	9
5	2	2-5	4	4	8
6	3	3-6	6	5	11
7	4	4-7	8	9	17
	5	5-7	6	8	14
	6	6-7	3	11	14
8	7	7-8	5	17	22

Ans.

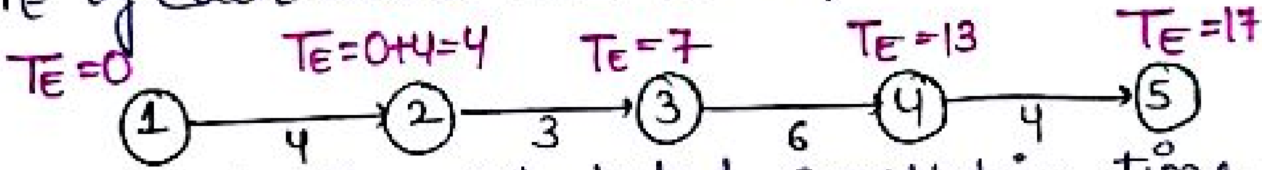
• Latest Allowable Occurrence Time (T_L)

It is the time by which an event must occur to keep the project on schedule. It is denoted by T_L.

Consider the network



It consist of 5 events & 4 activities.
T_E of each event can be computed i.e.



Now let the scheduled completion time for this project is 20 units.

$\therefore T_L^5 = 20$.

The activity 4-5 take 4 units of time, $\therefore$ T_L for 4 should not be less than 16

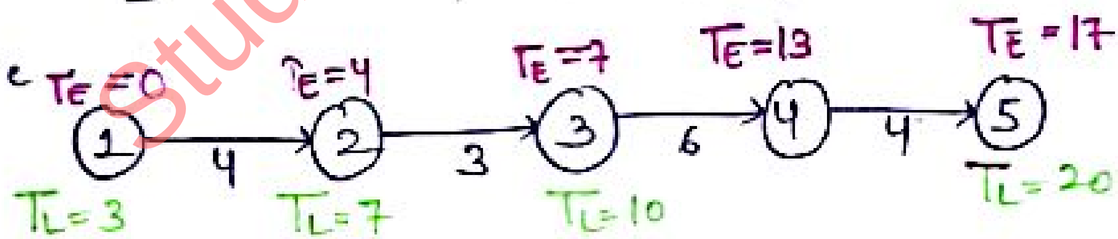
i.e. $\therefore T_L^4 = 16$

Similarly, $T_L^3 = 16 - 6 = 10$

$T_L^2 = 10 - 3 = 7$

$T_L^1 = 7 - 4 = 3$.

i.e

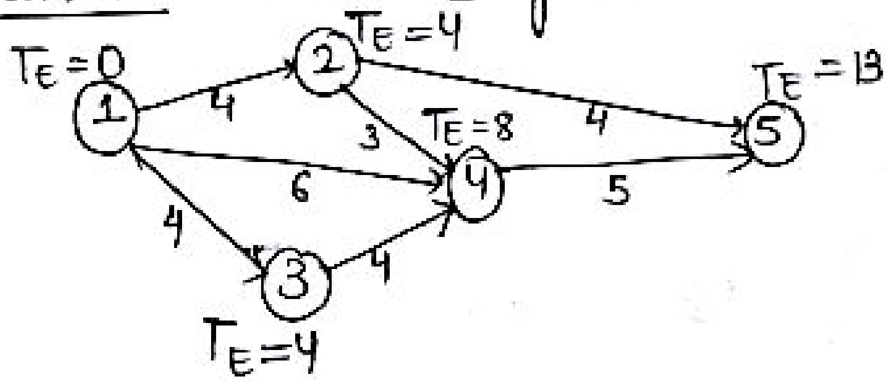


⟹ Formula for calculation of T_L

$$T_L^i = T_L^j - t_e^{ij}$$

If an event has 2 or 3 activities, then we will take T_L min.

Question-10 Find T_L of all events.



The scheduled completion time is 15 units.

Sol. $T_L^5 = 15$

So, * $T_L^4 = 15-5 = 10 \doteq T_L^5 - t_e$

* $T_L^3 = t_L^4 - t_e = 10-4 = 6$ $\therefore$ $\boxed{T_L^3 = 6}$

* $T_L^2 = T_L^5 - t_E = 15-4 = 9$

$T_L^2 = T_L^4 - t_E = 10-3 = 7$ } min

So $\boxed{T_L^2 = 7.}$

* Event 1 has 3 successor i.e 2, 3, 4.

$T_L^1 = T_L^2 - t_e(1-2) = 7-4 = 3$

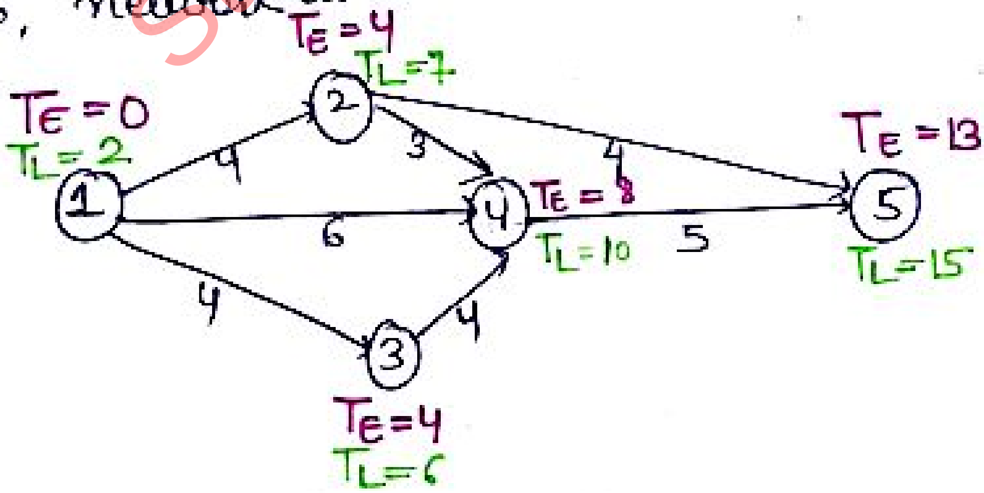
$T_L^1 = T_L^3 - t_e(1-3) = 6-4 = 2$

$T_L^1 = T_L^4 - t_e(1-4) = 10-6 = 4$

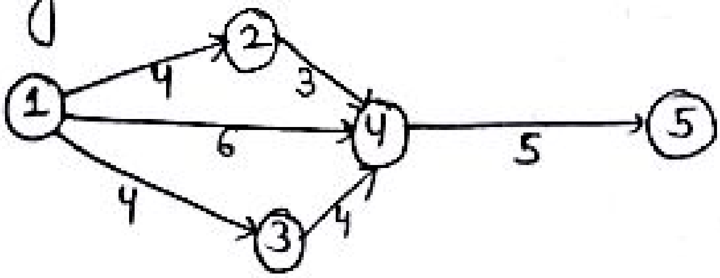
} min $= 2$

$\boxed{\therefore T_L^1 = 2.}$

So, network is :-



Question - 11 Find T_E & T_L of all the events in the network given below.



Sol :-

Event	Earliest Expected Time				Last Allowable Time			
	Predecessor Event	t_e^{ij}	T_E^i	T_E	Successor Event	t_e^{ij}	T_L^i	T_L
1	–	–	–	0	2 3 4	4 4 6	1 0 2	0
2	1	4	4	4	4	3	5	5
3	1	4	4	4	4	4	4	4
4	1 2 3	6 3 4	6 7 8	8	5	5	8	8
5	4	5	13	13	–	–	–	13

Slack :- The difference between T_E & T_L of an event is called the slack of that event.

Event	T_E	T_L	Slack
1	0	0	0
2	5	11	6
3	6	6	0
4	5	6	1
5	9	9	0

Slack can be positive, zero or negative.

1) Positive Slack :- If $T_L > T_E$, it is +ve slack.

2) Negative Slack :- If $T_L < T_E$, it is -ve.

3) Zero Slack :- If, $T_L = T_E$, it is zero slack.

Critical Path :- The value of slack of an event determines how critical that event is with respect to the project duration. A critical path is the path that connects the events having zero slack or min. slack in the network. Also, it is the longest path (time wise) in the project. A critical path is distinctly marked in the network - usually by a thick line.

Probability of Completion Time for a Project :-

If the T_E & scheduled time of completion of project i.e T_S are available to us, we can calculate a probability factor 'Z'. Using this we can find probability. The steps involved are :-

Step-1 First, Standard deviaⁿ (σ) corresponding to the critical path is calculated,

i.e $\sigma = \sqrt{\text{sum of variances along critical path}}$

$$\sigma = \sqrt{\Sigma \sigma_{ij}^2}$$

$$\text{Variance} = \frac{[(t_p^{ij}) - (t_o^{ij})]^2}{36}$$

Step-2 Knowing T_S & T_E, calculate Z

i.e $Z = \frac{T_S - T_E}{\sigma} = \frac{T_S - T_E}{\sqrt{\sigma_{ij}^2}}$

Step-3 With Z, we find % probability.

when Z = 0 → 50-50 chances of completion of project

Z is +ve → more than 50%

Z is −ve → less than 50%.

