CONSTRUCTION MANAGEMENT

Notes by-

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Project Cost : = Material cost + Construction cost.

Material cost can be minimize by providing optimum structural dimensions.

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* PERT :- (Project/ Programme Evaluation & Review Technique)

US Navy concered with control of contract for missile programme. This project ~~indt~~ include research & development work. Since such projects are never constructed in the past; neither cost nor time could be accurately estimated. ∴ completion time (Duration) of project is calculated by probability.

Contractors were asked to complete their time requirements on three time estimates - Optimistic time
Pessimistic Time
Most likely times.

These estimates are then mathematically assessed to determine completion time & the procedure is known as PERT.

Thus PERT system involves a probabilistic approach & it is best suited to research & developement work in which major uncertainties exists.

* CPM : Critical Path Mtd. / PPS : Project Planning & Scheduling :-

In other case, E.I. du Pont de Nemours company of Germany was constructing major chemical plants in America. The projects time & cost can be accurately estimated by experience of constructing such projects in the past. This method was originally developed & known as Project Planning & scheduling (PPS) & later on known as Critical Path Method. (CPM). CPM involves deterministic approach & is used in repetative projects.

* Advantages of CPM/PERT Network :-

CPM & PERT network are very powerful tools & ~~felici~~ facilitate the work of mgt. in the various phases of the project by following ways :-

① Planning Phase
② organizing phase
③ scheduling phase
④ controlling & Monimitoring phase
⑤ Evaluating Phase

Phases of a Project → controlling (POSCE) or (POSDC)
* Directing

① Planning Phase:- "Planning" is the process of choosing a particular method & order of work to be adopted for project from all the various ways & sequence in which it could be done. The sequence of steps read. to achieve the "optimum result" is the proper plan for the works & is shown schematically on network diagram.

Furthermore; it permits the ready evaluation & comparison of alternative works & helps in choosing the best plan based on min. cost & min. time.

② Organizing Phase:- [To give contract to best suited contractor]

It helps in awarding the contract to the best & efficient contractor because the network of the project furnished by the contractor along with the tender is the mirror image of resource capacity of the contractor & the methodology of the project.

[Men, Material, Machinary & Money - 4M ⇒ Resources]

③ Scheduling Phase:- [Determination of various Times]

Scheduling is the determination of timing of operations, of the project, which helps in preparing various "Calenders" as -

(4M) RESOURCES

① Material calender: From starting to end of project, the "delivery time" of material used in project are clearly mentioned on the material calender.

② Equipment Calender:- Type, quantity & duration of equipments needed are mentioned on equipment calender datewise.

③ Labour Calender: Type (skilled - semi-unskilled), number of labour needed & period in which they needed are mentioned in labour calender.

④ Finance calender:- The extent of finance needed for payment of labour, material, equipment are mentioned in finance calender.

⑤ Activity Time Calender:- The starting & finishing date of each activity is mentioned on Activity-Time calender. Thus by this calender completion date of projects can be calculated. It also gives a picture of ~~CPM~~ "Critical path" of project & the effect of any delay in const" activities on projects time.

④ Controlling & Monitoring Phase:-

Network facilitates in controlling the execution of the project activities to ensure timely completion of project through periodical reviewing & applying corrective measures.

⑤ Evaluating Phase:-

After completion of project, the planned & actual time & cost compared, the reasons for deviation are analysed & specific difficulties while execution are highlighted. These reports are made available to execution for use in future projects.

[For eg:- "Evaluation Report of DSK-Sai-Tarang"]

* Elements of Network:-

① Activity:- An activity is the performance of specific task such as bending of reinforcement, placing of concrete etc. It requires "time & resource" for its completion & represented by arrow. The length, shape & orientation of arrow has its significance.

eg:- concreting →

cleaning →

② Event:- (NODE) Event or node represents instant in time when certain activity has been "started or completed."

(OR)

Event describes start or completion of task/activity. It is represented by circle.

* Begining of an activity : Tail event : or I-node.
Completion of an activity : Head event or J node.

While drawing network, it is assumed that:-

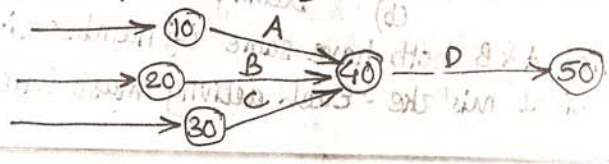
① Time flows from left to right.
② All events are numbered such that, J node number has a higher value than I node number. as shown -

eg:- (10) —Activity→ (20)
I Node J Node.

③ * Properties of an event:-

① Event is not completed until - all the activities flowing into it are not completed.
② No subsequent activity can start until its tail event is reached.

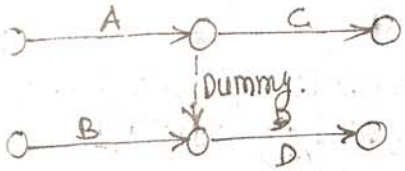
eg:



Basic Philosophy :-

from fig: 3 activities, A, B & C flowing into event No. 40. So event 40 will appear only when all 3 activities are completed in all respect – i.e. occurance time of event will be max. time of various paths directed inwardly to that event. & as soon event 40 will appear, the subsequent activity 'D' will start.

⑤ Dummy:- A dummy is an artificial activity represented on the arrow diagram by dotted lined arrow which indicates that an activity ~~flow~~ following the dummy cannot be started until the activity or activities preceeding the dummy are completed. A dummy activity does not require any time & resource

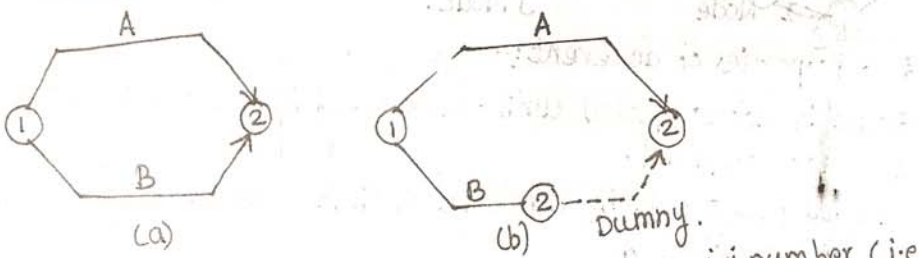


As shown in fig. 'D' cannot be started until both A & B are completed where as 'C' ~~can~~ depends only on 'A'. The purpose of dummy is to only provide the logical relationship & its use becomes essential when the activities like A & B ends at diff. position & D depends on both A & B.

The dummy brings the two ends (which are apart) together at one point from where 'D' can spring up.

Sometimes the dummy is used to identify the activity by its own i-j number.

* Mistake (Grammatical) in Network:-



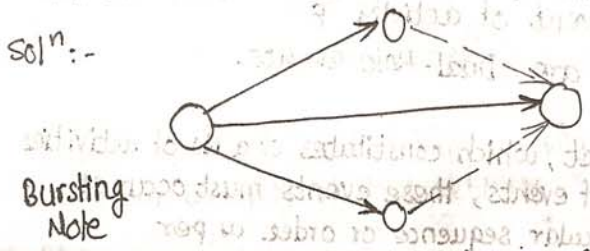
In fig. (a), two activities A & B both have same i-j number (i.e. 1&2) which makes a grammatical mistake - Each activity must have its

own identification. It has been reflected in fig (b) by using a dummy activity.

SG

Pbo:- There are 3 parallel paths in a part of a network bet^n a bursting node & the next merging node with only one activity in each path. Find the min. number of dummy arrows & draw the network.

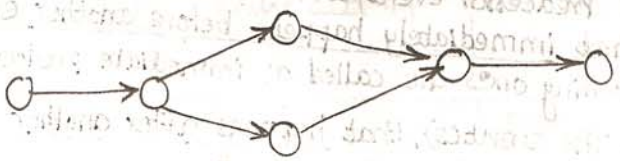
Soln:-



Ans:- Min 2 arrows (i.e. 3-1) are reqd. as shown.
Dummy.

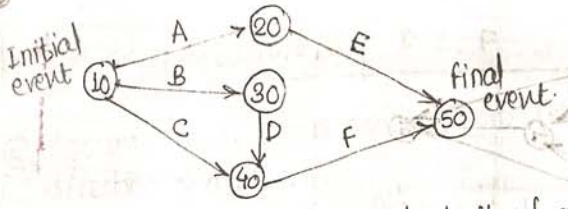
④ Network:- Network is an arrow diagram (consisting only arrows & circles) drawn to represent the inter-relationship & sequence of all the reqd. construction activities of a project.

for eg:-



* Rules of Network:-

① In a network, there are 3 types of events - ① Initial event
② Final event
③ Dual Role event



① Initial Event:- It has only tails of arrows & shows begining of project. There must be only one such initial event in a network. In fig. event (10) is initial event as, it has only tails of activities A, B & C.

② Final event:- It has only heads of arrows & shows end of project. There must be only one such final event in a network. Event (50) is final event, it has only heads of arrow of activities E & F.

③ Dual Role Event:- Except initial & final events; all intermediate events of project are known as dual-Role events. They must have atleast 1 tail & 1 head.

Dual Role events are head to some activity & tail to other activity, hence they are known as "dual Role" events.

Event (20) → head event of activity A & tail event of activity E

Event (30) ⇒ Head event of activity B & Tail event of activity D

Event (40) → Head event of activity C & D & Tail event of activity F

∴ Event (20), (30), (40) are Dual-Role events.

The completion of a project, which constitutes of a No. of activities passes through a number of events, these events must occur at definite time & in a particular sequence or order. as per sequence or order, events may be specified as-

① Immediate ~~Predecessor~~ Predecessor events
② Predecessor events
③ Immediate Successor events
④ Successor events.

