PROJECT ENGINEERING

Chapter 3 - Project planning and scheduling

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Project planning and scheduling

Contents:

Concept of Project Planning

- In simple sense, planning means thinking ahead of an operation to be performed.
- It is primary function of management.
- It is deciding in advance
  - What to do?
  - When to do?
  - Where to do?
  - How to do?
  - Who is responsible?
- It provides the end to be achieved

Concept of project planning

- Planning is the process by which managers define the goals and take necessary steps to ensure that these goals are achieved.
- Planning is a mental exercise that requires imagination, foresight and sound judgment.
- It is thinking before doing, looking ahead, anticipating future and deciding the course of action to be taken. (Richard Steers)

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Features of Planning

1. Process: It is systematic mental process of doing things and involves creative thinking and imagination.
2. Future/goal oriented: Planning is essentially thinking ahead and preparing for future. It anticipates future opportunities and threats to the best advantage of the organization. It is based in forecasting and environmental scanning. It provides direction to the organization.
3. Intellectual process: Planning is mental exercise involving creative thinking and imagination. A manager can prepare sound plans only when he has sound judgment, foresight and vision.

Features of planning

4. Primary Function: Planning serves as basis for other functions of management. It precedes all other functions of management such as organizing, staffing, leading/directing and controlling.

5. Pervasiveness: Planning is required in all types of organizations and at all levels of management. Every department prepares plan however scope of planning may differ from department to department from one level to another.

Features of planning

6. Continuous: Planning is continuous process. Plans are prepared for specific time period. At the end plan period new plans are prepared. Similarly as the conditions changes the new plans are prepared.

7. Aims at efficiency: Planning is directed towards efficiency at all levels of management. Sound planning leads to accomplishment of desired objectives at minimum possible cost. It helps in organization of resources. Alternatives are evaluated on the basis of efficiency.

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Importance of planning

- **Making objectives clear:** Planning makes goal clear and specific. This is because goals are to achieved and decided before choosing the course of action. Planning focuses attention on the organizational objectives and serves as a guide for deciding what action to be taken.
- **Helps in coordination:** Well defined objectives, policies and procedures helps in coordination i.e. it avoids duplication of works and inter department conflict.
- **Economy and Efficiency in operation:** It paves the way for the proper utilization of organization resources. It involves the development of one best way of doing which is economical too.

Importance of planning

- **Reduces risk and Uncertainty :** Planning enables to predict future events and prepare to face unexpected events. With the help of planning, managers can identify potential dangers and take steps to overcome them. Thus planning is helpful assessing and meeting future challenges.
- **Provide the basis of control:** Planning provides the standard against which actual performance can be measured and evaluated. Comparison of actual performance with the standard helps to indentify deviation and take corrective actions if necessary.

Importance of planning

- **Facilitates decision making:** Planning lays down targets. With the help of these targets managers can be better evaluate alternative course of actions and select the best one. With the help of planning hasty decisions and random actions can be avoided.
- **Helps in organization to be in right path:** Planning helps the organization to keep in right path. Employees understand how their actions relates to the organizational goals. Planning avoids aimless and adhoc decisions. It avoids snapshot decisions based on impulse and intuition. Planning provides systematic and orderly efforts towards the goals.

Objectives

- ✓ Proper design of each element of the project.
- ✓ Proper selection of plant and equipment.
- ✓ Proper arrangements of repair of plant and equipment at site.
- ✓ Procurement of required materials well in advance
- ✓ Ensure employment of skilled and unskilled employees.
- ✓ To provide welfare schemes for the workers
- ✓ To provide incentives for good workers
- ✓ To arrange constant flow of funds in entire project duration
- ✓ To provide required level of safety and compensations.
- ✓ Proper arrangements of communication and mobility in site.

Principle of Planning.

- The plan should be readily understandable
- The plan should be realistic not an optimistic
- The plan should be flexible
- The plan should be comprehensive
- The plan should incorporate the system of monitoring and controlling.

Concept of Project Planning

- According to David I. Clealand : Project planning is the process of thinking through and making explicit the projects' objectives, goals and strategies necessary to bring the project through its life cycle to successful termination.
- The task involved in Project Planning:

Feasibility Study: It determines the implement-ability of the project.

Appraisal: It is the evaluation of Project ability to succeed and done for feasibility.

Design: It is concern with the preparation of detailed engineering design, drawing, specifications as well as detailed engineering plans such as work schedule, cost estimate and resource allocation.

Function of Project Planning

- Stating the objectives of the project to be undertaken
- Definition of work requirement.
- Definition of resource needed such as funds, materials, machines, human resources, facilities.
- Determining the time frame of the overall project and also scheduling its various stages.
- To eliminate or minimize the risk and uncertainty.
- It provides a basis for organizing the work on the project and allocating responsibilities to individuals.

Work break down structure

- How many tasks does the project have?
- How much detail should the project plan have?
- This query is overcome by Work Break Down Structure
- Work break down structure as its name suggests represents a systematic and logical breakdown of a project into several components.
- It is constructed by dividing a project into major components each of which is further sub-divided into smaller components.
- WBS acts as a vehicle for breaking the works into the smaller elements, thus providing a greater responsibility that every major and minor activity are well accounted for their implementation.