Question-12 :- A project takes 20 days along the critical path & has $\sigma = 4$ days. What is the probability of completing the project within

(i) 20 days (ii) 24 days (iii) 18 days.

Sol:- (i) for T_S = 20 days,

Normal deviate, $Z = \frac{T_S - T_E}{\sigma} = \frac{20-20}{4} = 0$

∴ Z = 0, Probability = 50%.

(ii) T_S = 24 days, $Z = \frac{24-20}{4} = 1$

for Z = 1, Probability = more than 50%.

It can be calculated from Normal Distribution Funcⁿ Table

(iii) For T_S = 18 days, $Z = \frac{18-20}{4} = -0.5$

Z = −0.5, Probability = less than 50%

Question-13 A small project consists of 7 activities. The time estimates are given below :-

Activity/times	1-2	1-3	1-4	2-5	3-5	4-6	5-6
t_o	1	1	2	1	2	2	3
t_m	1	4	2	1	5	5	6
t_p	7	7	8	1	14	8	15

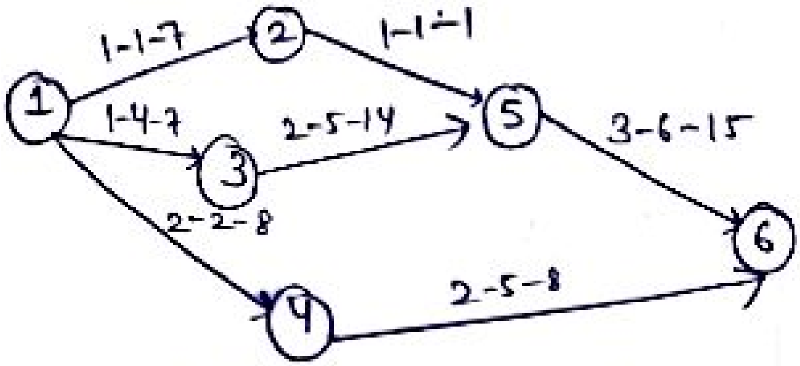
(a) Draw the network.

(b) Determine the critical path.

(c) Probability of not completing the project within 18 weeks

(d) " " completing project 3 weeks earlier than the expected time?

Sol (a) Network



1. Calculation of Expected times :-

Activity	t_o	t_m	t_p	t_e	σ^2
1-2	1	1	7	2	1
1-3	1	4	7	4	1
1-4	2	2	8	3	
2-5	1	1	1	1	0
3-5	2	5	14	6	4
4-6	2	5	8	5	1
5-6	3	6	15	7	4

2. Calculation of T_E & T_L

Event	Precedence Event	t_{ij}	$T_E^j = T_E^i + t_{ij}$	T_E max	Successor Event	$T_L^i = T_L^j - t_{ij}$	T_L min
1	—	0	0	0	2	7	0
					3	0	
					4	9	
2	1	2	2	2	5	9	9
3	1	4	4	4	5	4	4
4	1	3	3	3	6	12	12
5	2	1	3	10	6	10	10
	3	6	10				
6	4	5	8	17	—	17	17
	5	7	17				

(b) Critical Path = 1-3-5-6.

(c) P of completing in 18 weeks.

$P\left(Z = \frac{18-17}{\sigma}\right) \Rightarrow P(Z <= 1/3) = 63\%$

$\therefore P = 100 - 63 = 37\%$

(d) Probability of completing ... 3 weeks ...

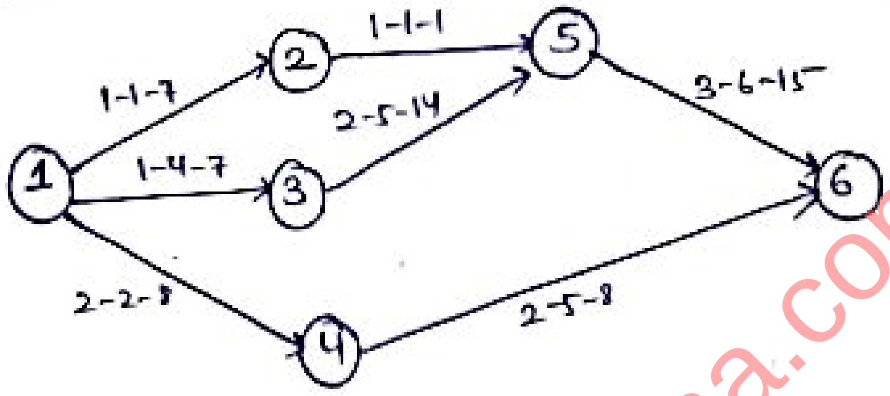
$17-3 = 14$

$P\left(Z <= \frac{14-17}{3}\right) = P(Z <= -1)$

Question-14 A project is composed of 7 activities :-

Activity (i-j)	1-2	1-3	1-4	2-5	3-5	4-6	5-6
t_o	1	1	2	1	2	2	3
t_p	7	7	8	1	14	8	15
t_m	1	4	2	1	5	5	6

Sol.



Activity	Expected Duration			t_e	Variance σ^2	Std. deviaⁿ σ
	t_o	t_m	t_p			
1-2	1	1	7	2	1	1
1-3	1	4	7	4	1	1
1-4	2	2	8	3	1	1
2-5	1	1	1	1	0	0
3-5	2	5	14	6	4	2
4-6	2	5	8	5	1	1
5-6	3	6	15	7	4	2

(i) Critical path is along 1-3-5-6.

(ii) Variance along Critical path $= 1+4+4$
$= 9$

(iii) Standard deviation along CP $= 1+2+2 = 5$.

—x—

(2) CPM (Critical Path Method)

It was discovered jointly by Dupont and Remington Rand Univac in 1957.

CPM is found to be of much use in the construction industry with applications in the construc^n of massive structures like dams, bridges, tunnels etc. CPM networks are usually used for repetitive type of projects, where fairly accurate estimates of time can be made for the activities of the project. Hence, CPM is not suitable for research & development type of projects.

CPM follows the deterministic approach, which assumes that enough information is available on the activities & hence only one time estimate is sufficient.

- **Difference between CPM & PERT :-**

1) CPM is an activity oriented while PERT is event oriented.

2) In CPM, time estimates are of a fair degree of accuracy, while In PERT, time estimates and not that accurate & there is uncertainty attached to it.

3) In CPM, cost is the governing factor while In PERT, time is the governing factor. In CPM, project duration is fixed & cost is min. while In PERT, it is assumed that the cost is directly proportional to time.

4) The critical path in CPM is that path which joins the critical activities, while In PERT, critical path is that path which joins the critical events.

- **Activity Times :-** CPM is an activity oriented network method. The various activity times are :-

1. Earliest Start Time :- The earliest start time of an activity is the earliest time by which an activity can start. This is therefore equal to the earliest event time of the tail event of the activity. This is denoted by EST

$EST = T_E^i$ [If the activity is i-j & tail event is T_E^i]

2. Earliest Finish Time :- The earliest finish time of an activity is the earliest time by which it can be completed. An early finish is said to occur if the activity starts at its EST & takes the estimated duration for completion.

$$\therefore \ EFT = EST + t^{ij}$$

$$\text{i.e.} \ EFT = T_E^{i} + t^{ij}$$

3. Latest Start Time :- It is the latest time by which an activity can start without delaying the completion of the project as a whole. For this, the activity should start by a time equal to the latest finish time less the activity duration.

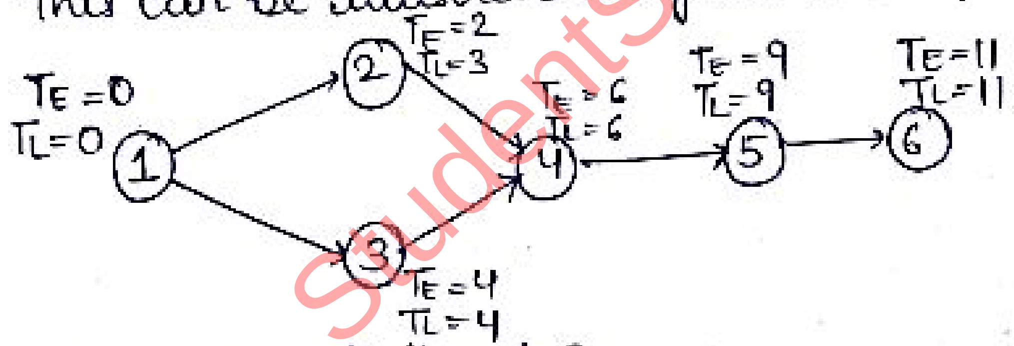
$$\therefore \ LST = LFT - t^{ij} .$$

4. Latest Finish Time :- It is the latest time by which an activity can be completed without delaying the project. This will be therefore equal to the latest allowable time of the head event of the activity.