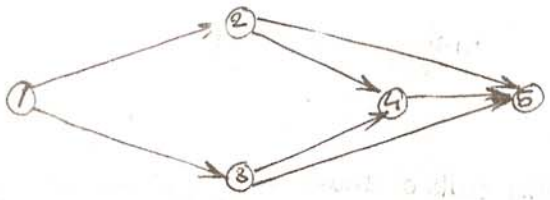
① Predecessor Events:- The event(s) that happens before another event are called as Predcessor event to that event.

The event(s) that immediately happens before another event without any intervening ones are called as immediate predecessor events

② Successor Event:- The event(s), that happens after another event are called as successor event to that event.

The events, that immediately happens after another event without any intervening ones are called as immediate successor events.

eg:-



Event	Predecessor Event	Immediately Predecessor event	Successor event	Immediately Successor event.
1	—	—	2, 3, 4, 5	2, 3
2	1	1	4, 5	4, 5
3	1	1	4, 5	4, 5
4	1, 2, 3	2, 3	5	5
5	1, 2, 3, 4	2, 3, 4	—	—

③ similar to an event activity may be classified as — or to be performed ④

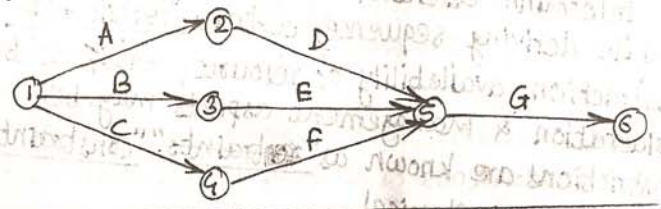
1] Predecessor activity: An activity that happens before other activity (s); is known as predecessor activity of that activity.

2] Immediate predecessor activity:- An activity that is reqd. to perform immediately before the activity without any intervening onces are called as Immediate predecessor activity to that activity.

3] Successor activity:- The An activity that is reqd. to perform after completion of an other activity is known as successor activity.

4] Immediate successor activity:- An activity reqd. to perform immediately after the completion of other activity is known as immediate successor activity of that activity.

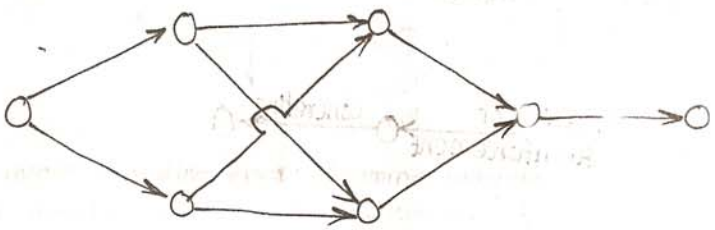
For eg:-



Activity	Predecessor activity	Immediate Prede-cessor activity	Successor activity	Immediately successor activity.
A (1-2)	—	—	D (2-5), G	D
B (1-3)	—	—	E, G	E
C (1-4)	—	—	F, G	F
D (2-5)	A	A	G	G
E (3-5)	B	B	G	G
F (4-5)	C	C	G	G
G (5-6)	A, B, C, D, E, F	D, E, F	—	—

④ Assume that time flows from left to right, which is given by direction of arrows.

⑤ Arrows should normally not cross each othe. If the situation is unfavorable, the length of arrow should be broken to bridge over the other as shown -



⑥ It is essential to number the events in a discrete manner. Every activity in a network is identified by its own i-node & j-node number. The No's may be arranged as -

Regular fashion – Viz 1, 2, 3, ...
skip manner – Viz. – 10, 20, 30, ...
Random manner – Viz – 1, 3, 17, ...

$j > i$

But keep in mind that j node should be higher than i-node.

Or use Fulkerson Rule of Node Numbering.

Constraints:-

When list of activities of a project has been prepared, the next step is to determine essential relationship among these activities. While deriving sequence, certain "restrictions" w.r.t. physical construction, availability of resource, equipment, labour, safety consideration & management aspects may be imposed. These restrictions are known as "~~constraints~~." "constraints."

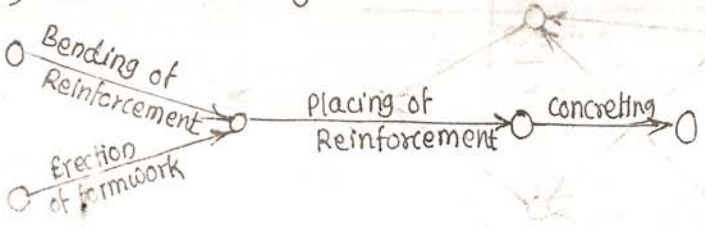
There are 5 constraints – ① Physical
② Safety
③ Resource
④ Crew
⑤ Management.

① Physical constraint:-

There may be some constraint for the start of particular activity & particular activity itself may be restriction for the start of its related activity. Following 3 questions are put to each activity in the list & answers obtained determines the relationship & sequence among the activities.

a) What activities must precede this activity?
b) What activities must succed this activity?
c) What activities may be done parallel or concurrent to this activity?

for eg:- Placing of reinforcement for roof slab cannot be started until bending of reinforcement & erection of formwork are completed, & as soon as placing of reinforcement is finished; concreting is followed.



② Safety constraint:-

Safety constraints are required for the sequential seperation of activities which could be otherwise be concurrent.

For eg:- Ground Floor concreting operation may be prohibited while steel formwork is being assembled immediately overhead.

③ Resource Constraint:- [E4M- Men, Machinary, Money, Materials]

Resource constraints such as non availability of M, due to any reason.

⑤ Crew consbaint:-

eg: Welding specialist crew may be hard to obtain & all welding operation may have to be done in sequence with a small crew available at the disposal, whereas they could otherwise done concurrently.

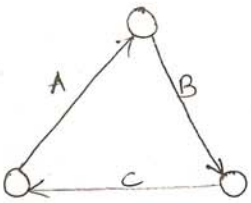
⑥ Management constraint:- Sequence of activity is controlled by mgt. decision

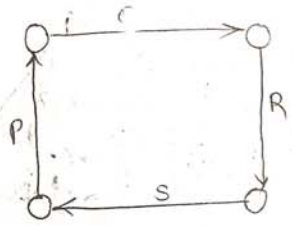
Crew constraint is the reflection of resource capacity of a contractor, & it differ from contractor to contractor.

* Errors in Network:-

Sometimes causes of error:- ① Constructional mistakes → Looping error, Dangling error
② conceptual mistakes. → Wagon wheel error.

① Looping error:-

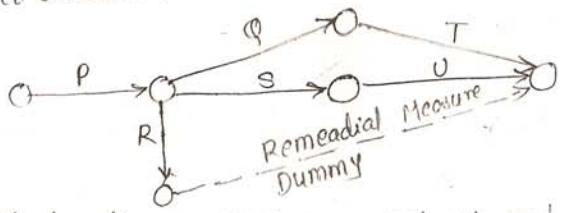




Sometimes "impossible" situation in the net ork logic may arise [What a contrast sentence"!] as shown in fig; because of constructional mistake in the direction of arrow.

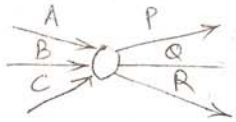
Such a network is known as looping error.

② Dangling error:- Project will be completed only when all its activities are completed. But in the fig, duration of activity R does not affect the project duration, such a error is known as dangling error.



To avoid dangling error: Examine network such that, except in case of final events, all other events should have one preceed immediate predecessor activity & immediate successor activity. as shown

③ Wagon wheel error :-



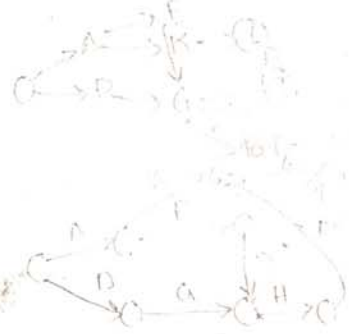
From fig; it is concluded that -

P, Q, R can not be started before A, B, C all are completed.

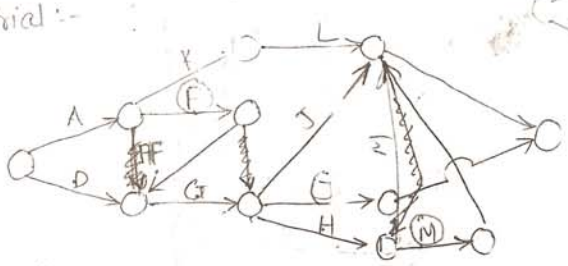
But in reality (Not ideal) this ~~many~~ may not be true. There may not be constructional error but may be conceptional error, that - activities P Q R are independent on any one activity A or B or C.

Prob:- Draw the arrow diagram for the following situation

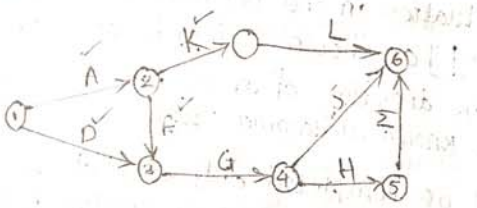
(a) A & D starts at the same time.
(b) F follows A
(c) K follows A but precedes L
(d) G follows F but precedes J
(e) H follows F but precedes H
(f) M follows H but precedes L
(g) J & L terminates at the time.



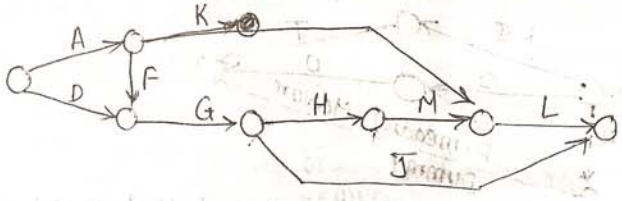
soln :- 1st trial :-



2nd Trial



soln :-



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* Critical Path analysis:

Each activity connecting i node event with j node event requires a duration time for completion.