Work break down structure

- Usually the project manager is responsible for structuring a project into several components.
- The level of smaller components should be such that each of which should be:
  - Manageable so that specific authority and responsibility can be assigned.
  - Independent so that there happens to be minimum interfacing with and dependence on other ongoing elements
  - Integratable so that the total package can be seen
  - Measurable in terms of progress

Advantages/uses of WBS

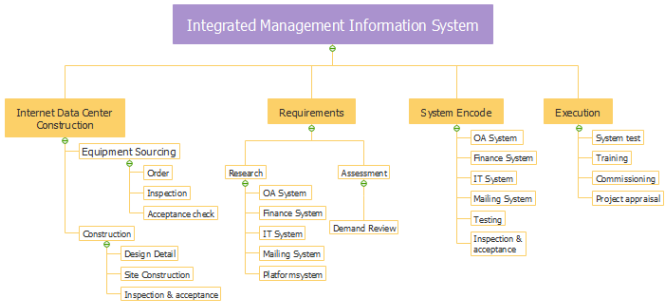
- Planning can be performed
- Costs and budget can be established
- Risk analysis can be done
- Control and contract administration can be done
- Schedules can established
- Network analysis can be done
- Responsibility matrix can be established
- Coordination can be established
- When summed up the total program can be described

Roles of WBS

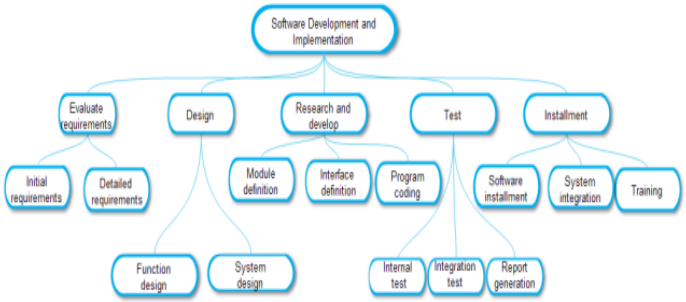
- Partition of project into smaller component to improve the accuracy of the cost estimate
- Provide mechanism for collecting and organizing actual cost
- Provide the mechanism for performance measurement and control.
- Each activities in WBS is a self contained unit for which responsibility can be assigned to a person or group for effective management.

WBS

WBS (Example)



WBS (Example)



Levels of WBS

- Total program
- Project
- Task (Activity)
- Sub tasks
- Work package
- Level of effort

Levels of WBS

- Total program = set of projects
- Projects = summation of activities
- Task = summation of subtask
- Level 1 is generally used for the authorization
- Release of all works budgets are prepared at level 2
- Schedules are prepared at level 3

  – The upper three levels of WBS are normally specified by the project manager office, while lower levels are generated by the contractor for in house control.

Characteristics

- Top three levels of the WBS reflect integrated efforts and not department specific
- The summation of all elements in one level must be the sum of all work in the next lower level
- Each element of work should be assigned to one and only one level of effort. For example the construction of the foundation of a house should be included one project not extended over two or three
- The WBS must be accompanied by a description of the scope of effort required.

Preparation of WBS

- In setting up WBS tasks should :
  - Have clearly defined start and end dates
  - Be usable as a communications tool in which results can be compared with expectations.
  - Be estimated on total time duration
  - Be structured so that a minimum of project office control and documentation is necessary.

Criteria for developing WBS

- The WBS and work description should be easy to understand
- All schedules should follow WBS
- No attempt should be made to subdivide work arbitrarily to the lower possible level
- Since scope of effort can change during a program every effort should be made to maintain the flexibility in the WBS
- The WBS can act as tangible milestone
- The level of WBS can reflect the trust you have in certain line groups

Project scheduling with Bar chart, CPM and PERT

- Scheduling is laying out of the actual jobs of the project in time order in which they have to be performed, manpower and material requirements needed at each stage of construction are calculated, along with the expected completion time of each jobs.
- Scheduling is used for following proposes.
  - To control financing and payment
  - To predict project completion time and activity
  - To serve as a record
  - To manage risk and uncertainties.

Scheduling Methods

Project scheduling methods:

1.Bar chart

1.1 Gantt chart

1.2 Linked bar chart

1.3 Milestone chart

2. Network diagrams

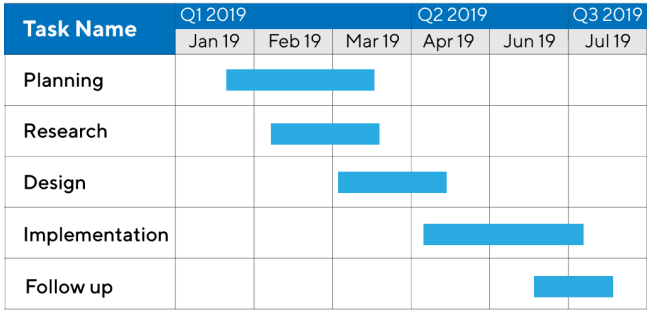
2.1 CPM (Critical Path Method)

2.2 PERT (Program Evaluation and Review Technique)

Bar chart/ Gantt chart

- It is graphical representation of project activities shown in time scale bar line with no links shown between the activities.
- A bar chart is a scheduling technique in which activity during is drawn to scale on a time base.
- A bar chart is **also called Gantt chart** since it was **developed by Henry Gantt**.

Gantt Chart (Example)



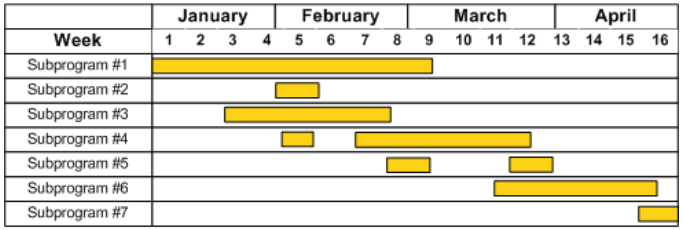
Steps in preparing Bar chart

- Listing the work of activities
- Estimation of work duration
- Identifying the start and completion date in calendar format
- Drawing each activity as horizontal bar in chronological order according to its start date

Advantages of Bar Chart

- Easy to understand
- The status of the project can be assessed in short time
- Easy to develop and implement
- No training is required
- Appropriate for small project
- Starting point for planning

Example – Bar chart



Example of a bar chart used for planning major programs, sometimes referred to as a Gantt chart

Disadvantage of bar chart

- Not suitable for big and complex project.
- Difficulties in seeing immediately and exactly overall project duration if changes occur in any particular activity.
- No detail but gross planning
- It does not show specifically which activities to control and expedite and how much
- It does not depict the dependencies of activities upon each other.
- Updating means to redraw the entire chart again and again
- Do not provide the methods for optimizing resource allocation
- It is difficult to show critical path critical activities and floats available.