$$\therefore \ LFT = \text{latest event time of the activity } i\text{-}j .$$

$$\text{i.e.} \ LFT = T_L^{j}$$

This can be illustrated by an example:-



For the activity 1-2,

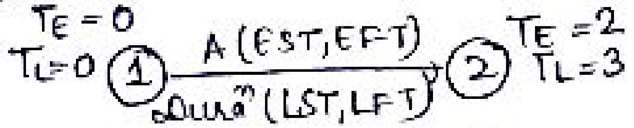
$$EST = T_E^{i} = 0 = 0$$

$$EFT = T_E^{i} + 2 = 0 + 2 = 2$$

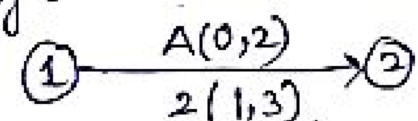
$$LFT = T_L^{j} = 3$$

$$LST = T_L^{j} - t^{ij} = 3 - 2 = 1 .$$

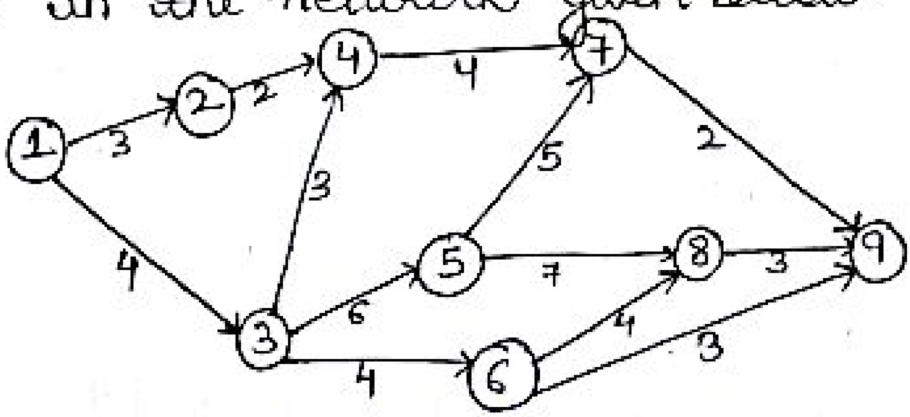
These values can be written as :-



eg. For activity 1-2



Question-15 Find the earliest occurrence times of the events in the network given below.



- $T_E^j = (T_E^i + t^{ij})_{max}$.
- T_{E_1} of event 1 = 0 (first event).
  - T_{E_2} of event 2 = 0 + 3 = 3
  - T_{E_3} " 3 = 0 + 4 = 4
  - T_{E_4} of event 4 = 3 + 2 = 5, 4 + 3 = 7 } max so,

T_{E_4} for 4 = 7

- T_{E_5} of event 5 = 4 + 6 = 10
- T_{E_6} of event 6 = 4 + 4 = 8
- T_{E_7} of event 7 = 7 + 4 = 11, 10 + 5 = 15 } max,

So, T_{E_7} = 15

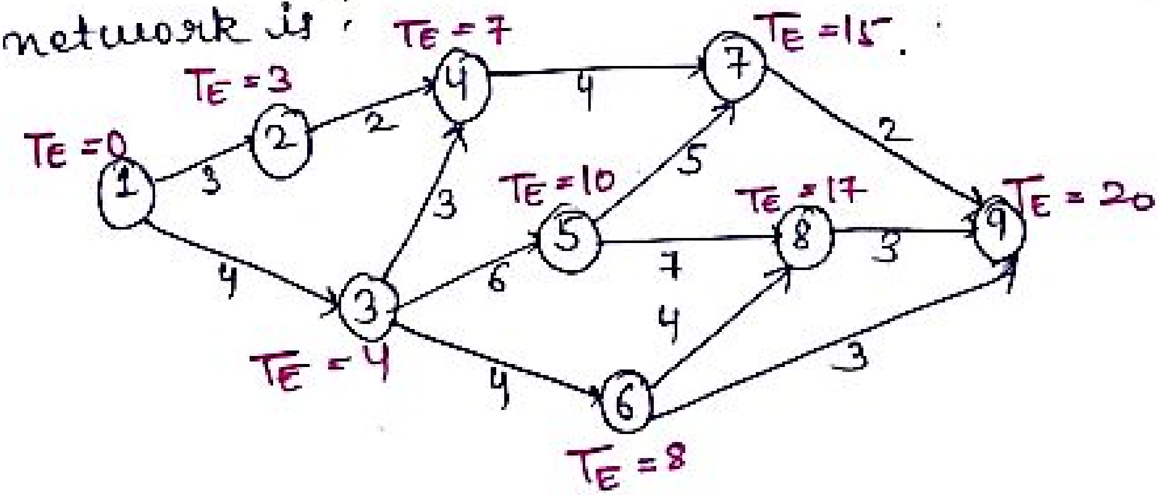
- T_{E_8} of event 8 = 10 + 7 = 17, 8 + 4 = 12 } max

T_{E_8} = 17

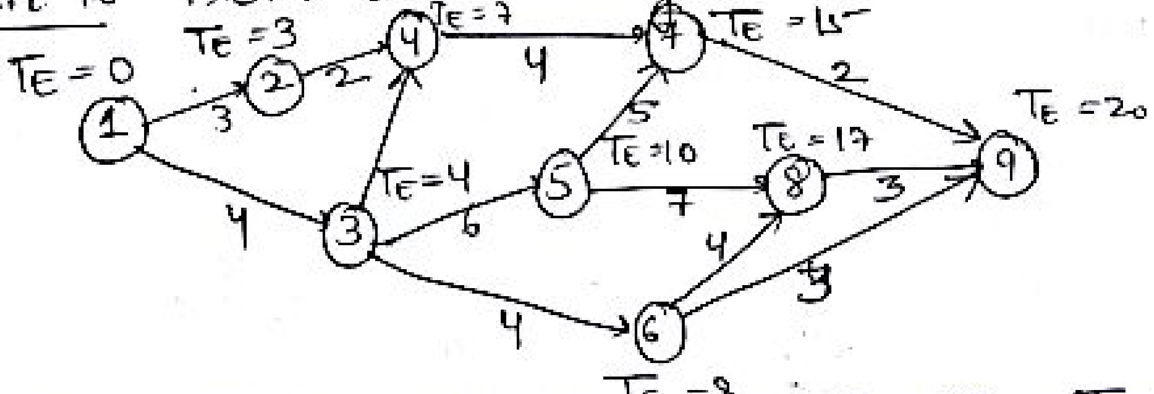
- T_{E_9} = 15 + 2 = 17, 17 + 3 = 20, 8 + 3 = 11 } = 20

T_{E_9} = 20.

So network is:



Question-16 From the data of Q-15, Find T_L.



Sol. Since T_S is not given, so T_L of 9 = T_E of 9.

$\therefore \quad T_{L_9} = 20$

$T_{L_8} = 20 - 3 = 17$

$T_{L_7} = 20 - 2 = 18$

$T_{L_6} = \left.\begin{matrix} 20 - 3 = 17 \\ 17 - 4 = 13 \end{matrix}\right\} \min$

$\therefore \quad T_{L_6} = 13$

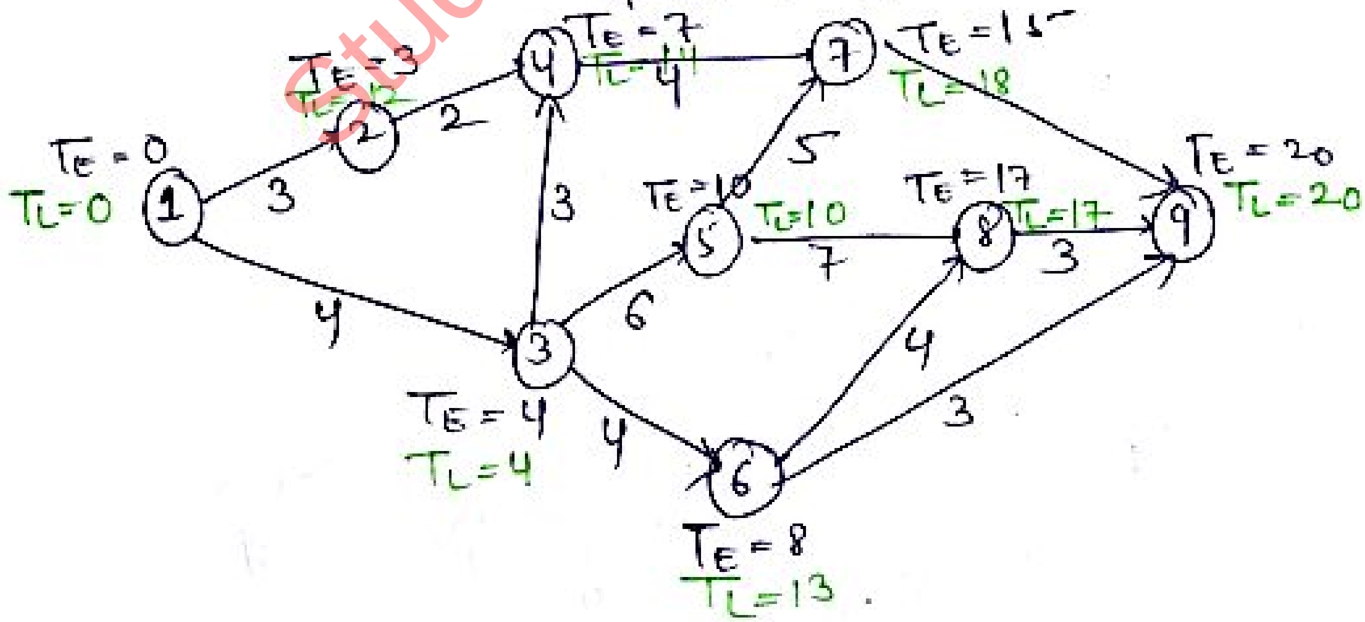
$T_{L_5} = \left.\begin{matrix} 17 - 7 = 10 \\ 18 - 5 = 13 \end{matrix}\right\} \min = 10$

$T_{L_4} = 18 - 4 = 14$

$T_{L_3} = \left.\begin{matrix} 10 - 6 = 4 \\ 13 - 4 = 9 \end{matrix}\right\} = 4$

$T_{L_2} = 14 - 2 = 12$

$T_{L_1} = \left.\begin{matrix} 12 - 3 = 9 \\ 4 - 4 = 0 \end{matrix}\right\} = 0.$



• **Float** :- The float is similar to slack in PERT. The difference is that float is associated with the activity times while slack is with event times.