In CPM: Duration is determinstic [Accurately determinate]
In PERT: Duration is probabilistic

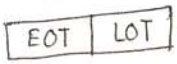
An event can not be completed untill & unless all the activities flowing in to it have been completed. Therefore the time at which an event occurs is max. time of various paths directed towards that event.

"Total Project Time": It is the max. time among all paths originating from initial event & terminating at final event, indicating the completion of the project.

The path of longest duration is defined as "Critical Path" & the activities lying in this path are called as "Critical Activities".

Any delay in critical activity will result in consequent delay in the completion of entire project. The project cannot be completed earlier than this project time given by critical path. So the time taken by Critical path is the "shortest (min.) possible time" to complete the project.

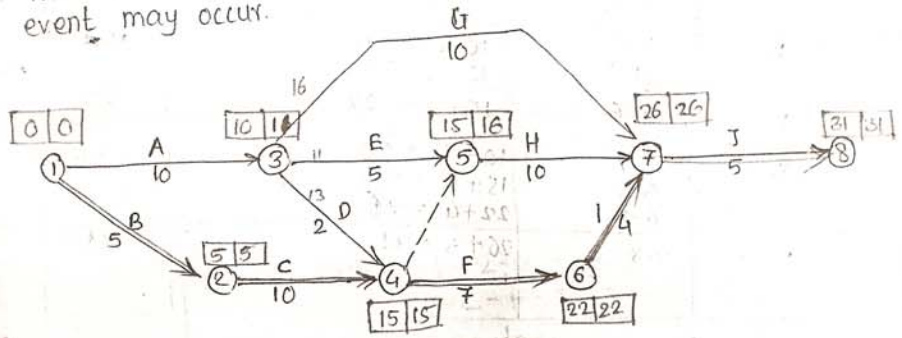
The project time is calculated by the event time mentioned in the time box of each event on the network. Time box consist of two compartments. The value in the left compartment stands for EOT [Earliest Occurance Time] & value in Right compartment stands for LOT [Latest Occurance Time]



← Time box.

Calculation of EOT:- [Farliest Occurance Time]

① Begining at the initial event, calling it "ZERO" time.
② Proceed in each event in sequence & calculate EOT at which th event may occur.



Event ① ⇒ Initial Event ∴ Zero time

Event ③ ⇒ ECT = 10 days.
i.e. EOT of (1) + Time taken by activity 1-3 (or A).

Event ② ⇒ EOT = 0 + 5 = 5 days.

Event ④ ⇒ EOT ⇒ Two paths :- 1-3-4 &
1-2-4.

∴ Total duration of 1-3-4 = 10+2 = 12 days
Total duration of 1-2-4 = 5+10 = 15 days. → Max. time of all paths directed towards ④.

∴ Event ④ will occur only when both paths are completed.

∴ Event ④ will be completed in 15 days.
i.e. The max. time of 2 paths directed towards event ④

This technique of determining the EOT is known as "Method of forward pass"

In forward pass, calculation must begin from initial event & must end at final event of the project :

$$(EOT)_j = (EOT)_i + t_{i-j}$$

i.e. EOT of succeeding event = EOT of preceeding event + Time bet event i & j
(j) (i) (i-j)

The chosen value of $(EOT)_j$ is max. from all calculations :

Total Project Time = EOT of final event

Table for calculation of EOT

Node No.	No. of path	(i-j) activity	$(ECT)_j = (ECT)_i + t_{i-j}$	EOT
1	—	—	—	0
2	1	1-2	0+5=5	5
3	1	1-3	0+10=10	10
4	2	3-4 2-4	10+2=12 5+10=15	15
5	2	3-5 4-5	10+5=15 15+0=15	15
6	1	4-6	15+7=22	22
7	3	3-7 5-7 6-7	10+10=20 15+10=25 22+4=26	26
8	1	7-8	26+5=31	31

Calculation of LOT (Latest Occurance Time)

"LOT is defined as the latest possible time at which an event can take place without upsetting the total project time calculated by method of forward pass."

LOT of the final event = EOT of final event
= Total project durat^n

∴ For calculating LOT; start from final event & move in backword direction by substracting the activity time from its j-node LOT value. This method is known as "backward pass".

LOT of all network is calculated & written in right compartment of time box.

$$\therefore (LOT)i = (LOT)j - ti\text{-}j \longrightarrow \text{Min. Time}$$

Node Number	No. of paths	Activities	LOT Calculat^n	LOT
8	—	—	31 - 0 = 31	31
7	1	7-8	31 - 5 = 26	26
6	1	6-7	26 - 4 = 22	22
5	1	5-7	26 - 10 = 16	16
4	2	4-6 4-5	22 - 7 = 16 16 - 0 = 16	16
3	3	3-7 3-5 3-4	26 - 10 = 16 16 - 5 = 11 15 - 2 = 13	11
2	1	2-4	15 - 10 = 5	5
1	2	1-3	11 - 10 = 1	0
		1-2	5 - 5 = 0 — Ans.	

All the nodes having same EOT & LOT value are identified as "Critical nodes" & the path connecting the critical nodes is known as "Critical Path".

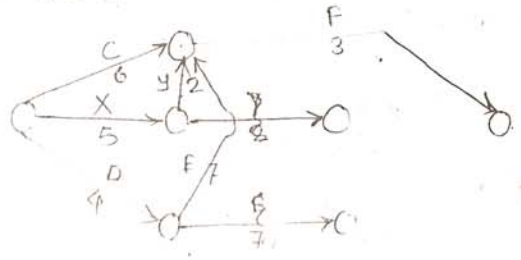
The No. of critical path may be one or more than one but time taken by each critical path will be the same & known as "project Time".

∴ Critical Path = 1-2-4-6-7-8
or B-C-F-I-J.
Project Time = 31 days ⇒ Ans.

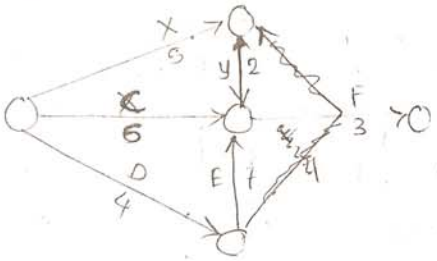
Pro: The activity data of a project is tabulated as below. If the project is to start on 1st Aug. 1994 (Wednesday) with 5 days work per week & with 15th & 29th August as holidays, prepare the CPM calender & forecast the date on which project will be completed.

Activity	Preceding Activity	Duration (Days)
X		5
Y		2
C		6
D	Y, C	4
E	X	7
F	X	3

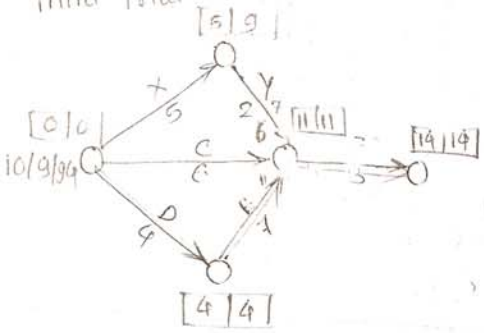
1st Trial :-



Second Trial



Third Trial :-



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Critical Path :- D-E-F
Project Duration = 14 days.

Starting date of project = 10/8/94 (Wednesday) - 8 AM

CPM calender :-

Aug. 94.

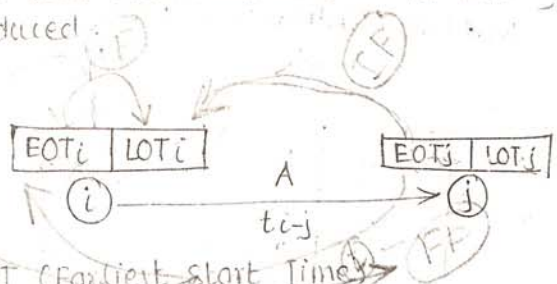
SUN	MON	TUE	WED	THU	FRI	SAT
-	1	2	3	4	5	6
7	8	9	10 (X) (C) (D)	11	12	13
14	15	16 (X) (C) (D)	17 E	18 (Y)	19	20
21	22 (X)	23 (E)	24	25	26 F	27
28	29	30 F	31			

∴ Project completion Date : 31/08/2004 → 5 pm. (Wed)

Activity	Duration	Scheduled start	Scheduled finish	Remark
X	5	10/8/94 (wed)	17/08/94 (wed)	-
Y	2	18/8/04 (Thu)	19/08/94 (Fri)	-
C	6	10/8/94 (wed)	18/08/94 (Thu)	-
D	4	10/8/94 (wed)	16/8/94 (tue)	Critical
E	7	17/8/94 (wed)	25/08/94 (Thu)	critical
F	3	26/8/94 (Fri)	31/08/94 (wed)	critical

Activity Times & Floats:-

With respect to start & finish of an activity, bet^n the bounds of limiting times (EOT & LOT), several terms for defining activity times can be introduced:-



① EST (Earliest Start Time):-

EST ⇒ Earliest possible time at which an activity can start.

$$(EST)_{i-j} = (EOT)_i \Longrightarrow \text{Forward Pass.}$$

② EFT (Earliest finish Time)

Earliest possible time at which activity can finish.

$$(EFT)_{i-j} = (ECT)_i + t_{i-j} \Rightarrow \text{Forward Pass}$$

③ Latest Start Time (LST):-

The latest start Time is the latest possible time by which an activity can start without any delay of project time forecast on the basis of EOT of final event.

$$(LST)_i = (LOT)_j - t_{i-j} \dots > \text{Backward Pass}$$

④ Latest finish Time (LFT):-

The latest finish time is the latest possible time that an activity can finish without any delay in completion of project

$$(LFT)_{i-j} = (LOT)_i \Longrightarrow \text{Backward Pass}$$

Floats:-

Float denotes the "flexibility" range within which the start time or finish time of an activity can fluctuate without affecting completion of project.