Example

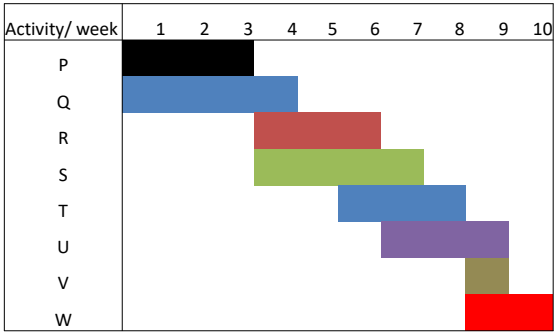
- A Project consists of following activities with their time of completion(week) as follow :

Activity	Duration	Activity	Duration
P	3	T	3
Q	4	U	3
R	3	V	1
S	4	W	2

- Activity P and Q can be performed in parallel
- Activity R and S cannot start until completion of P
- Activity T cannot start until half of activity S is complete
- Activity U succeeds activity R
- Activity V and W succeeds T

Draw a bar chart and find out completion time of project

Solution:



Here, the project completion time is 10 weeks

Linked bar chart

- It is modified version of Gantt bar chart. It was developed to overcome some of the inherent limitations of bar chart.
- It shows the links between an activity and preceding and succeeding activities.
- The link bars are very complicated and sometimes impossible to show graphically. They are mainly four types of relationship between activities.

Relationship Between Activities

Finish to Start

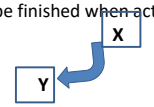
- Activity Y can't start until activity X is finished

Start to Start

- Activity Y must start when activity X start

Start to finish

- Activity Y should be finished when activity X starts



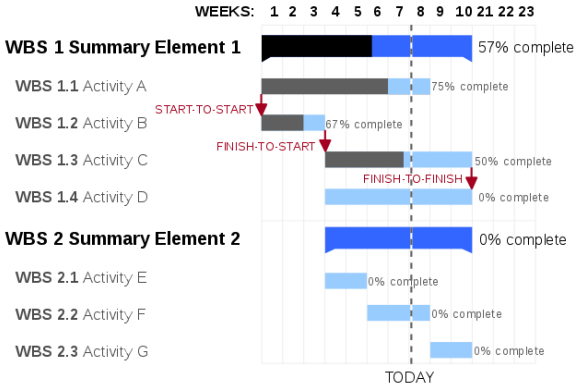
Relationship Between Activities

Finish to Finish

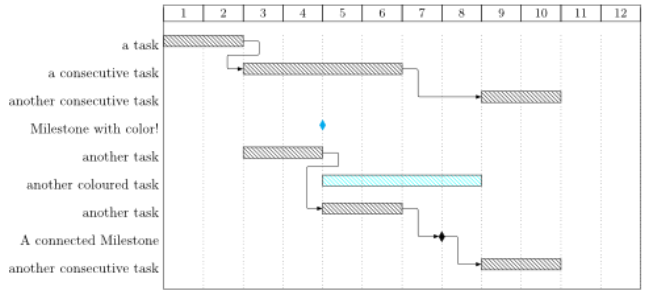
- Activity Y must be finished when activity X finishes

- The linked bar chart has an advantage of exhibiting the effect of delay on succeeding activities and also it can provide some information of the extra time available with an activity for its completion
- The extra time available for activity for its completion is called float.

Linked Bar Chart (Example)



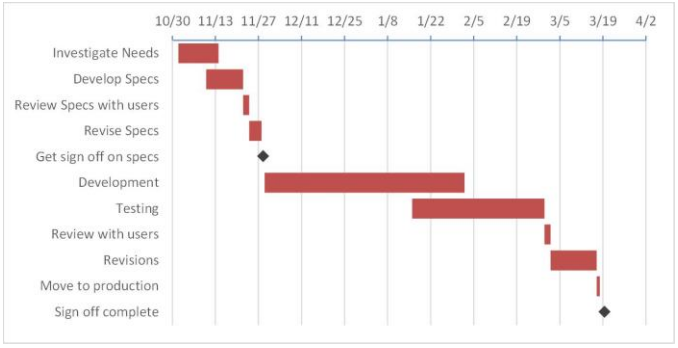
Linked Bar Chart (Example)



Milestone Chart

- Milestone chart is an improved version of a bar chart in which some of the limitations of the bar chart are eliminated.
- Bar charts are converted into the milestone bar chart by placing small triangles or circles or flag at strategic locations of bar to indicate the completion at certain milestone within each activity or group of activities.
- A milestone implies some specific stage or point where major activity either begins or ends or cost data become critical.

Milestone Chart (Example)



Milestone Chart

- Each bar in a milestone chat again represents an activity or job or task and all the bars taken together represent the entire project.
- A milestone chart shows the relationship within same activity or job or task.
- Thus as compared to bar chart better control can be achieved with the help of milestone chart but still possesses the same deficiency that it does not depict the interdependencies between the various tasks or relationship between the milestones of different task.