Float denotes the flexibility range within which the activity start & finish times may fluctuate without affecting the total project duration.

There are 4 types of floats. They are :-

1. Total Float.
2. Free Float.
3. Independent Float
4. Interfering Float.

1. **Total Float** :- It is the time span by which the starting or finishing of an activity can be delayed without affecting the overall completion time of the project.

$$\text{Total Float} = F_T^{ij} = (T_L^j - T_E^i) - t^{ij}$$

i.e. $F_T = T_L^j - (T_E^i + t^{ij})$

also, $F_T = (T_L^j - t^{ij}) - T_E^i$

but $T_L^j - t^{ij} = LST$

and $T_E^i = EST$

$\therefore$ $\boxed{F_T = LST - EST}$

Similarly, $\boxed{F_T = LFT - EFT}$

2. **Free Float** :- Free float is that duration by which an activity can be delayed without delaying any other succeeding activity. Free float is a portion of the total float.

$$\text{Free float} = F_F^{ij} = T_E^j - (T_E^i + t^{ij})$$

but $T_E^i + t^{ij}$ is the EFT of activity i-j.

$\therefore$ F_F of i-j $= T_E^j - EFT$

also, $F_F = T_E^j - (T_E^i + t^{ij})$

$F_T = T_L^j - (T_E^i + t^{ij})$

$F_F = T_E^j - (T_L^j - F_T) = F_T - (T_E^j - T_E^i)$

$\therefore$ $\boxed{F_F = F_T - S_j}$

S_j = Head Event Slack.

3. Independent Float :- It is the excess time available if the preceding activity ends as late as possible & the succeeding activity starts as early as possible. This Independent float is a part of the free float.

$$F_{ID} = T_E^{i} - T_L^{i} - t_{ij}$$

$$= F_F + T_E^{i} - T_L^{i} = F_F - (T_L^{i} - T_E^{i})$$

$$\boxed{F_{ID} = F_F - S_i}$$

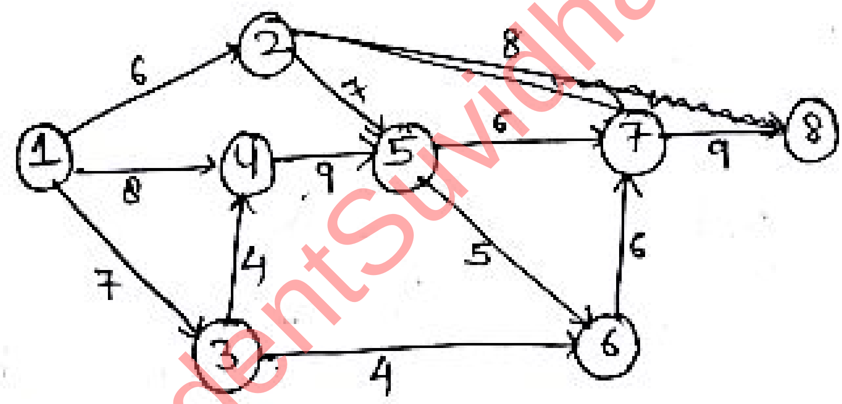
4. Interfering Float :- It is the difference between the total float & free float. This is equal to the head event slack. This is the potential downstream difference.

$$F_{IT} = F_T - F_F$$

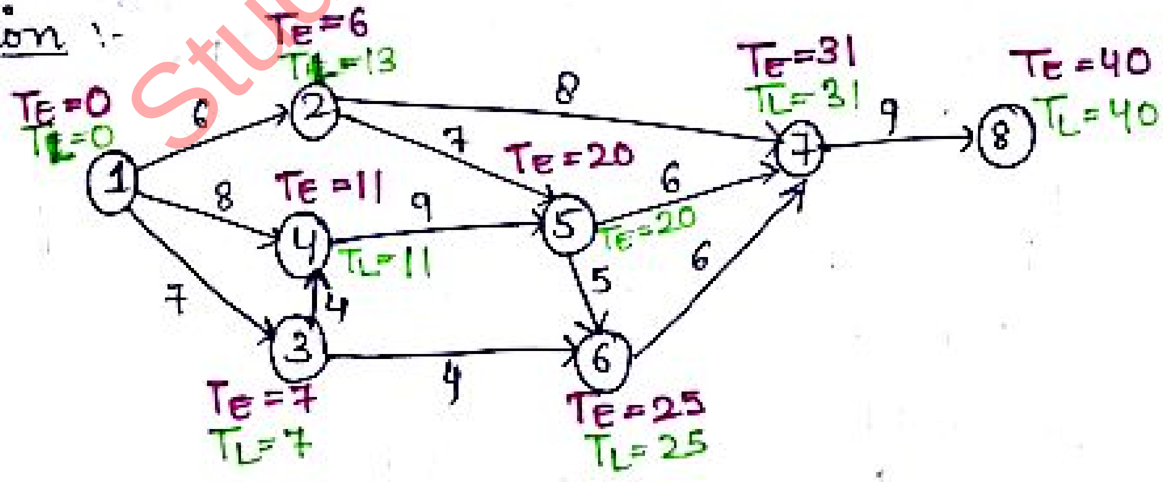
$$= F_T - (F_T - S_j)$$

$$\boxed{F_{IT} = S_j = T.F - F.F}$$

Question 17. Find the floats of all the activities and the critical path of the network given below.

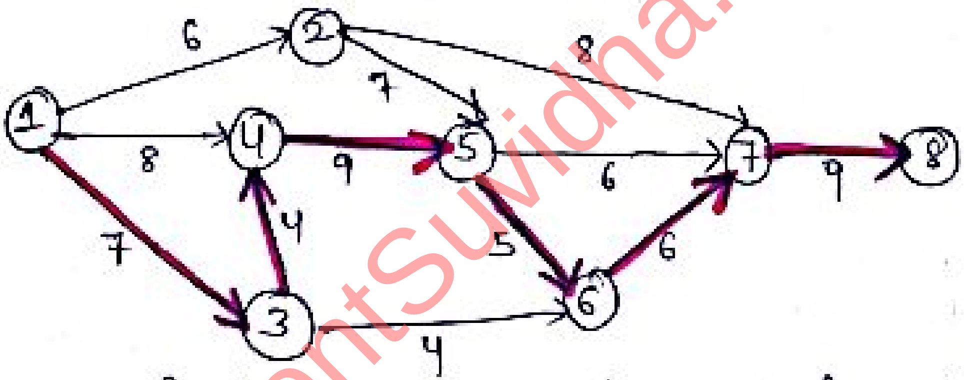


Solution :-



Activity	Duration	Tail Event		Head Event		Activity Times				Floats			
		T_E^i	T_L^i	T_E^j	T_L^j	EST	EFT	LST	LFT	T.F	F.F	Ind F	Int F
1-2	6	0	0	6	13	0	6	7	3	7	0	0	7
1-3	7	0	0	7	7	0	7	0	7	0	0	0	0
1-4	8	0	0	11	11	0	8	9	11	3	3	3	0
2-5	7	6	13	20	20	6	13	13	20	7	7	0	0
2-7	8	6	13	31	31	6	14	23	31	17	17	10	0
3-4	4	7	7	11	11	7	11	7	11	0	0	0	0
3-6	4	7	7	25	25	7	11	21	25	14	14	14	0
4-5	9	11	11	20	20	11	20	11	20	0	0	0	0
5-6	5	20	20	25	25	20	25	20	25	0	0	0	0
5-7	6	20	20	31	31	20	26	25	31	5	5	5	0
6-7	6	25	25	31	31	25	31	25	31	0	0	0	0
7-8	9	31	31	40	40	31	40	31	40	0	0	0	0

From the column of total float, we can see that activity 1-3, 3-4, 4-5, 5-6, 6-7, 7-8 have zero float, hence these activities lie on the critical path.



The Critical path has been darkened for ease.

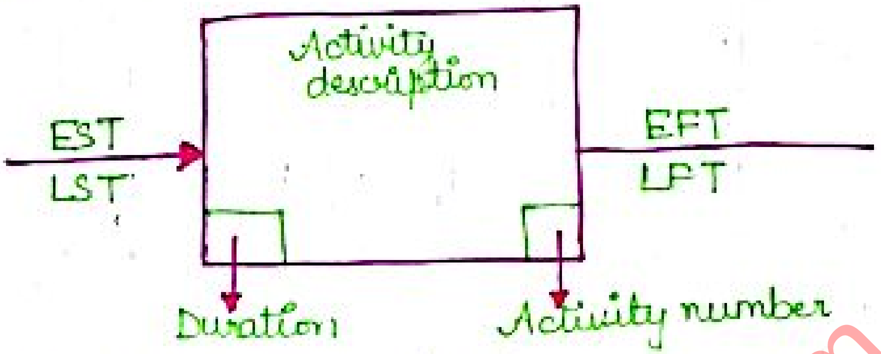
- **Criticality & Critical Activity :-**

1. **Subcritical Activities :-** When float is +ve, the activity needs normal attention but has some flexibility.
2. **Critical Activity :-** When float is zero, the activity needs extra attention. this has no freedom of action.
3. **Super Critical Activity :-** When float is −ve, such activities require very special attention & care.