Types of float ① Total Float - Total float of an activity is the "excess of max. available time over the activity time".

"Activity complete होण्यासाठी आवश्यक असलेल्या वेळेव्यतिरिक्त जास्तीत जास्त राखून ठेवलेला वेळ"

$$(TF)_{i-j} = [(LOT)_j - (ECT)_i - t_{ij}$$
$$= LST - EST$$
$$= LFT - EFT$$

② Free Float (FF) :- Free float of an activity is the "excess of available time over the activity time when all jobs starts as early as possible"
~~Start and jobs starts as early as possible~~ Free float indicates that the use of this float does not affect the successiding activity.

$$(FF)i-j = [(EOT)j - (EOT)i] - tij$$

③ Independent Float (IF) : Independent float of an activity is the "excess of min. available time over activity time".
In some cases absorption of this float does not affects predecessor nor successor activity, That's why it is called as Independent.

$$(IF)i-j = [(EOT)j - (LOT)i] - ti-j$$

④ Interfering Float (INT F.) "It is the diff. bet° total float & Free float".
It is equal to head event slack

~~(INF)~~. $(INT.F)i-j = [(LOT)j - (EOT)j]$
$= (TF)i-j - (FF)i-j$

When all the floats are zero, such activity is known as critical activity & path of such critical activity is "Critical Path".

* Slack :- "Slack denotes flexibility range within which an event can occur"
∴ Slack of an event = (LOT - EOT)

Any How : Remember.

Durat° ti-j ②	EOT ③	LOT ④	EST ⑤	EFT ⑥	LST ⑦	LFT ⑧	TF ⑨	FF ⑩	IF ⑪	INT.F ⑫	Slack ⑬
	EOTj+ ti-j ⑤+②	LOTj - tij ④-②	EOTi ③	EOTi+ ti-j ⑤+②	(LOT)j - tij ④j-②	(LOT)j ④j	⑦-⑤ ⑧-⑥	③j-⑤i - ②	④j-④i -②	⑨ - ⑩	④-③

TF :- Single Time box (Same)
FF : E2 - d
IF : दोन्ही आतील -
INT.F : TF - FF

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Resource allocation & Resource Levelling :-

A resource is a physical variable such as –

① M : Men : (Skilled / Unskilled / Semi-skilled)
② M : Materials
③ M : Machinaries (Tools, plants, equipments)
④ M : Money.

These 4M are directly responsible to convert "Plans & Specifications" in to finished product.

But all the resources may not be available in abundance, there may be lack of some resources, eg - availability of manpower may be restricted or availability of Machinaries may be restricted. In some cases space to work is restricted, so it is not possible to work simultaneously (concurrent parallel activities).

Under such restricted resource condition, various activities of project are rescheduled (Taking floats into consideration) in such a way that demand of some resources is more or less uniform along the project period, This objective can be derived in 3 steps –

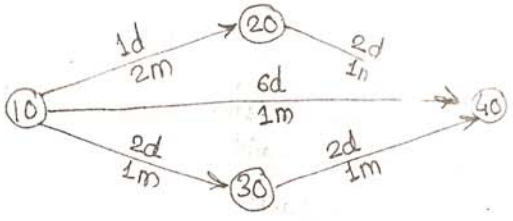
① Resource allocation.
② Resource Smoothening.
③ Resource Levelling.

① Resource allocation :-

Resource allocation simply means that deciding what resources are required for each activity of the project. To determine the resources reqd. for each activity in "Resource Usage Profile" i.e. "Histogram" is prepared on the basis of EST or LST.

for eg :- consider a simple netwic ..
Deviation of each activity is denoted in terms of days (d)
Requirement of labour for each activity .. denoted in terms of men (m).

If. ~~It can be seen that~~, during each activity 2 mens are required.



Resource of 2 men is available during the whole project.

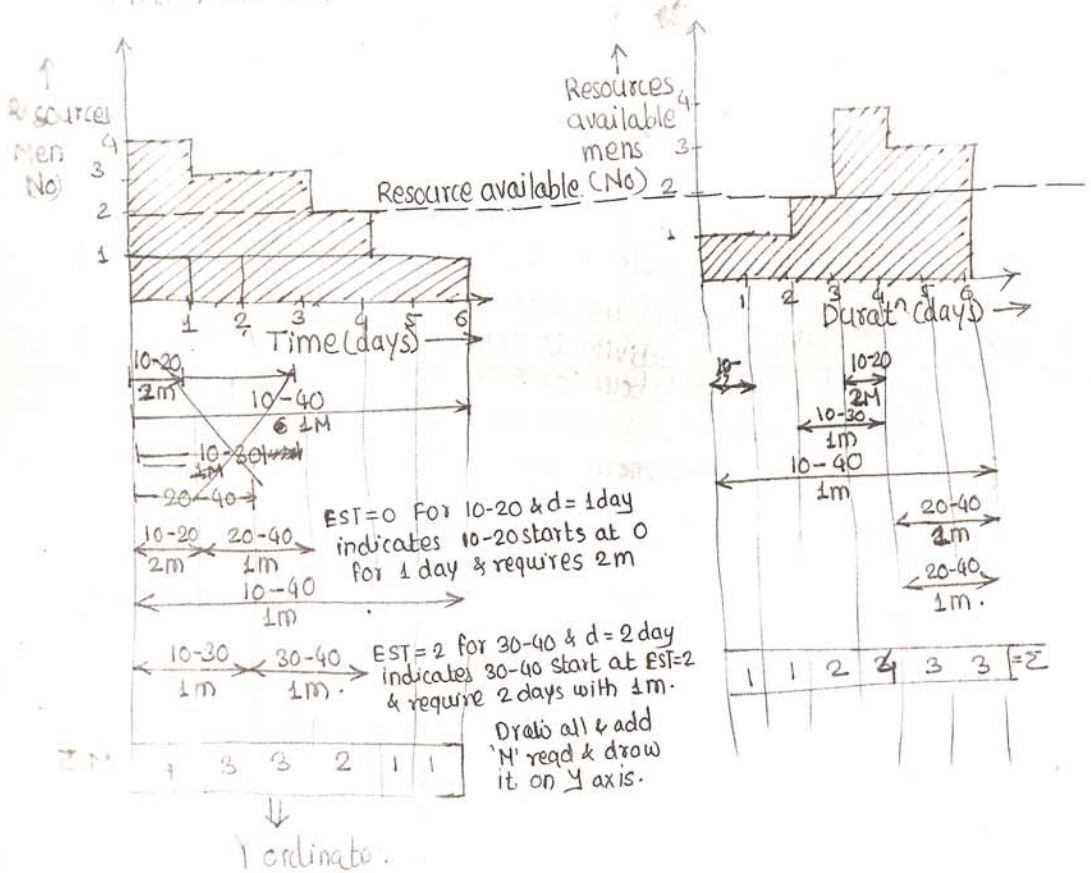
Activity	Duration (Days)	EST	LST	TF	Remarks
10-20	1	0	3	3	
20-30	2	0	2	2	
10-40	6	0	0	0	Critical.
20-40	4	2	4	2	
30-40	2	2	4	2	

∴ Critical Path : 10 - 40
Project duration = 6 days.

Histogram of Resource available : →

a) Based on EST

b) Based on LST



Histogram based on EST & LST can be presented in Tabular form as -

Resources available	2	2	2	2	2	2
Resources reqd (EST)	4	3	3	2	1	
Resources reqd (LST)	1	1	2	4	3	
Days.	1	2	3	4	5	6

∴ It can be concluded that,

Resources reqd : More or less than Resources available, per day. i.e. Requirement of labours fluctuates substantially over the project duration 6 days.

The process of resource allocation consist of allowing or fitting the activities ~~in to~~ according to availability of resource within the stipulated time period. i.e. adjustment of activities such that resources reqd = Resources available. & This can be achieved by the following steps:

① Resource Smoothening
② Resource Levelling.

Imp ① Resource Smoothening :- If project duration is not changed but some activity starting time is shifted by their available float so that uniform demand of resource is generated, this is called as resource Smoothening.

Imp ② Resource Levelling :- The starting time of activity is such rescheduled that peak demand does not exceed available ~~demand~~ resources. If it does not give desirable results by consideration of floats, the total project duration is extended by short time & known as resource Levelling.

If resource availability is limited & it can not be satisfied by varing the period, in such cases, project duration is extended to min. possible exten such that demands for resources = Available resources.

Imp ★ Updating :- The process of incorporating changes & rescheduling & replanning of network is called as network updating.

During the progress of work, in case the project is behind the schedule date due to unavailability of extra labour, poor supply of matl. etc, then, such changes needs to modified network diagram, such changes are known as updating.

Frequency of updating depends upon type of project [illegible].

1) If project period is small ⇒ Updating should be [illegible] because any "slippage" occuring in [illegible] will [illegible] the project as a whole.

2) If project is large ⇒ Updating in initial [illegible] very critical since, few "slippages" will be [illegible] project progresses. However when project [illegible] period approaches, updating should be done frequently.

* Controlling & Monitoring:-

Controlling [illegible] monitoring is complementary to planning [illegible] once the "Schedule Plan" is been prepared [illegible] [illegible] to complete [illegible] scheduled date.

Control [illegible]:-

Compare at regular intervals -

Actual Achievement of Project to Desired [illegible].

When anyone compares projects - There are 3 possibilities -

① Some activities are ahead scheduled Plan :⇒ Enough resources.
② some activities are going on schedule ⇒ Adequate resources.
③ some activities are behind the schedule ⇒ Lack of Resources.

The last possibility gives a sort of warning to construction engineer, to pay serious attension on those activities, otherwise project will not complete within scheduled date.