Network Diagrams

- There are two popular network based scheduling Techniques:
  - Critical Path Method (CPM)
  - Program Evaluation and Review Technique (PERT)

Network Diagrams

- Critical path is graphical network base scheduling technique that evolved in late 60's US agencies insisted on their use by contractors on major government projects.
- Basic concepts of CPM such of activities, events and predecessors have become a regular part of language of project managers

Network Diagrams

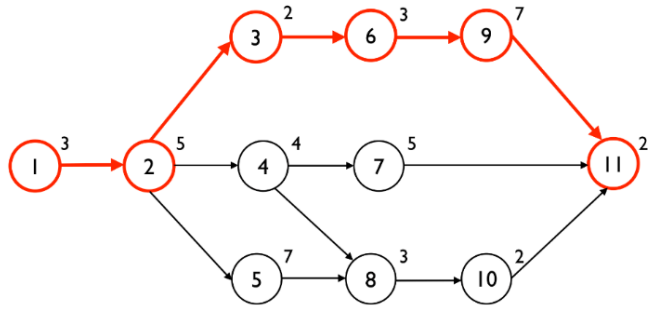
- CPM enables planners and managers to thoroughly analyze the timing and sequential logic of all operations required to complete the project.
- In 1957 CPM was developed by Morgan R. Walker of DU Pont and James E. Kelly of Remington Rand for preparing the shut down schedule of chemical plant.
- US navy developed the project management tool known as PERT (1958) for Polaris Missile project

Terminologies in Network Diagram

Activity

- An activity is an any identifiable job that has a beginning and end.
- An activity consumes time, manpower and material resources.
  - Examples: excavation of foundation.
  - Construction of walls
  - Construction of roofing
- An activity is represented by a straight arrow with circles at both ends ().
- The circle placed at the beginning of the arrow represents the starting point of the activity while the circle placed at the end of the arrow represents the finishing point of the activity.

Network Diagram Example



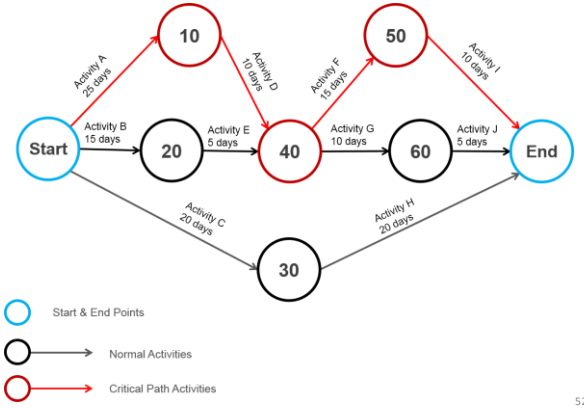
Terminologies in Network Diagram

Event

- An event (also called Node) is the beginning or end of the activity.
- An event does not consume time, manpower or material resources.
- An event represents a specific point in time and is represented by the circle.
- Thus the two circles placed at the beginning and end of the activity are called events.

- Event 1 is tail event eg. Start of Recce for survey
- Event 2 (completion of recce) is head event of the activity recce for survey and tail event for activity placing of pegs. It is called dual role event
- Event 3 is the head event for activity detailed survey using instrument.

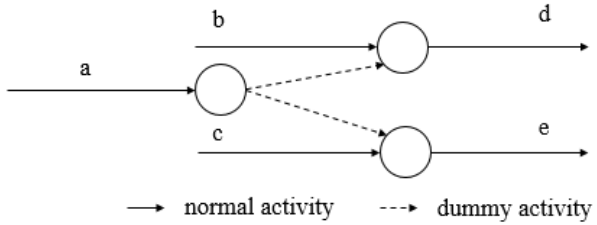
Network Diagram Example



Dummy activity

- A dummy activity is an imaginary activity included in the network.
- Since it is not a real activity it does not consume time manpower and material resources.
- It is included in the network to maintain the network logic and to avoid the ambiguity.
- A dummy activity is represented by dotted arrow.
- Unnecessary dummies make network messy and creates confusion.

Dummy activity



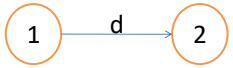
Activity duration

- Activity duration is the amount of time estimated for its completion.
- The time unit for the project can be minutes, hours, working days or calendar days,

Earliest time and latest time

There are following types of earliest and latest time.

- **Earliest start time:** It is the earliest possible time an activity or operation can be started.
- **Earliest Finish Time:** It is the earliest possible time for completion of activity or operation
- **Latest finish time:** It is the latest time the activity or operation must be completed so that scheduled completion date of work can be achieved.
- **Latest Start Time:** It is the latest the possible time an activity can be started without delaying the project.



- d = activity duration
- EFT= EST (1-2) + d
- LST = LFT (1-2) – d

Rules of Drawing Network Diagram

- All activities shall be represented by way of straight arrows pointing towards right
- There must be single initial node as well as ending node in a network . The initial node has only outgoing arrows where as ending node has only incoming arrows.
- There shall not be crisscrossing of arrows
- The arrows of a network can't form loops
- There shall not be unnecessary dummy activities in the network. Dummy activities shall be introduced only when absolutely necessary.

Numbering of Events (Fulkerson's Rule)

Developed by D.R Fulkerson

- Identify the initial event and assign it no.1
- Neglect all the emerging arrows from initial event 1. this will create a new initial event. Number these initial events as 2,3,4 etc.
- Neglect all the emerging arrows from these numbered events, it will create few more initial events.
- Follow the above procedure till the end of the network is reached.
- The last event is assigned with the highest number in the network.

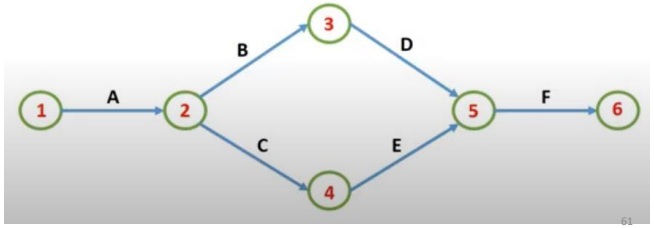
Skip Numbering

- In large projects all the activities cannot be correctly foreseen and included in the network.
- It may need modification in the form of addition and/or deletion of activities during execution.
- Tedious task of numbering is the events after modification can be avoided by numbering the events in multiple of 10s (10,20,30) instead of 1,2,3.
- This method is called skip numbering.