3. A-O-N Networks (Activity on Node Networks)

These networks also known as Precedence networks. Here, nodes represent the activities & arrows their interdependence or precedence relationships

- **Representation of node in A-O-N network :-**



Nodes are usually represented by squares or rectangles but circles and other convenient geometrical shape can also be used.

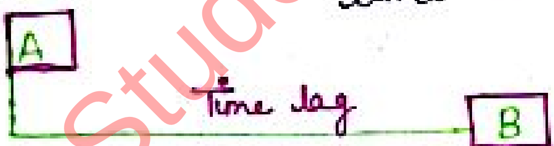
- **Logic of Precedence Diagram :-**

Four basic relationships are as follows :-

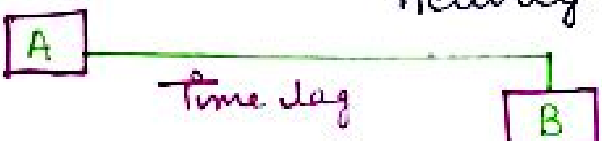
(i) Finish to start :-

Activity 'B' cannot start until Activity 'A' has been completed.

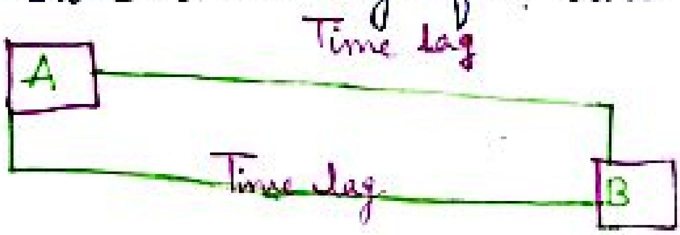
(ii) Start to Start :- Activity B can start at the same time as Activity A, but not before it.



(iii) Finish to Finish :- Activity B cannot be finished until Activity A has been finished

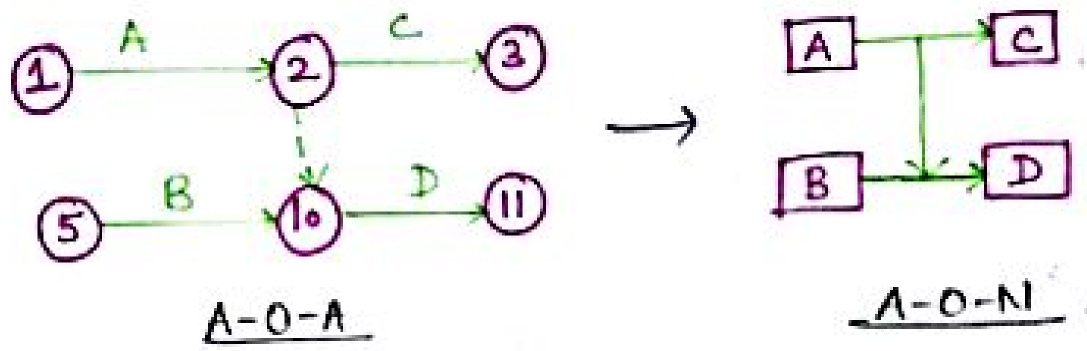


(iv) Start to Start combined with finish to finish :-
Activity B cannot be started & finished earlier than the stated time lag after the start & finish of 'A'



4. Activity on Arrow (A-OA) Networks :-

• Representation of relationships :-



In A-O-A diagram.,
Activity A & B go on concurrently
C succeeds A.
D succeeds B, &
D is dependent on A also.

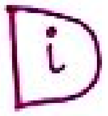
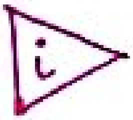
• Advantages of Precedence Networks (A-O-N)

1) They can show activities which should be allow to overlap each other or must be separated by a time delay.
2) It is self sufficient as it contains the necessary information regarding the project.
3) Revisions & modifications can be carried out easily without affecting most of the activities.
4) No arrow is required to show the logical sequence of activities in a precedence network.
5) It adopts simple notations similar to engineering flow charts & hence can be easily understood.

5. GERT (Graphical Evaluation and Review Technique) :-

GERT is the most extensively developed and widely studied system employing probabilistic networks. In GERT, nodes are considered to have an input & an output side, each characterised by certain logical relations with respect to connecting jobs. 2 types of output sides are used which determine the type of branching that occurs from the node. Thus, deterministic branching is used when all activities preceding from a node will be undertaken & probabilistic branching is used only one of several emanating activities is to be performed.

Symbols for the output sides of nodes are as follows:

Symbol	Explanation
	Deterministic branch node. With the release of node i, all jobs emanating from the node will be initiated.
	Probabilistic branching node. With the release of node i, one of the emanating activities will be initiated.

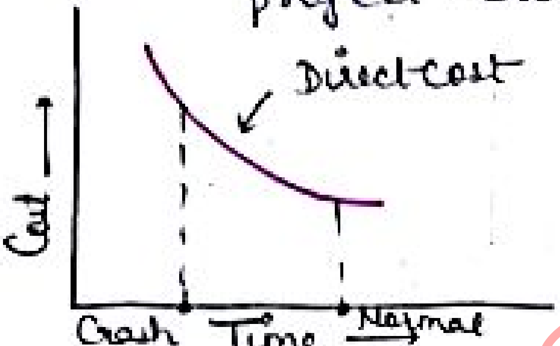
- **Advantages of GERT networks :-**

1) The GERT network is quite useful in showing inconsistencies, inefficiencies, redundancies in the procedure or policies in question.
2) In executing policy, the GERT network is quite useful in designing the information flow procedures.
3) It could also be quite useful in speeding up action at each branching node in the network.
4) Another potential use of GERT is in the planning & scheduling of the activities & are associated with the extremely expensive programs carried out in the hostile environment of space or on the ocean floor.

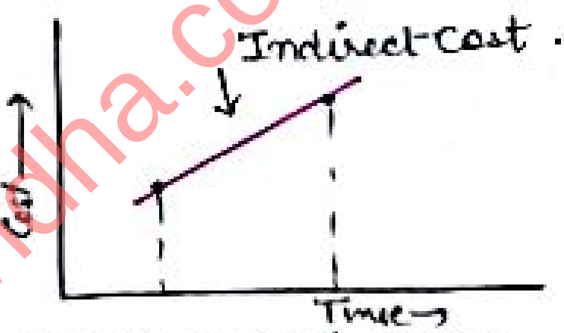
Cost Planning :-

In a project there may arise situations wherein it would be desirable to cut down the total project time. This naturally leads to cost considerations. Whenever a project is conceived, cost is incurred on the purchase of materials, plant & equipment, which form a major part of expenses in a project. It is also incurred on manpower who are engaged in converting these resources into assets. So, Costs are categorised as:-

1. **Direct Costs** :- The direct costs of a project are of major concern and it depends on the completion time of the project. But, the variation is not linear. Normally there is an optimum duration for a project for which the direct cost is minimum. During this time & the resources are optimally used. This duration of the project is called 'normal duration'. Direct costs are directly related to the project etc. material, labourers etc.



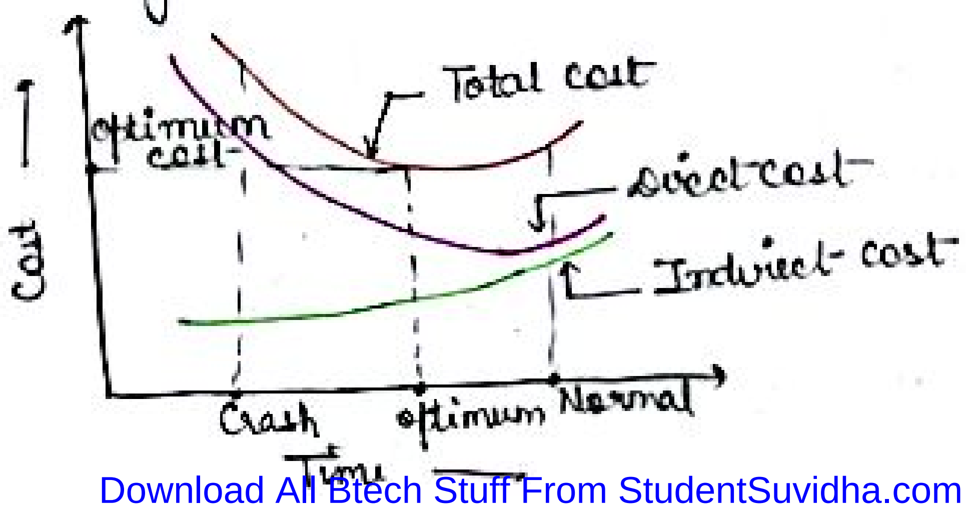
Direct Cost curve



Indirect Cost curve

2. **Indirect Costs** :- In addition to the cost of buying resources and the cost of operations involved, every project incurs some indirect costs in terms of overheads, administrative expenses, depreciation, loss of profit, loss of revenue and penalty. These indirect cost increase with duration.