The detailed study of such activities tells the reason for why it is behind the schedule - The reason may be one of the following:-

i) Lack or deficiency of labour (Men)
ii) Lack of machinaries (equipments, tools, plants)
iii) Lack of material due to any reason.
iv) Lack of ~~mag~~ management desision.

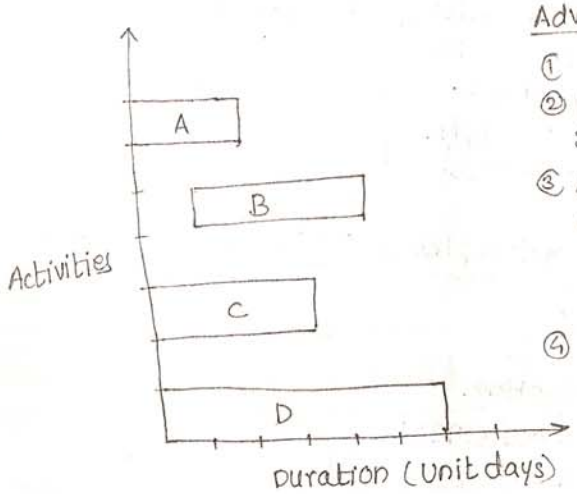
After finding reson, it is obeous to find the solution to correct the delay & this correction is applied & network is rescheduled (UPDATED) so that project will complete within scheduled period.

* Controlling :-

Controlling is one of the important phases of project. It requires an upward flow of information rough a suitably designed reporting system. The information so get is analysed to find corrective measure. So that project will be complete within scheduled period.

* Bar chart :- (Grantt chart)

The Bar chart is one of the method of planning & controlling developed by Henry Grantt for US Navy in 1900. It consist of preparation of chart which shows different activities by horizontal bars representing schedule of diff. activities.



Advantages of bar chart:-

① Simple, easy mtd. of scheduling.
② Each activity is shown indepen seperately.
③ Actual progress can be compared with desired progress & modificat (updating) can be done at any stage.
④ It can represent possible delay.

* Disadvantages :-

① Sequence & independence of each activity is not clearly seen
② The serious disadvantage of bar chart is that, it does not shows "Critical activities".

CONSTRUCTION MANAGEMENT

Notes by-

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Pro: 1

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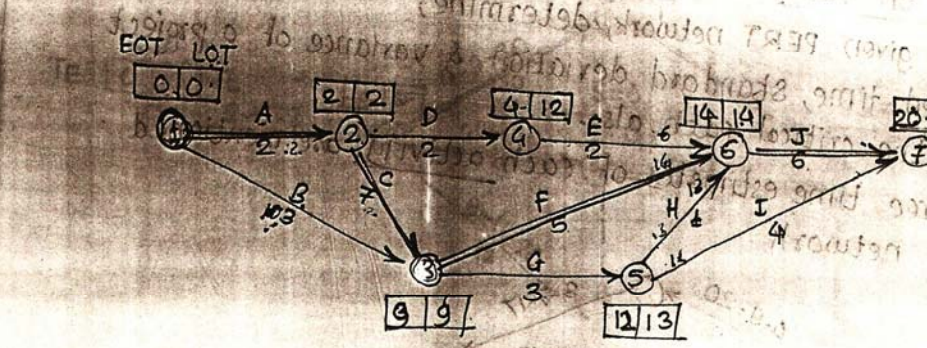
Ans: Critical Path: 1-2-3-6-7 ⑥
or A-C-F-J
Project duration = 20 days



Event	Activity	Durat^n	EOT	LOT	EST	EFT	LST	LFT	TF	FF	IF	INT F	
1-2	A	2	0	0	0	2	0	2	0	0	0	0	
1-3	B	3	9	9	0	3	6	9	6	6	6	0	
2-3	C	7	9	9	2	9	2	9	0	0	0	0	
2-4	D	2	4	12	2	4	10	12	8	8	0	8	
4-6	E	2	14	14	4	6	12	14	8	8	0	0	
3-6	F	5	14	14	9	14	9	14	0	0	0	0	
3-5	G	3	12	13	9	12	10	13	1	0	0	1	
5-6	H	1	14	14	12	13	13	14	1	1	0	0	
6-7	I	4	14	14	12	16	16	20	4	4	3	0	
6-7	J	6	20	20	14	20	14	20	0	0	0	0	

Use formulae:-

① $(EOT)_j = (EOT)_i + t_{i-j}$; $(EOT)_{1st} = 0$
② $(LOT)_i = (LOT)_j - t_{i-j}$; $(EOT)_{last} = (LOT)_{last}$
③ $(EST)_{i-j} = (EOT)_i + t_{i-j} = (EOT)_i$
④ $(EFT)_{ij} = (EOT)_i + t_{i-j}$
⑤ $(LST)_j = (LOT)_i - t_{i-j}$
⑥ $(LFT)_{ij} = (LOT)_j$
⑦ $(TF)_{i-j} = (LST - EST) = (LFT - EFT)$
⑧ $(FF)_{i-j} = (EOT)_j - (EOT)_i - t_{i-j} = EST_j - EFT$ considered.
⑨ $(IF)_{i-j} = [EOT]_j - (LOT)_i - t_{i-j}$
⑩ $(INT.F)_{i-j} = (TF)_{i-j} - (FF)_{i-j}$
$= (LOT)_j - (EOT)_j$

b] Probability factor z, corresponding to $x = 35$ days is,

$$z = \frac{x - \mu_T}{\sigma_T} = \frac{35 - 31}{3.97} = 1.007 \approx 1.$$

∴ From given table 1.1 → See Notes.

$$\boxed{Pr = 84.13\ \%\ \text{for}\ z = 1.0} \longrightarrow \text{Ans. (b)}$$

c] For 90 % probability, the value of $z = 1.32$ → Table 1.4.

$$\therefore z = \frac{x - \mu_T}{\sigma_T}$$

$$\therefore 1.32 = \frac{x - 31}{3.97}$$

$$\therefore \boxed{x = 36.24\ \text{days}} \longrightarrow \text{Ans. (c)}$$

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$\therefore$ at $x = \mu_T$, $z = \frac{\mu_T - \mu_T}{\sigma_T} = 0$

at $x = x$, $z = \frac{x - \mu_T}{\sigma_T} = z$

$\therefore$ Substituting,

$$P = \frac{1}{\sigma_T \sqrt{2\pi}} \int_0^x \cdot e^{-z^2/2} \times dx \cdot d\sigma_T$$

$$\boxed{P = \frac{1}{\sqrt{2\pi}} \int_0^x \cdot e^{-z^2/2} \cdot dz}$$

Remember for UPSC Exam. V. Imp.

where $z = \frac{x - \mu_T}{\sigma_T}$

z = Normal deviate & hence 'P' can be obtained from table, corresponding to 'z'

If x is +ve → i.e. x is towards $+\alpha$ ⇒ Right side,
chances of project completion on schedule = More than 50%

If x is −ve → i.e. x is towards $-\alpha$ ⇒ left side,
chances of completion of project on schedule ⇒ less than 50%

If $x = 0$; i.e. coinsides with μ_T,
chances of completion of project on schedule → 50-50%

Difference bet° CPM & PERT :-

Defination of CPM/PERT :- CPM/PERT is a graphical representation of inter-relationship, sequence of all the activities of construction from start to end of project.

CPM/PERT [Critical Path Method / Programme/ Project Evaluation & Review Techniques] are very very powerful tools of project Management which facilate POSDC & evaluation, in very effective way.

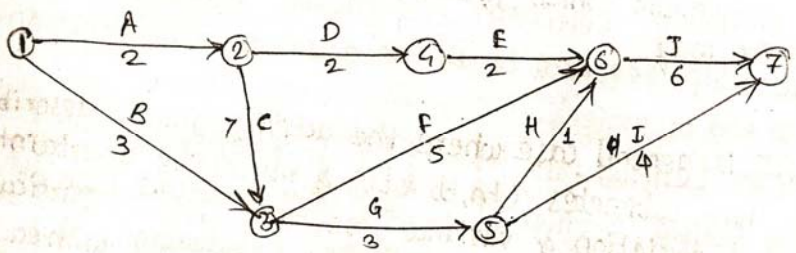
Relationship :-

PERT is general case where the activity time is described by three time estimates (ta, tb & tb) ., measuring uncertainty by standard deviation & variance, whereas CPM is a particular case of PERT, when three time estimates coinsides with each other (called as deterministic time) & standard deviation & variance disappears.

CPM	PERT
① It is basically have deterministic approach, in the network design.	① It have probabilistic approach.
② only one time estimate for each activity.	② 3 time estimate for each event ① Pessimistic Time estimate (tb) ② Optimistic Time estimate (ta) ③ Most likely Time estimate (tm)
③ Activity oriented	③ Event oriented.
④ Time & cost are controlling factor. i.e. project is completed at optimum durat? & optimum cost.	④ Only Time is controlling factor. i.e. project is completed at most likely duration only without considering cost.
⑤ Critical event must have zero slack. & zero float.	⑤ Critical events may be +ve, -ve or zero slack, depending upon project scheduled duration.
⑥ Recommended for repetitive nature of work where past experience is adequately available.	⑦ Recommended for Research & development oriented project where no past experience is available or where great uncertainty lies in the time estimation.

Problems:- ①

Find the critical path & project duration of the given CPM project. Also calculate all time & floats in a tabular manner.



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* Slack :-

T_E	T_L

→ Time box.

$$\text{slack} = (S) = (T_L - T_E)$$

∴ slack denotes "range within which the event can occur" or vary".
∴ slack gives idea of "spare time" — (शिल्लक वेळ).
More slack ⇒ More time to work ⇒ Less to worry about.
Less slack ⇒ less time to work ⇒ More to worry about.