Example

- Draw a Network Diagram for following data and number them using Fulkerson's rule:

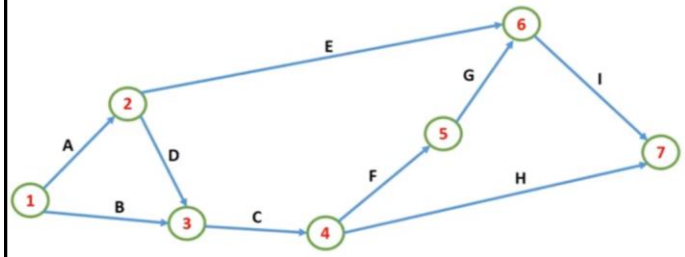
Activity	A	B	C	D	E	F
Predecessor	-	A	A	B	C	D,E



Example

- Draw a Network Diagram for following data and number them using Fulkerson's rule :

Activity	A	B	C	D	E	F	G	H	I
Predecessor	-	-	B,D	A	A	C	F	C	E,G



Critical Path Method (CPM)

- A network represents the logical sequence of activities contained in an each path in a network will have a different duration.
- The path that have a longest duration is called critical path and the activities in the critical path are called critical activities.
- The critical path sets the overall duration of the project.

Characteristics of Critical Path

- A critical path is longest path time (time-wise) connecting the initial and final events.
- A critical path may run through dummy activity/ activities.
- Since critical path is the path having the longest time duration, it does not mean it will have maximum number of activities.
- It is possible that a network may have more than one critical path. i.e. if two paths have the same time duration which is maximum then such paths will be the critical paths.
- It determine the total project duration.

Finding critical path in a large network

Forward pass computation

- All activities in the network are assumed to start as early as possible.
- Calculation begins from left to right side of network.
- When two or more than two activity merge into an event, the largest value is taken as an earliest occurrence of the event.
- It gives EST and EFT of each activity.

Finding critical path in a large network

Backward pass computation.

- All activities in the network are assumed to start as late as possible.
- Calculation begins right to left side of network.
- When two or more than two activity merges to event, the smallest value is taken as late occurrence of time of event.
- It gives LST and LFT of each activity.

Activity float analysis

- For the events that lie on the critical path, the EST and the LFT are equal. In other words slack of the these events is given by i.e.

  Slack = EST –LFT
- The free time available for the activity is called float. Thus float for an activity is similar to the slack of event.
- There are four types of float.

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

Activity float analysis

Total float:

- Total float represents the maximum time by which the completion of an activity can be delayed without affecting the project completion time.
- If an activity is delayed by the time equal to its total float, that activity and all the other subsequent activities in that path become the critical activities.
- **Total float of the activity = LFT of head event- EST of tail event –duration or LFT –EFT or LST -EST**

Activity float analysis

Free Float

- Free float of an activity is the delay that can be permitted in an activity so that succeeding activities in the path are unaffected.
- **Free float of an activity= EST of head event – EST of tail event – duration < TF**

Independent float

- Independent float of an activity is the spare time available for that activity, if that activity is started as late as possible and is finished as early as possible.
- **Independent float of an activity = EST of the head event –LFT of tail event - duration**

Interfering float

- It is the difference between Total float and free float

Use of different floats for management decisions

- All activities that lie in the critical path have their total floats equal to zero.
- If the total float of an activity is used entirely in that activity, it would make that activity and all the succeeding activities in the path critical.
- Hence it is not advisable to use the total float completely in an activity as this will leave cushion available if subsequent activities need additional time for completion than originally planned.

Use of different floats for management decisions

- Free float can be used completely for the activity since this does not disturb the succeeding activities.
- However preceding activities should be finished as planned.
- Independent float of an activity: since this does not disturb succeeding activities. Hence independent float can be used without any constraints.

Advantages of critical path method

- It makes dependencies variable
- It enables the calculation of float of each activity.
- It encourages the project manager to reduce the project duration.
- It enables the project manager to optimise efficiency
- It provides opportunities to the respond to the negative risk going over schedule.

Disadvantages of CPM

- For large and complex projects, there will be the thousands of activities and dependency relationships. Without the software it might be difficult managing this
- It may be difficult to print the project network diagram with thousand of activities
- It doesnot account resource levelling and resource allocation.

Numerical Example

- Consider the details of a project as shown in table:

- Construct the CPM network
- Determine the critical path and project completion time
- Compute total floats and free floats

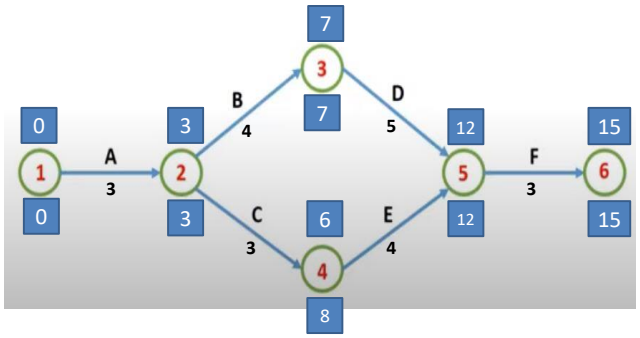
Activity	A	B	C	D	E	F
Predecessor	-	A	A	B	C	D,E
Duration	3	4	2	5	2	3

Solution: (Procedure)

1) First draw the network diagram
2) Compute the EST and LFT on the diagram
   - $ES_j = Max\ (ES_i + D_{ij})$
   - $LF_j = Min\ (LF_i - D_{ij})$
3) Check for critical paths
   - $Es_i = Lf_i$
   - $Es_j = Lf_j$
   - $Es_j - Es_i = Lf_j - Lf_i = D_{ij}$
4) Calculate Floats:

- Total Float : $TF_{ij} = Lf_j - ES_i = D_{ij}$
- Free Float : $FF_{ij} = ES_j - ES_i - D_{ij}$
- Independent Float: $IF_{ij} = ES_j - LF_i - D_{ij}$
- Interfering float : Int = TF - FF