3. **Total Cost or Total Project cost** :- The direct cost & indirect costs added together constitute the total project cost.



We shall now explain the following terms:

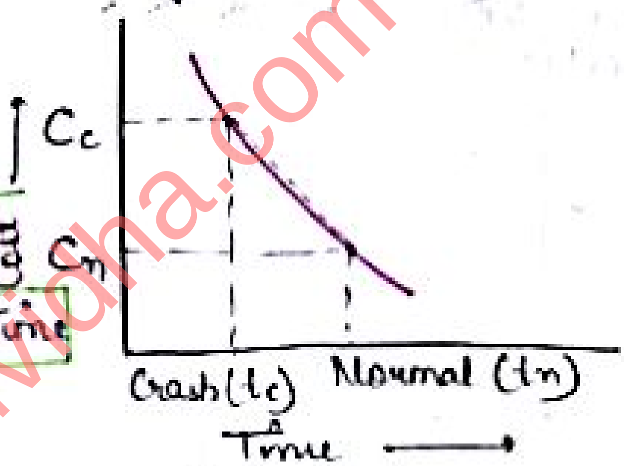
1. **Normal Time (t_n)** :- It is the standard time that an estimator would usually allow for an activity.

2. **Crash Time (t_c)** :- It is the min. possible time in which an activity can be completed by employing extra resources. It is that time beyond which the activity cannot be shortened by any amount of increase in resources.

3. **Normal cost (C_n)** :- This is the direct cost corresponding to the completion of the activity in the normal time duration.

4. **Crash Cost (C_c)** :- It is the direct cost corresponding to the completion of the activity within crash time.

5. **Cost Slope (C_s)** :-
The cost slope is defined as follows :-



Cost Slope

$$\text{Cost slope} = \frac{\text{Crash cost} - \text{Normal cost}}{\text{Normal Time} - \text{Crash Time}}$$

i.e

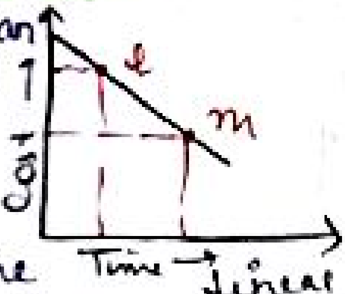
$$C_s = \frac{C_c - C_n}{t_n - t_c} = \frac{\Delta C}{\Delta t}$$

where, ΔC = Increase in cost.
Δt = Decrease in time.

- **Optimisation of cost through network** :-

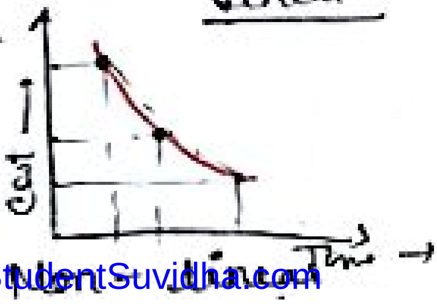
Time cost trade-off relationship :-

We assume that cost of executing an activity i-j increases linearly with the decrease in the duration as shown. Such a curve is called cost time trade-off curve. It exhibits the relation between the inc. in cost & dec. in time i.e trade off curve.



Linear

In many instances, such a trade off curve is not linear.



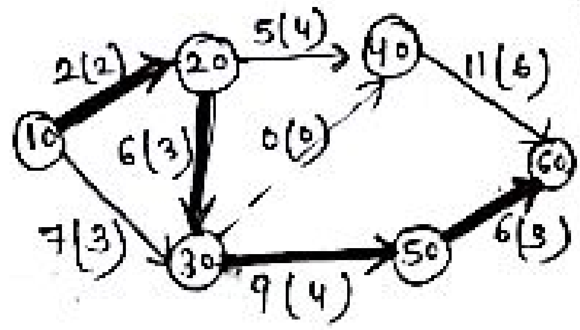
Non-linear

Steps involved in optimization of cost.

1. Analyse the past records & determine the direct cost versus time relationship for various activities.
2. The cost slopes for different activities are calculated & is arranged in the ascending order.
3. Compute the direct cost for the network with normal duration of activities.
4. The activities in the critical path are crashed as per ranking starting from the critical activity having the least cost slopes.
5. The crashing of critical activities is continued in ascending order of the slopes.
6. The parallel non-critical activities are crashed will have become critical by the reduction of critical path duration due to crashing in previous step.
7. The crashing is continued till a stage is reached beyond which no further crashing is possible.
8. At every stage of crashing, calculate Total Project Cost by adding Direct & Indirect costs.
9. The total cost duration curve is plotted.
10. The optimum duration corresponding to least project cost is obtained from the curve.

Problems :-

Question-18 Determine the min. cost & optimum duration for the project network. Indirect cost is Rs 80/day & Fig is :-
Critical Path is 10-20-30-50-60 = 23 days.

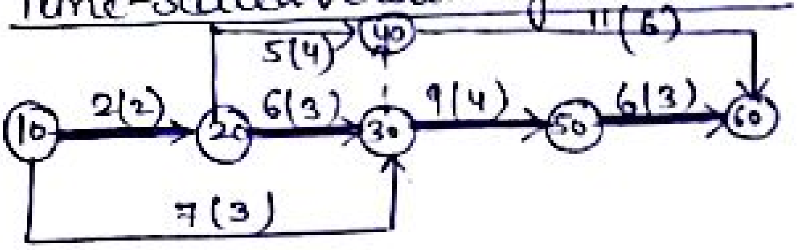


→ Critical path

Activity	t_n(day)	t_c(day)	C_n(Rs)	C_c(Rs)
10-20	2	2	1000	1000
10-30	7	3	500	900
20-30	6	3	300	420
20-40	5	4	200	250
30-40	0	0	0	0
30-50	9	4	600	900
40-60	11	6	600	1000
50-60	6	3	700	910

Solution - 18

Step-1 Time-scaled version of network



Step-2 Cost slopes

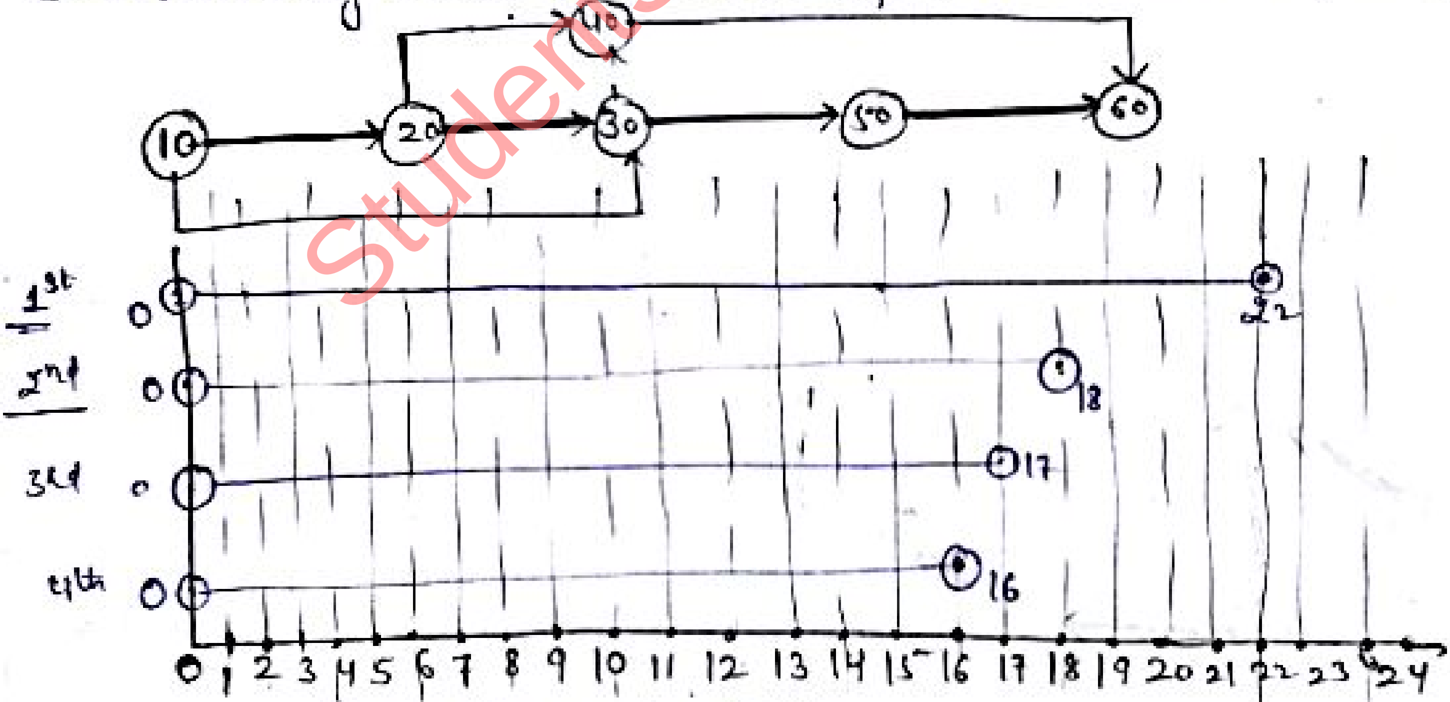
Activities	ΔC (Rs)	Δt (days)	Cost slope (Rs/day)
10-20	1000-1000 = 0	0	—
10-30	900-500 = 400	4	100
20-30	420-300 = 120	3	40
20-40	250-200 = 50	1	50
30-40	0	0	0
30-50	900-600 = 300	5	60
40-60	1000-600 = 400	5	80
50-60	910-700 = 210	3	70

Step-3 Normal duration of project = 2+6+9+6 = 23 days.