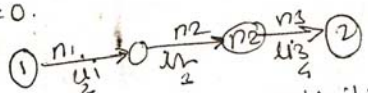
slack may be +ve, -ve or zero, depending upon $[T_L \leqq T_E]$

① Positive slack : $+S \Rightarrow T_L > T_E$:→
Project is ahead (पुढे) of schedule ⇒ Excess Resources available

② Zero slack : $S = 0 \Rightarrow T_L = T_E$:→
Project is going on schedule (वेळेवर) ⇒ Adequate Resources.

③ Negative slack :- $\therefore S \Rightarrow T_L < T_E$:→
Project is behind (मागे) of schedule ⇒ Less Resources. (Lack of)

* Critical Event :- Event having least slack value.
* Critical Path :- Path joining critical event.
Critical path may be one or may be more than one.
Critical path is longest path joining first & final event.
In CPM : Critical activities are those, which have zero floats.
i.e. $TF = 0$, $FF = 0$, $IF = 0$, $INT.F = 0$.



* Central limit Theorem :-
Central limit theorem states that, "If there are n activities lying along a critical path, each having its own β-distribution with expected mean time ($\mu_1, \mu_2, \mu_3, \ldots, \mu_n$), standard deviation ($\sigma_1, \sigma_2, \sigma_3, \ldots, \sigma_n$) & variance ($V_1, V_2, V_3, \ldots, V_n$) resp., then the distribution of time for a project as a whole will approximately normal distribution curve, have, mean expected time (μ_T), & standard deviation (σ_T) & variance (V_T) give by,

$$\mu_T = \mu_1 + \mu_2 + \mu_3 + \ldots + \mu_n$$
$$\sigma_T = \sigma_1 + \sigma_2 + \sigma_3 + \ldots + \sigma_n$$
$$V_T = V_1 + V_2 + V_3 + \ldots + V_n$$
$$\sigma_T = \sqrt{\sigma_1^2 + \sigma_2^2 + \sigma_3^2 + \ldots + \sigma_n^2}$$

$$V = \left(\frac{t_b - t_a}{6}\right)^2$$
$$\sigma = \frac{t_b - t_a}{6}$$

If there are more than one critical path in PERT network, find Variance (V_T) along each critical path & select critical path which have greater value of V_T.

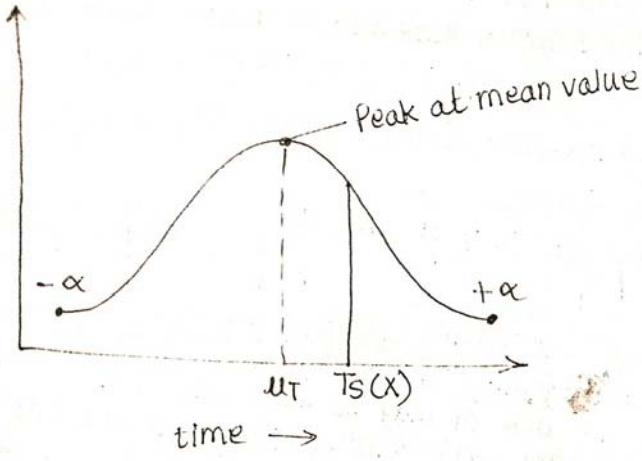
* Probability of completion of project :-

"Once the μ_T, V_T & σ_T of the "PROJECT" (Note - not event), is determined, it is possible to calculate — "chance of project completion ~~of~~ on schedule" by theory of probability

To calculate this, it is assumed that —

① Normal Probability distribution curve., which have mean value (μ_T) & standard deviation (σ_T).

② Normal distribut^n curve is symmetrical @ apex (i.e. μ_T) & extends from $-\infty$ to $+\infty$ as shown.



(Normal distribution curve).

To find chances of meeting Ts (or x) it is necessary to plot a normal distribution curve which is symmetrical @ μ_T.

~~with~~ The probabilities (P) for the interval from mean value (μ_T) to value of x is given by definite integration -

$$P = \frac{1}{\sigma_T \cdot \sqrt{2\pi}} \int_{\mu_T}^{x} e^{-\left[\frac{(x-\mu_T)^2}{2\sigma_T^2}\right]} \cdot dx.$$

Put $z = \frac{x - \mu_T}{\sigma_T}$

$$\therefore \frac{dx}{dz} = \frac{dz}{dx} = \frac{d}{dx}\left(\frac{x}{\sigma_T} - \frac{\mu_T}{\sigma_T}\right)$$

$$= \left(\frac{1}{\sigma_T} - 0\right)$$

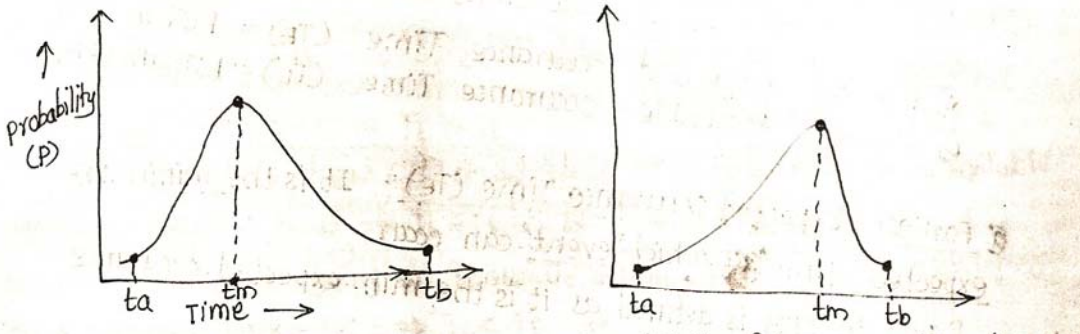
$$\therefore dz = \frac{dx}{\sigma_T} \quad \& \quad dx = dz \cdot \sigma_T$$

- Beta Distribution Curve :-

(β) - Beta distribution curve gives most satisfactory time estimate in PERT analysis.

β-distribution curve is unsymmetrical about its apex. & hence there are two types -

1) Beta-distribution for optimistic estimate (skew towards ta)
2) Beta-distribution for pessimistic estimate (skew towards tb)



① β-distribution for optimistic estimate ② β-distribut^n for pessimistic estimate

* Conditions should be satisfied to obtain type of distribution curve in PERT analysis :-

① Distribut^n should have small probability to reach ta (short Time)
② Distribut^n should have small probability to reach tb (Longest Time)
③ Distribut^n should have one & only one tm. (Unimodel) which is free to move bet^n two extremes ta & tb.
④ Distribut^n should be such that ; it is possible to measure uncertainty easily.

Above ④ requirements are satisfied by β-distribution curve & hence β-distribution curve fits for PERT analysis.

In PERT analysis 3 Time estimates are replaced by "Expected mean time (te)" & uncertainty is measured by -

1) standard deviation (σt) or
2) variance (Vt).

V.Imp.

① Expected mean time of activity (te) = $\frac{ta + 4tm + tb}{6}$

② Standard deviation of an activity (σt) = $\frac{tb - ta}{6}$

③ variance of an activity = $Vt = \sigma t^2 = \left(\frac{tb-ta}{6}\right)^2$

standard deviation = $\frac{1}{6}$ (Range) i.e $\frac{1}{6}$ of (tb - ta).

∴ Hence, smaller the range (tb ~ t), σt = less, ⇒ More certain activity duration.

i.e. certainty of activity occurs when tb = ta = tm &,

$\sigma t = 0$ & $Vt = 0$.

As $\sigma t = 0$, $V = 0$, it is a case of CPM.

PERT is General Case
CPM is particular case of PERT

Critical Path Analysis of PERT Network :-

① Convert 3 time estimates namely ta, tb, tm in to one i.e. "te".
② A systematic & scientific mtd. of finding critical path lies in the calculation of 2 event times as -
a) Earliest Expected occurance Time (TE) = EOT in CPM.
b) Latest Allowable occurance Time (TL) = LOT in CPM.

① Earliest Expected Occurance Time (TE) :- It is the minimum expected time at which "event" can occur.
[EOT in CPM is defined as it is the min. expected occurance time of "Activity"].

& $(T_E)_j = (TE)_i + t_{i-j}$ ⇝ Same as EOT.

Forward Pass -> Maximum Duration is taken.
(TE) First activity = 0
(TE) Last activity = Project duration.

② Latest allowable occurance Time (T_L)
T_L is the maximum time within which it is expected that event may occur, to keep project on schedule.

$(T_L)_i = (TL)_j - t_{i-j}$ ⇝ Same as LOT

Backward Pass ⇒ Minimum duration is selected.
(TL) of Last activity = (TE) of last activity or may be given
i.e. it is reqd. to find out, will project be completed at given duration.

(TE) First activity = 0.

* Schedule Completion Time :- (Ts)
Whenever a PERT network is taken in hand; a decision is made regarding the completion of project & expected completion period is known as 'schedule completion Time) (Ts).

Normally $T_S = T_L$ of last activity

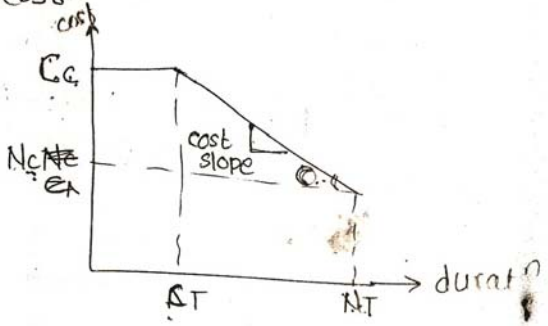
* Crash cost :- The cost of project, after applying overtime & other special resources to complete the period at crash duration or min. durat^n.

* Crash duration :- (Min. duration) The minimum possible time reqd. to complete the project after applying overtime & other special respources. i.e. ~~cost corr~~ durat^n corresponding to crash cost.

* Optimum cost :- Project cost corresponding to min. cost duration, without applying ~~no~~ other resources

* optimum duration :- Min. duration reqd. to complete the project corresponding to optimum ~~co~~ cost.