Activity	A	B	C	D	E	F
Predecessor	-	A	A	B	C	D,E
Duration	3	4	3	5	4	3



Tabulation

S.N	Act.	Dur.	EST	EFT	LST	LFT	TF	FF	Ind	Int	Rem.
1	A	3	0	3	0	3	0				Cr
2	B	4	3	7	3	7	0				Cr
3	C	3	3	6	5	8	2				
4	D	5	7	12	7	12	0				Cr
5	E	4	6	10	8	12	2				
6	F	3	12	15	12	15	0				Cr

Check for critical paths

- $Es_i = Lf_i$
- $Es_j = Lf_j$
- $Es_j - Es_i = Lf_j - Lf_i = D_{ij}$

Calculate Floats:

- Total Float : $TF_{ij} = Lf_j - ES_i = D_{ij}$
- Free Float : $FF_{ij} = ES_j - ES_i - D_{ij}$
- Independent Float: $IF_{ij} = ES_j - LF_i - D_{ij}$
- Interfering float : Int = TF - FF

Numerical Example

- Consider the details of a project as shown in table:

- Construct the CPM network
- Determine the critical path and project completion time
- Compute total floats and free floats

Activity	A	B	C	D	E	F	G	H	I
Predecessor	-	-	B,D	A	A	C	F	C	E,G
Duration	2	3	5	4	2	5	4	3	2

Numerical Example (HW)

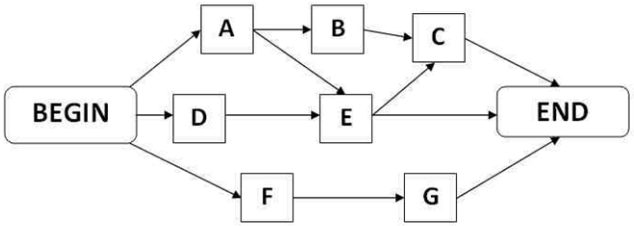
- Consider the details of a project as shown in table:

- Construct the CPM network
- Determine the critical path and project completion time
- Compute total floats and free floats

Activity	Immediate Predecessor(s)	Duration	Activity	Immediate Predecessor(s)	Duration
A	-	2	H	C,D	6
B	-	5	I	C,D	2
C	-	4	J	E	5
D	B	5	K	F,G,H	4
E	A	7	L	F,G,H	3
F	A	3	M	I	12
G	B	3	N	J,K	8

Activities on Node (A-O-N)

- It uses circles to represent the project activities with an arrow linking them together to show sequence in which they are to be performed.
- In AON method dummy activity is omitted and shows EST and LFT directly in network.
- It is possible to establish 4 types of relationship as in Linked bar chart.
- AON is also known as Precedence Diagram Method (PDM)



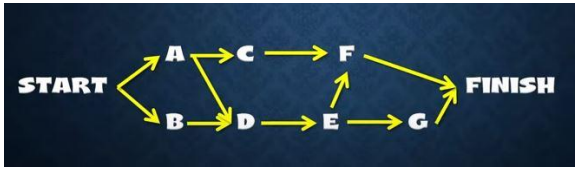
Example- (AON)

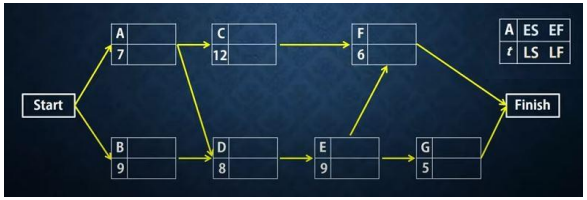
- Consider the details of a project as shown in table:

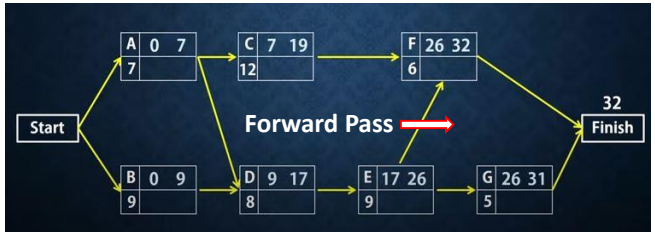
- Construct the CPM network
- Determine the critical path and project completion time
- Compute total floats and free floats

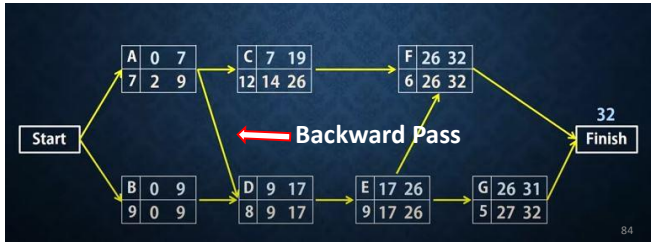
Activity	A	B	C	D	E	F	G
Predecessor	-	-	A	A,B	D	C,E	E
Duration	7	9	12	8	9	6	5

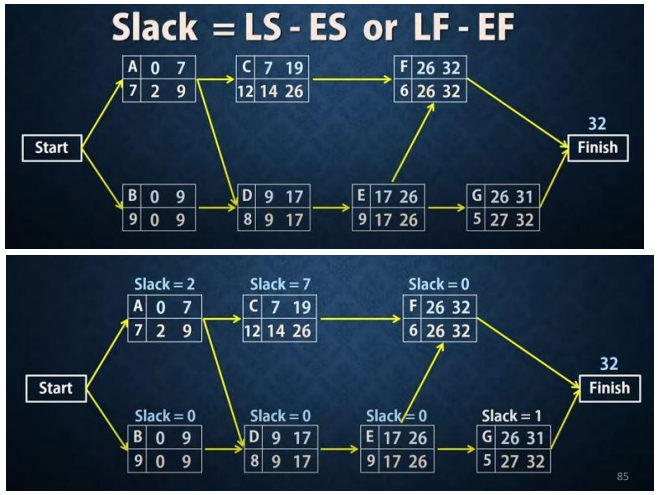
Solution

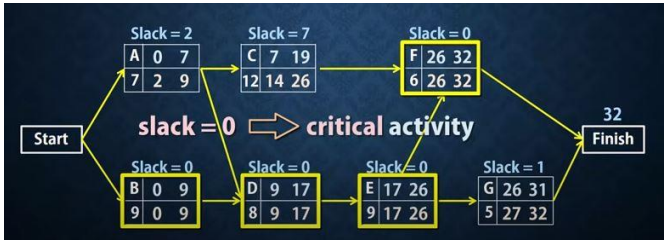












Hence Critical Activities are - B-D-E-F

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PERT (Program evaluation and Review Technique