Total direct cost = 1000+500+300+200+600+600+700
= Rs 39·00

Step-4 First stage crashing or First Scheduling :-

Since, activity 20-30 has least slope, it is crashed by 1 day.



New duration = 22 days

Extra cost of crashing = 1×40 = 40 Rs.

Total direct cost = 2600 + 40 = Rs 2640.

Step-5 Second Stage Crashing

Activity 30-50 has got least cost slope, it is crashed by 4 days.

New duration = 18 days.

Extra cost of crashing = 240 Rs i.e (4×60 = 240)

Total DC = 2640 + 240 = 2880

Step-6 Third stage crashing → Activity 30-50 & 40-60 is crashed by 1 day

New duration = 17 days.

Extra cost = 60 + 80 = 140 Rs.

DC = 2880 + 140 = 3020.

Step-7 Fourth Stage crashing :-

Activity 50-60 & 40-60 are crashed by 1 day.

New duration = 16 days

Extra cost = 80 + 70 = 150 Rs.

DC = 3020 + 150 = Rs 3170.

∴

Project duration (days)	23	22	18	17	16
Direct cost (Rs)	2600	2640	2800	3020	3170
Indirect cost (Rs)	1840	1760	1440	1360	1280
Total cost (Rs)	4440	4400	4320	4380	4450

∴ Optimum Project duration is 18 days & Optimum cost = Rs 4320.

——— X ———

Line of Balance Technique :-

• Introduction :- Line of balance is a planning technique for repetitive work. In this technique, the required resources for each stage or operation are found out so that the subsequent stages of the activities are not interfered with and the target output can be achieved. The technique can be applied in repetitive works involving construction projects such as high rise building, tunnels etc.

The technique of LOB can be used for assembling, selecting, interpreting & presenting in graphical form, the essential factors involved in construction from initial stage to the completion time. This technique is highly effective in determining areas of weakness & focusing on items requiring immediate attention.

• LOB in Construction :- When LOB is used, 2 things are likely to be achieved :-

(i) Work will be completed as per the commitment made.

(ii) At each important stage, work will be completed only when needed. This means resources will not be spent until they are required.

• Scheduling with LOB :- The procedure is :-

(1) Prepare a logic diagram.

(2) Estimate the man hours required to complete each operation.

(3) Choose buffer times which will guard against the risk of interference between operations.

(4) Calculate the required output target to meet a given project completion date.

(5) Complete the LOB schedule.

(6) Examine the schedule & access possible alternatives to bring about a more 'balanced' schedule.

• Example :- An ancillary unit specializing in the manufacture of special purpose high pressure coolant pumps has entered with a contract with a large machine tool manufacturing company. The contract is as follows :-

Month	Planned operation	Cumulative
1	50	50
2	100	150
3	150	300
4	200	500
5	200	700
6	200	900
7	200	1100
8	150	1250
9	50	1300
10	50	1350

Acc. to this, the company has to supply 50 coolant in 1st month, 100 in 2nd & so on.
But the planned schedule could not be achieved.
So, after completion of 5 months, it was decided by ancillary unit to take stock of situation. This is called LOB study which is made at the beginning of 6th month. i.e

Month	Unit supplied	Cumulative
		0
1	0	50
2	50	150
3	100	300
4	150	450
5	150	

• Advantages of LOB technique :-

① It provides a very detailed picture of any repetitive project.

② Reduces the amount of network planning & scheduling since only one network is used for each type of unit.

③ Provides a simple & effective tool for programming the ordering & delivery of materials & their incorporation into the construction.

④ By monitoring progress, early corrective action can be taken.

—x—

Resource Allocation through Network Techniques :-

A resource is a physical variable quantity such as manpower, material, money, equipment, time or space, which are required for carrying out a project.

For completion of projects on time & within the estimated cost, coordination alone is not enough. Proper allocation & utilisation of resources are essential. Unless resources are not made available in right time & right quantity, work cannot be proceed. Assigning the resources along the various activities in appropriate quantity or number is called Resource allocation.

The resource allocation can be done in 2 ways :-

1. **Resource Smoothing :-** If duration of completion of project is the constraints then resource smoothing should be applied without changing the total project duration.

The periods of min. demand for resources are located & the activities are shifted according to the float availability & requirement of resources. Thus, the intelligent utilisation of floats can smoothen the demand of resources to the max. possible extent. This type of resource allocation is called resource smoothing.

2. **Resource Levelling :-** Here, whenever the availability of resources become less than its max. requirement, the only alternative is to delay the activity having larger float. In case, 2 or more activities require same amount of resources, the activity with min. duration is choosen for resource allocation.

Objectives of Resource Allocation :-

1. The completion of project on time and within the estimated cost.
2. Resources are adequate & are being used at all times & they do not remain idle at any time.
3. Advanced knowledge of resources & their conflicts.
4. Reduce the frequent variation in resource requirement.

Criteria of Resource Allocation :-

(1) Order or Criticality. (the lower the float, more is criticality & higher priority it deserve).

(2) When 2 or more activities are equally critical, allocate the resources to an activity which involves more quantum of work & in turn needs more of over all resources.

(3) By chance, if there is a tie in this stage, the activity requiring larger crew size may be given more priority. This means that attempt is made to prepare a schedule of activities at the Earliest start within the available resources.

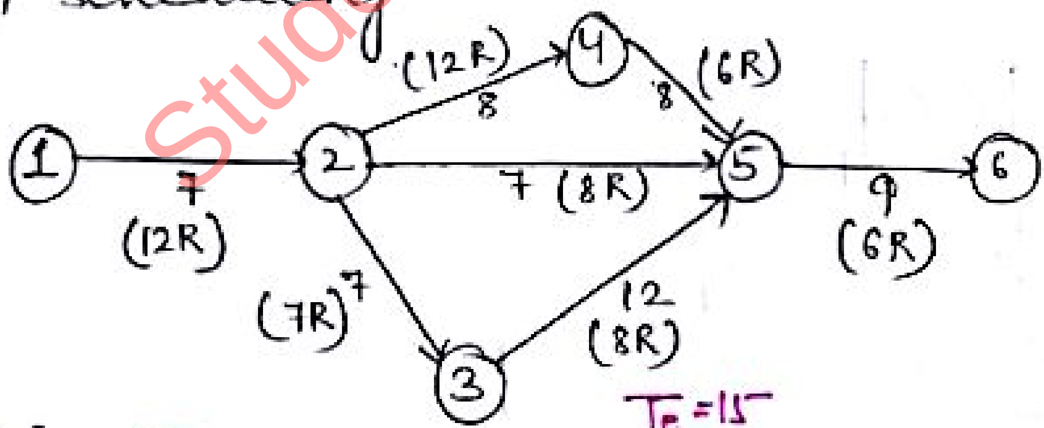
Steps involved in Resource Allocation :-

(1) Use time-scale version of the given network.

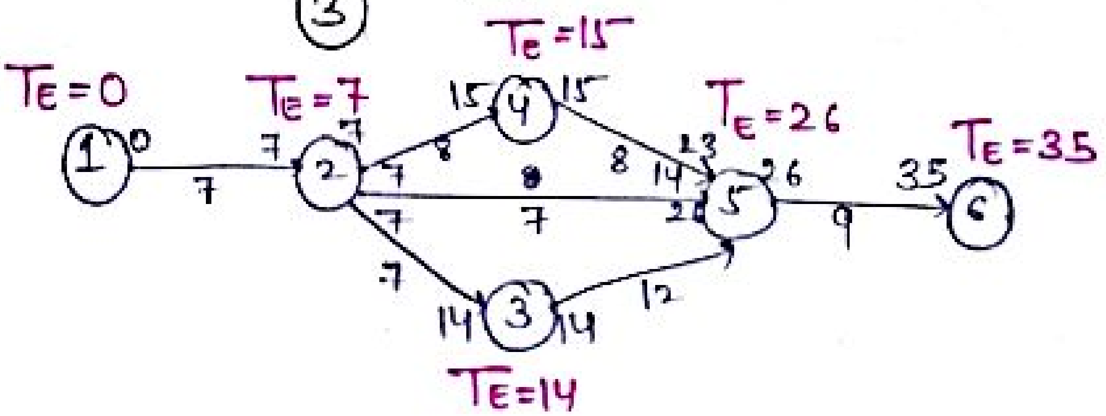
(2) The critical path should be shown along the horizontal line.

(3) Events entered in the time-scale version either at their EST or LST.