* cost slope = $\frac{Cc - Nc}{NT - CT}$



* PERT :-

Very often, activity time of a project may not be possible to be forecasted in a confident & deterministic manner. This is true in case of research & development programme. This is true for projects, where preceeding activity is known but nature of project is such that, it involves a great amount of uncertainty in time estimation such as - weather conditions, failure of equipment, injury to labour, absentism, & lack of method availablility for completing activity.

The important function of the management is to take decision under such situation & balancing the risk associated with the particular problem. In order to balancing the risk, a mathematical model, based on "probability" is worked out & known as PERT - (Project / Programme Evaluation & Review Technique).

PERT introduces "uncertainity" in to account by three kinds of time estimates of activity duration, which are -

① The optimistic Time Estimate (आशावादी) (tα)
② The Pessimistic Time Estimate (निराशावादी) (tb)
③ The Most likely Time Estimate (जवळजवळ शक्य) (tm).

"Optimistic see opportunity in every problem,
Pessimistic see problem in every opportunity!"

① The Optimistic Time Estimate (ta)

The optimistic time estimate is the minimum time reqd. to complete the activity, if nothing "exceptionally" goes wrong. "Ideal conditions" are assumed during the execution of activity

② The Pessimistic Time estimate (tb)

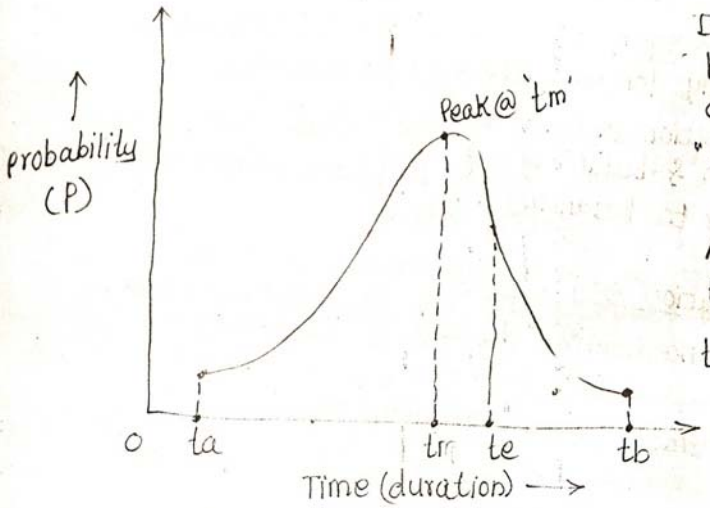
The pessimistic Time estimate is the maximum time reqd. to complete the activity if "unusually" everything goes wrong. "Abnormal conditions" are assumed during the execution of activity.

Of course, major uncertainities such as labour strike, flood, acts of God are excluded from this estimate, otherwise, theoretically ∞ time will require to complete the activity.

③ The Most Likely Time Estimate (tm) :- As, it can be imagined that 'ta' will be very short & 'tb' will be very large. The time estimate will lie in bet' ta & tb. Therefore, to calculate most likely time estimate is based on experience & judgement being based on the time required, if the activity is repeated number of times under some condition.

This time indicates most probable occurance time. It reflects the sition —" Things are usual, nothing exciting".

* General shape of probability distribution curve associated with three time estimates of PERT is —



(Probability distribution Curve for activ. duration)

It can be seen that, 'ta' & 'tb' have very less probability of occurance.

"tm" has maximum probability of occurance.

Activity will be completed within ta & tb.

te = Expected mean time. (obtained by dividing the area approxmately half).

Optimization Through CPM Technique :-

The object of finding out critical path of network is to identify those critical activities or events, which needs full attension with a view to complete project on time. The project duration is calculated from critical path. But in many instances, it is desirable to cut down the cost of project duration. This naturally leads to cost consideration.

Some component of Total cost $\propto$ Duration

& some component of Total cost $\propto \frac{1}{\text{Duration}}$.

Hence their exists a particular value of duration at which total cost of project is minimum. This minimum cost of project is known as optimum cost & duration corresponding to optimum cost is known as optimum duration.

In some condition, cost is not considered only time is considered. for eg :- in the event of national emergency (war, Flood, earthquake, famine etc). The ~~servial~~ servival of nation depends on project completion, not the cost associated. of course, cost assosiated under such situation would be highest.

Direct - 4M
Dura ↓ → 4M ↑
4M ↑ → cost ↑
Dura ↓ → cost ↑

Project cost

Indirect cost $\propto$ ~~Total cost~~ duration

Direct cost $\propto \frac{1}{\text{Project cost}}$

Fixed Indirect cost

eq^n :- $(y = x)$

As per name suggests, cost involved is independent of project duration eg : initial expenditure (purchase of resources), installation, licence fee, royalties, taxes etc.

Variable indirect cost.

eq^n :- $(y = x + c)$

The cost which are more or less directly proportional to project duration.

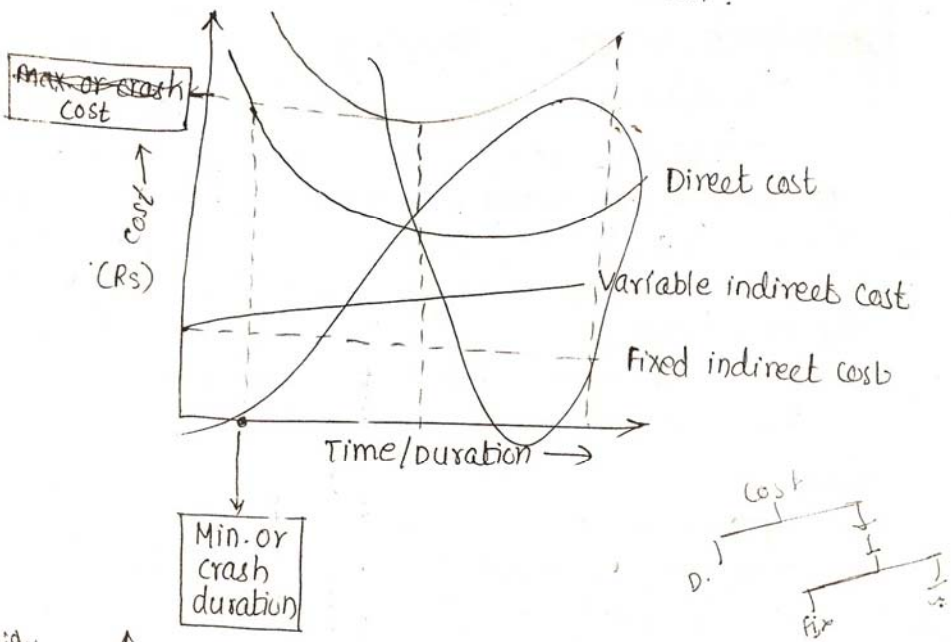
eg : overhead expendature on office, supervision cost, cost of providing ammenities, interests etc.

eq^n $y = \frac{1}{x}$

Direct cost is the [illegible] is directly depend on duration of project. The cost of resources involved in completion of ~~project~~ various activities, such as 4M, payment of subcontractor etc.

When the project time is to be decreased, to get same work done, it is necessary to increase amount of labour, machinary & certain types of time saving matls. (such as use of rapid hardening cement in place of OPC), which means simply increase direct cost.

sometimes work is to be completed by paying overtime, working in shift which also increases direct cost. Hence direct cost is inversly proportional to project duration.



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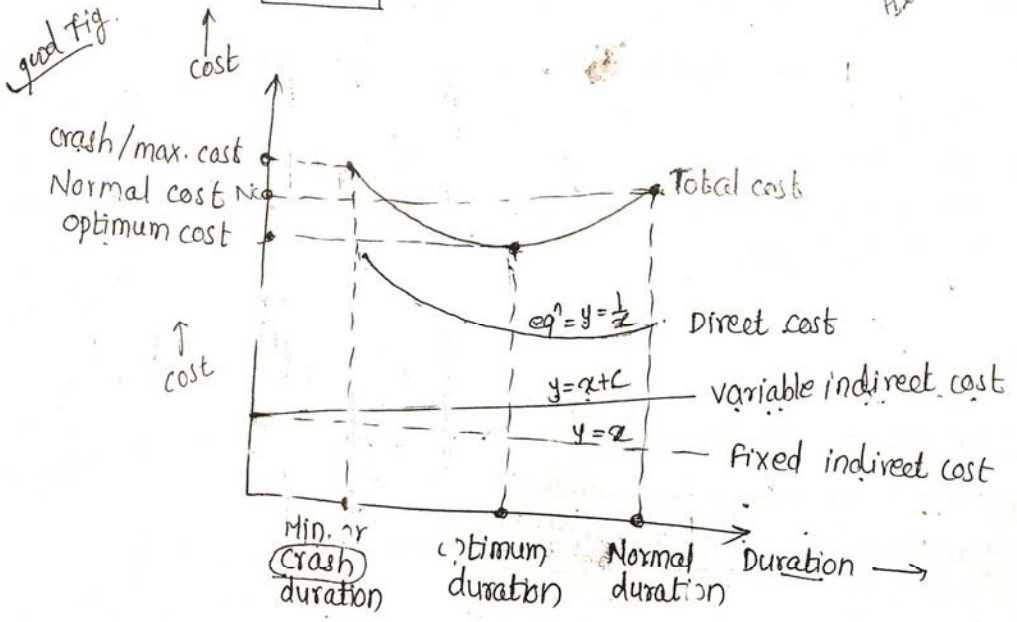


Total direct cost = Sum of individual direct cost of each activity.

* Normal cost (Nc) :- It is the cost of project such that project is completed by employing normal resources i.e. not using overtime or other special resources.

* Normal duration (N_T) : It is min. time reqd. to complete the project without any overtime or other special resources.