- Like CPM, PERT is also a network based planning tool developed by US Navy in 1956/1957 and used for scheduling Ballistic Missile Project, Launching Nuclear Missile from sub-Marine
- But unlike CPM, Pert is used for novel projects like research and development where it is difficult to estimate the experience such as civil engineering works.
- It is probabilistic approach for estimating the duration of an activity and event oriented network diagram.

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PERT

PERT uses three time estimate:

- Optimistic time estimate
- Pessimistic time estimate
- Most likely time estimate

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Optimistic Time Estimate (t_o)

- It is the minimum time required to complete the activity in ideal situation.
- In arriving the Optimistic time estimate, it is assumed that everything is favorable in completing the activity in the shortest possible time.

Pessimistic time estimate (t_p)

- It is the maximum time required to complete the activity in the worst situation
- In arriving the pessimistic time it is assumed that everything is unfavorable for completing the activity in time and every possible delay and situation is encountered.

Most likely (probable) time estimate (t_m)

- It is the time required to complete the activity in normal circumstances.
- In arriving the most likely time it is assumed that conditions are neither favorable nor unfavorable but normal

Expected time estimate: (t_e)

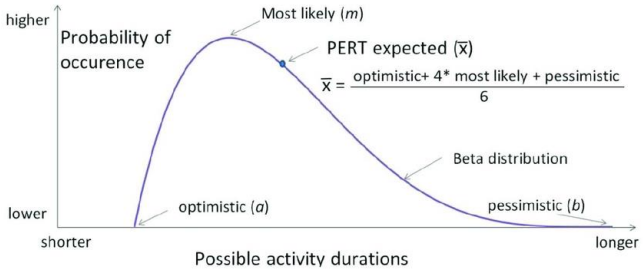
- From these three time estimates, we calculate the average time (expected time)

$$t_e = \left(\frac{t_o + 4t_m + t_p}{6}\right)$$

$$\text{S.D}(\sigma) = \left(\frac{t_p - t_o}{6}\right)$$

- Variance = S.D. ^{2} = (σ^2)

Probability of occurrence of activity time



Numerical Question

Activity	Predecessor Activity	Optimistic time estimate (to days)	Most likely time estimate (tm days)	Pessimistic time estimate (tp days)
A	-	2	4	6
B	A	3	6	9
C	A	8	10	12
D	B	9	12	15
E	C	8	9	10
F	D, E	16	21	26
G	D, E	19	22	25
H	F	2	5	8
I	G	1	3	5

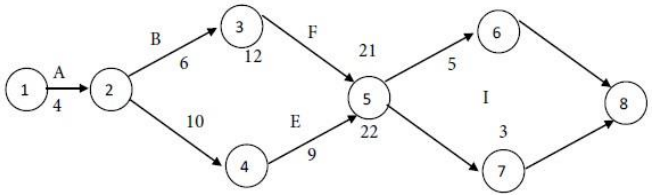
Solution:

Activity	Predecessor Activity	Optimistic time estimate (to days)	Most likely time estimate (tm days)	Pessimistic time estimate (tp days)	te	S.D	Variance
A	-	2	4	6			
B	A	3	6	9			
C	A	8	10	12			
D	B	9	12	15			
E	C	8	9	10			
F	D, E	16	21	26			
G	D, E	19	22	25			
H	F	2	5	8			
I	G	1	3	5			

Solution:

Activity	Optimistic time estimate (to)	4 x Most likely time estimate	Pessimistic time estimate (tp)	to+ 4tm + tp	Time estimate $t_e = \frac{t_o + 4\,t_m + t_p}{6}$
A	2	16	6	24	4
B	3	24	9	36	6
C	8	40	12	60	10
D	9	48	15	72	12
E	8	36	10	54	9
F	16	84	26	126	21
G	19	88	25	132	22
H	2	20	8	30	5
I	1	12	5	18	3

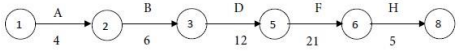
Then Draw network Diagram as :



Note: there is error in this diagram

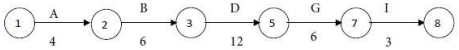
Then Find the Critical Path and Critical Activities from the network diagram:

Path I



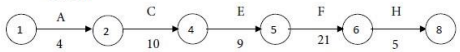
Time for the path: 4+6+12+21+5 = 48 days.

Path II



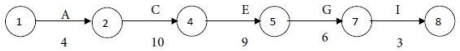
Time for the path: 4+6+12+ 6+3 = 31 days.

Path III



Time for the path: 4+10+9+ 21+5 = 49 days.

Path IV



- Expected Project Completion Time =
- Variance of te (σ^2)= sum of variance of all activities along the critical path =
- Standard Deviation of Critical Path = σ = $\sqrt{variance}$

Numerical Example (PERT)

- A project consists of seven activities with the following time estimates. Find the probability that the project will be completed in 30 weeks or less.