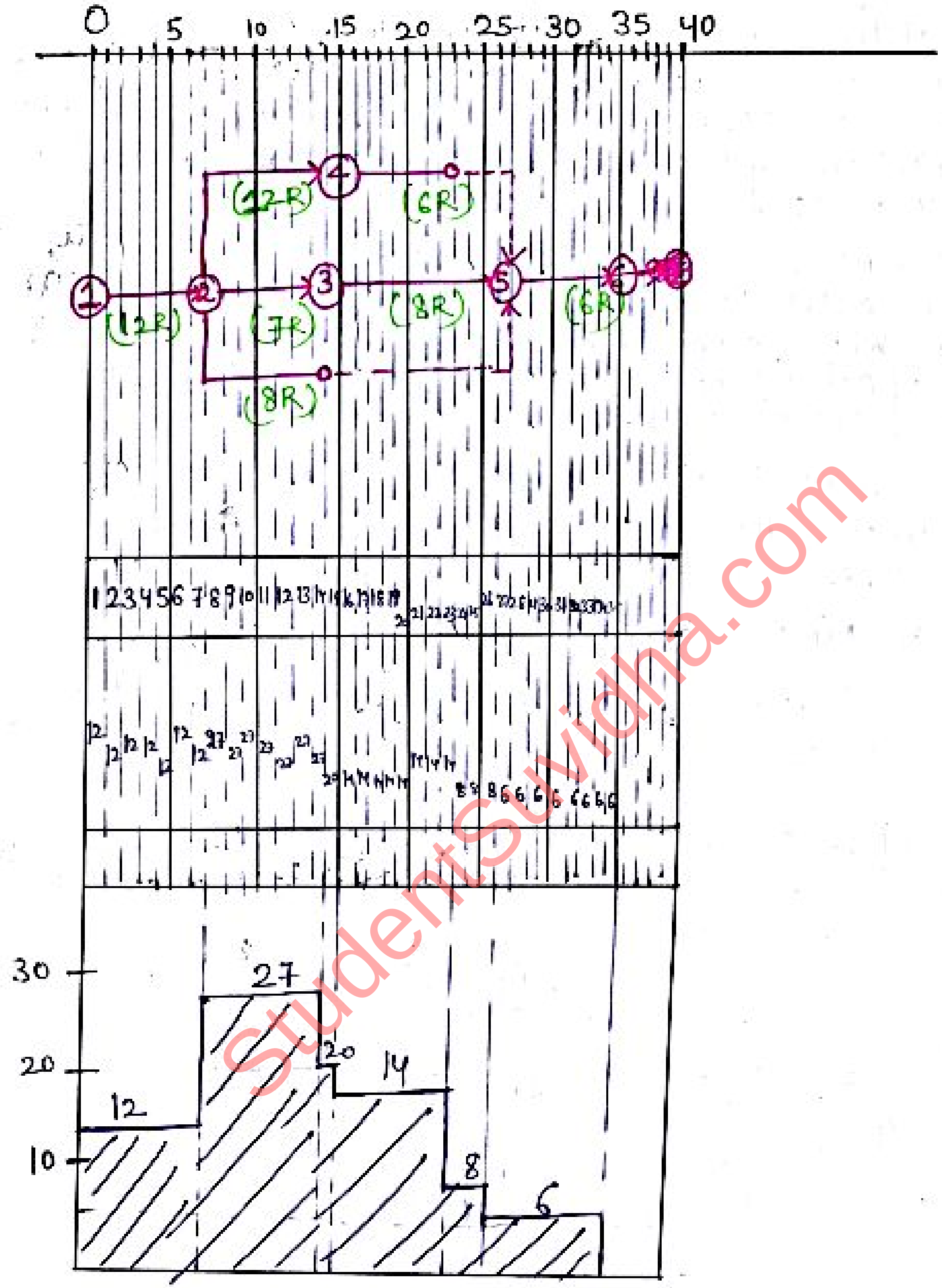
Question-19 :- Consider the network shown below & do the resource allocation i.e EST scheduling & LST scheduling.



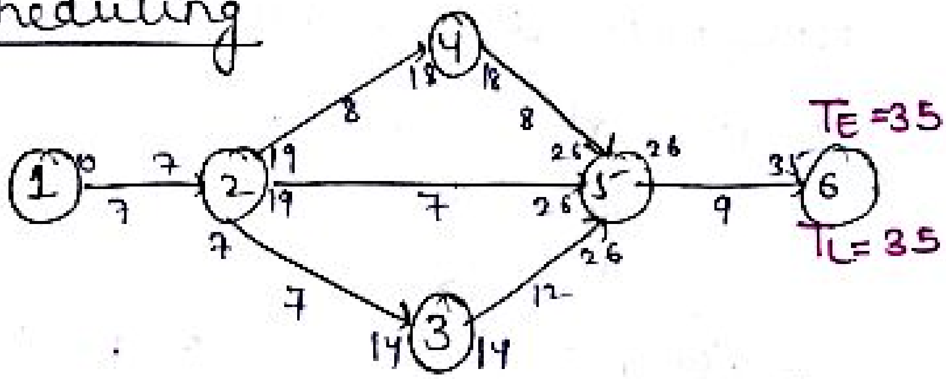
Solution.

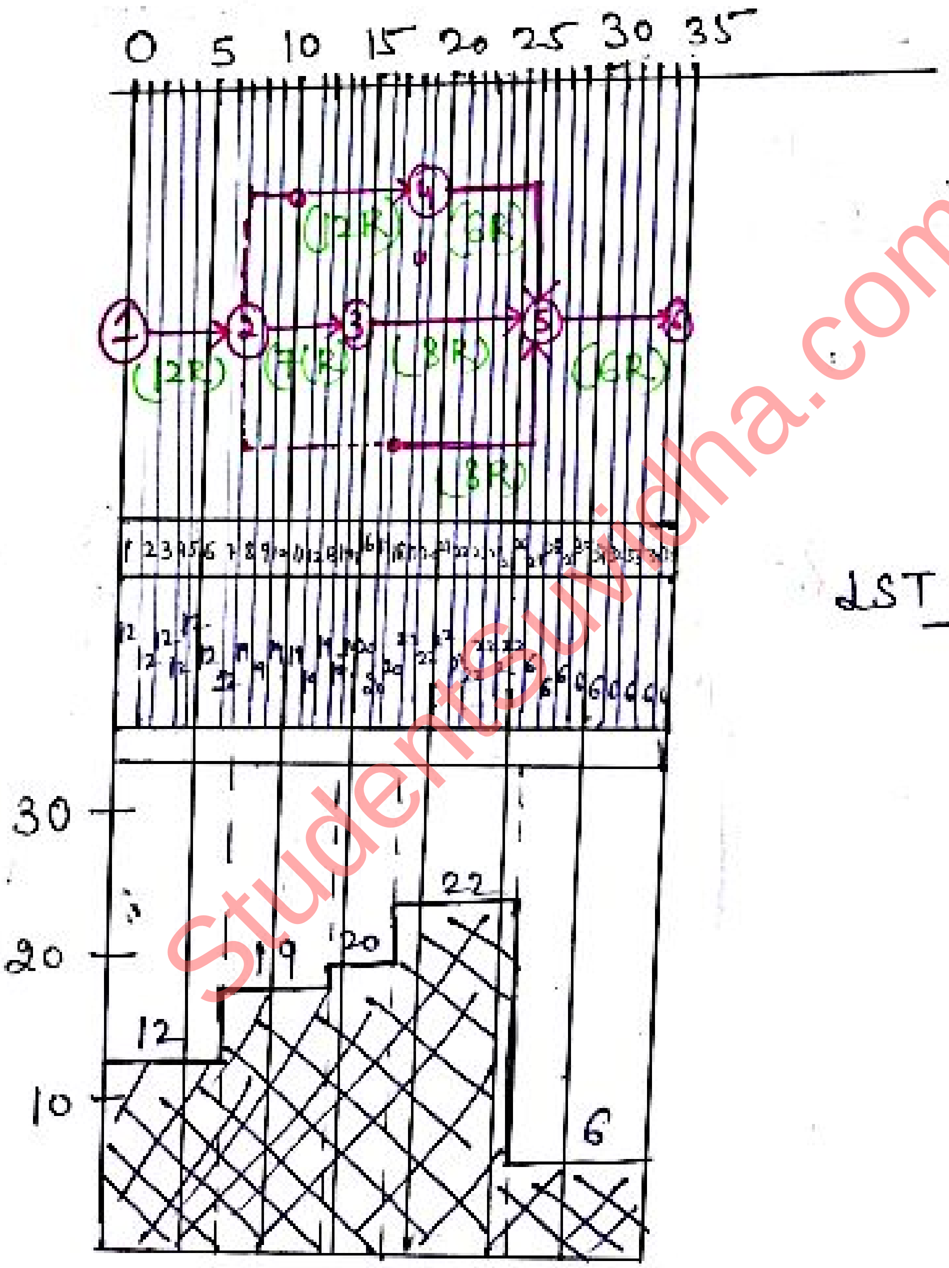


EST scheduling



- LST Scheduling





LST Scheduling -

- **Effective Force Ratio & Idle Force Ratio :-**

Effective Force Ratio (EFR)

$$= \frac{\text{Effective force}}{\text{Total effective area}} \times 100$$

$$= \frac{\text{Area of shaded portion EST schedule}}{(27 \times 35)} \times 100$$

$$= \frac{483}{945} \times 100$$

EFR = 51.11%

Idle Force Ratio (IFR) = 100 − EFR

= 100 − 51.11

IFR = 48.89%