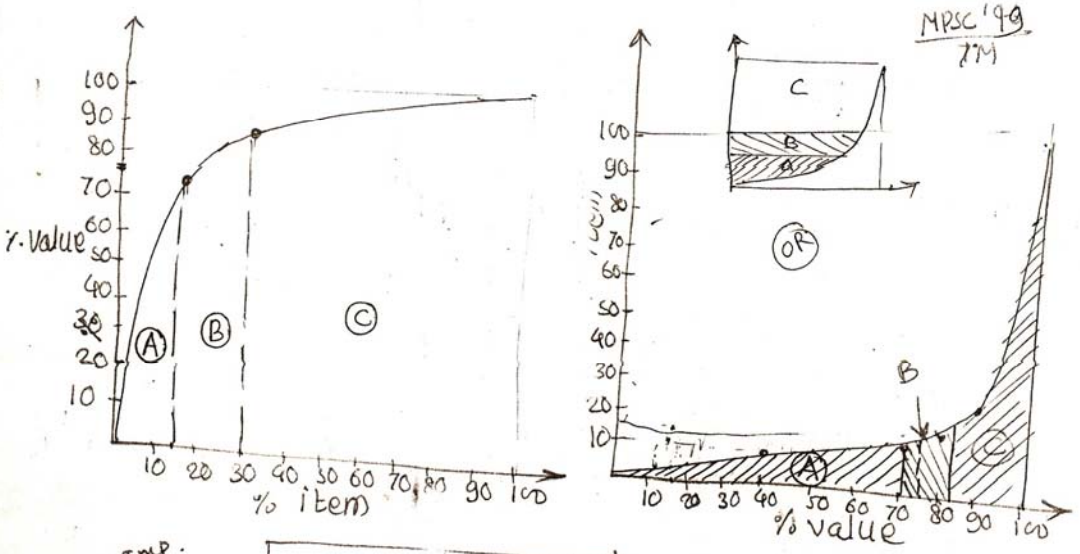
ii) B-Type item:-

These items are 10 15% of total item & contributes about 10-15% of total cost on matls.

iii) C-Type items

These are 70-75% of total item & contributes only 5-10% of total cost on matl. hence they are insignificant. Procuring policy of C item is exactly opposite to that of A type. 'C' items should be procured infrenquently & No. of items are more.

MPSC '99
7M



	% Item	% Value
A	~~10~~ 15	70
B	15	15
C	70	15

Draw ABC analysis:-

~~Item~~ Annual consumption (Units) ①	~~% item~~ Unit Price (Rs) ②	~~% cost~~ Annual Usage ③ ~~①×②~~	Total Cost Decending order ④	Cummulative Usage Value ⑤	% Cummulative Usage ⑤ / ~~last~~	% item	Remark
Given	Given	①×②	③ ↓ dec.	④ + ↓	⑤1 / ⑤Last ×100	@1 / last ×100	A - 15-70 B - 15-15 C 70-15
					Draw Graph.		

CPM & PERT

Scientific management:- Art of knowing exactly what is to be done & the best way to doing it.

CPM (CPPS)	PERT
① Deterministic approach	① Probabilistic
② One time estimate	② 3 Time estimate
③ Activity oriented	③ Event oriented
④ Time & cost controlling factor	④ Time is only controlling factor
⑤ Critical activity zero slack	⑤ +ve, -ve, 0,
⑥ Repetative nature	⑥ R&D
⑦ Particular case	⑦ General case

* Phases of project: POSDCE

① Planning:- Process of choosing mtd & sequence of work.

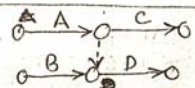
② Organising:- To give contract to best suited contractor.

③ Scheduling:- Calenders: Time.
- a] Matl. calender:
- b] Machinary / Equipment calender
- c] Men: Labour: Skilled / unskilled.
- d] Money: Finance calender:-
- e] Time Activity Time Calender:-

④ Controlling, Monitoring, Directing Phase

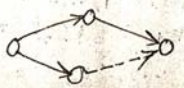
⑤ Evaluating Phase:- (मूल्यांकन)

Dummy:-



D depends on A [Logical Mistake]

Length of arrow is less.



Last activity. [Grammetical]

* Types of Event: ① Initial (1st)
② Final (Last)
③ Dual Role (Intermediate)

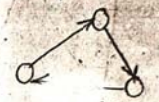
① Immediate Event / Activity:- Predecessor
② Predecessor event / activity
③ Immediate successor event / activity
④ Successor event / activity.

* Constraints:- ① Physical - (Incomplete work)
② Safety -
③ Resources -
④ Crew -
⑤ Management (Decision)

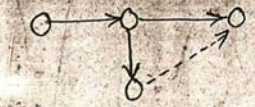
Error in Network:-

a] Constructional Error

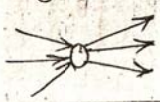
① Looping Error

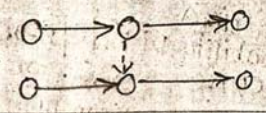


② Dangling Error



b] Conceptual Error:-
Wagon-wheer error





(CPM) * Earliest Occrance Time (EOT): It is the min. time at which activity can occur.

* Latest Occurance Time (LOT):- It is the max. time, whi within which activity may occur.

(PERT) * Earliest Expected [illegible] Time (TE)
Min. time expected [illegible] event can occur [illegible]

* Latest Allowable Occurance Time (TL)
Max. expected occurance time of event within which event can occur.

(CPM) Project completion Time: LOT of last activity

(PERT) Schedule Completion Time: TE of last activity

(CPM) The nodes having zero slack are called as critical nodes & path connecting all critical nodes is called as "Critical Path".

(PERT) The events having zero (+, -, zero) slack is called as critical event & path connecting all critical event is critical path.

Floats:- Time Estimates

① Earliest Start Time (EST):- Earliest possible time at which activity can start
(EST)i-j = (EOT)i

② Earliest Finish Time (EFT):- Earliest possible time at which activity can finish

③ (EST)i-j = (EOT)i + ti-j

⑤ Latest start Time (LST):- Latest possible time within which activity can start
(LST)i-j = (LOT)i - ti-j

④ Latest finish Time (LFT): Lastest possible time within which activity can finish

Floats: ① Total Float (TF)
② Free Float (FF)
③ Independent Float (IF)
④ Interfering Float (INTF)

Float :- "Flexibility range within which activity can start or finish can fluctuate".

① TF : Excess of max. available time over the activity time.

$(TF)_{i-j} = (LOT)_j - (EOT)_i - t_{ij}$

i.e. Diff. bet^n Time Box

② FF :- Excess of available time over activity time when job starts as early as possible.

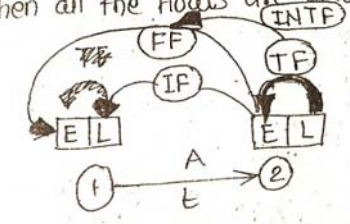
$FF = \square 2$ → Backward. - t

③ IF :- Excess of min. available time over activity time.

[आवश्यक - d]

④ INTF :- Diff. bet^n TF & FF.

* When all the floats are zero ⇒ Critical acti.



ALL BACKWARD

Bar chart : Grantt chart : US Navy 1910

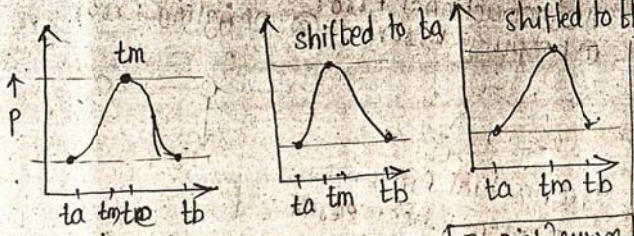
PERT :-

Time Estimates : ① Optimistic Time Estimate (ta)
② Pessimistic Time estimate (tb)
③ Most likely Time estimate (tm)

ta :- Min. time reqd. to complete the project if nothing goes wrong (Ideal cond^n)

tb :- Max. time reqd. to complete the project if everything goes wrong (Wrost cond^n)

tm :- The ~~activity~~ time reqd. for completion of event is within ta & tb. But tm is the most likely time estimate & it has more probability of being exact time than other.



Probability Dist^n curve | β-Dist^n curve for ta | β-Dist^n curve for tb

te = Expected mean Time.

β-Dist^n curve are Unsymmetrical @ y axis.

β-Dist^n curve gives most satisfactory time estimates.

t_e = Expected mean time = $\frac{t_a + t_b + 4t_m}{6}$

δ = Standard deviation = $\frac{t_b - t_a}{6}$

Variance = $\delta^2 = \left(\frac{t_b - t_a}{6}\right)^2$

* Central Limit Theorem :-

If there are n activities lying along CP each having their own β-Dist^n with, $t_{e1}, t_{e2}, t_{e3}, \ldots$ and $\delta_1, \delta_2, \delta_3, \ldots$ & $V_1, V_2, V_3 \ldots$ (same Meaning of symbols). Then,

$$\begin{cases} t_e = t_{e1} + t_{e2} + t_{e3} + t_{e4} + \cdots \\ \delta = \delta_1 + \delta_2 + \cdots \\ V = V_1 + V_2 + \cdots \end{cases} \Rightarrow \text{only Critical activity}$$

If there are more than one C.P, The CP is selected whos V is max.

Plans & specifications + 4M (Resources) → Finished Product

Resource allocation : Deciding @ Resource Adjustment of activities such that, Resour... available = Resource Reqd.

① Resource smoothing :- No change in project durat^n, but EST is shifted so that demand of 4M is uniform.

② Resource Levelling :- change in PD

Updating :- Incorporating changes & rescheduling & replaning of network

Project behind schedule : Less R
Project according to sch : Adequate
Project Ahead of sch : More R
Small Project Frequent updating
Large Project Later stage