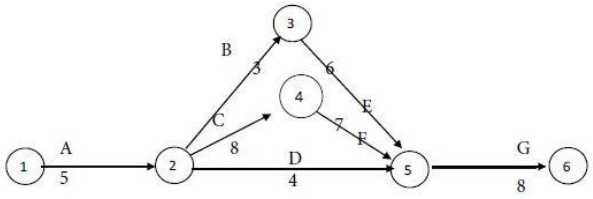
Activity	Predecessor Activity	Optimistic time estimate (to days)	Most likely time estimate (tm days)	Pessimistic time estimate (tp days)
A	-	2	5	8
B	A	2	3	4
C	A	6	8	10
D	A	2	4	6
E	B	2	6	10
F	C	6	7	8
G	D, E, F	6	8	10

Solution:

- From the three time estimates , and , calculate for each activity. The results are furnished in the following table:

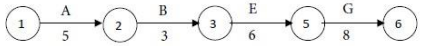
Activity	To	Tm	Tp	Te	SD	Var
A	2	5	8	5		
B	2	3	4	3		
C	6	8	10	8		
D	2	4	6	4		
E	2	6	10	6		
F	6	7	8	7		
G	6	8	10	8		

With the single time estimates of the activities, the following network diagram is constructed for the project.



Compare the paths and find the critical paths:

Path I

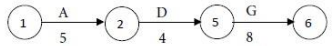


Time for the path: 5+3+6+8 = 22 weeks.

Path II

Time for the path: 5+8+7+ 8 = 28 weeks.

Path III



Time for the path: 5+4+8 = 17 weeks.

Compare the times for the three paths.

Maximum of {22, 28, 17} = 28.

It is noticed that Path II has the maximum time.

Therefore the critical path is Path II. i.e., 1 → 2 → 4 → 5 → 6.

The critical activities are A, C, F and G.

The non-critical activities are B, D and E.

Project time = 28 weeks.

Then, Find the standard deviations and variance for critical activities.

Critical Activity	Optimistic time estimate (to)	Most likely time estimate (tm)	Pessimistic time estimate (tp)	Range (tp -to)	Standard deviation = $\sigma = \frac{t_p - t_o}{6}$	Variance $\sigma^2 = \left(\frac{t_p - t_o}{6}\right)^2$
A: 1 2	2	5	8	6	1	1
C: 2 4	6	8	10	4	$\frac{2}{3}$	$\frac{4}{9}$
F: 4 5	6	7	8	2	$\frac{1}{3}$	$\frac{1}{9}$
G: 5 6	6	8	10	4	$\frac{2}{3}$	$\frac{4}{9}$

Standard deviation of the critical path = $\sqrt{2} = 1.414$

The standard normal variate is given by the formula

$$Z = \frac{\text{Given value of } t - \text{Expected value of } t \text{ in the critical path}}{\text{SD for the critical path}}$$

So we get $Z = \frac{30 - 28}{1.414} = 1.414$

- We refer to the Normal Probability Distribution Table.
- Corresponding to Z = 1.414, we obtain the value of 0.4207
- We get 0.5 + 0.4207 = 0. 9207

  Therefore the required probability is 0.92

- i.e., There is 92% chance that the project will be completed before 30 weeks. In other words, the chance that it will be delayed beyond 30 weeks is 8%

STANDARD NORMAL TABLE (Z)

Entries in the table give the area under the curve between the mean and z standard deviations above the mean. For example, for $z = 1.25$ the area under the curve between the mean (0) and z is 0.3944.

z	0.00	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09
0.0	0.0000	0.0040	0.0080	0.0120	0.0160	0.0190	0.0239	0.0279	0.0319	0.0359
0.1	0.0398	0.0438	0.0478	0.0517	0.0557	0.0596	0.0636	0.0675	0.0714	0.0753
0.2	0.0793	0.0832	0.0871	0.0910	0.0948	0.0987	0.1026	0.1064	0.1103	0.1141
0.3	0.1179	0.1217	0.1255	0.1293	0.1331	0.1368	0.1406	0.1443	0.1480	0.1517
0.4	0.1554	0.1591	0.1628	0.1664	0.1700	0.1736	0.1772	0.1808	0.1844	0.1879
0.5	0.1915	0.1950	0.1985	0.2019	0.2054	0.2088	0.2123	0.2157	0.2190	0.2224
0.6	0.2257	0.2291	0.2324	0.2357	0.2389	0.2422	0.2454	0.2486	0.2517	0.2549
0.7	0.2580	0.2611	0.2642	0.2673	0.2704	0.2734	0.2764	0.2794	0.2823	0.2852
0.8	0.2881	0.2910	0.2939	0.2969	0.2995	0.3023	0.3051	0.3078	0.3106	0.3133
0.9	0.3159	0.3186	0.3212	0.3238	0.3264	0.3289	0.3315	0.3340	0.3365	0.3389
1.0	0.3413	0.3438	0.3461	0.3485	0.3508	0.3513	0.3554	0.3577	0.3529	0.3621
1.1	0.3643	0.3665	0.3686	0.3708	0.3729	0.3749	0.3770	0.3790	0.3810	0.3830
1.2	0.3849	0.3869	0.3888	0.3907	0.3925	0.3944	0.3962	0.3980	0.3997	0.4015
1.3	0.4032	0.4049	0.4066	0.4082	0.4099	0.4115	0.4131	0.4147	0.4162	0.4177
1.4	0.4192	0.4207	0.4222	0.4236	0.4251	0.4265	0.4279	0.4292	0.4306	0.4319
1.5	0.4332	0.4345	0.4357	0.4370	0.4382	0.4394	0.4406	0.4418	0.4429	0.4441
1.6	0.4452	0.4463	0.4474	0.4484	0.4495	0.4505	0.4515	0.4525	0.4535	0.4545
1.7	0.4554	0.4564	0.4573	0.4582	0.4591	0.4599	0.4608	0.4616	0.4625	0.4633
1.8	0.4641	0.4649	0.4656	0.4664	0.4671	0.4678	0.4686	0.4693	0.4699	0.4706
1.9	0.4713	0.4719	0.4726	0.4732	0.4738	0.4744	0.4750	0.4756	0.4761	0.4767
2.0	0.4772	0.4778	0.4783	0.4788	0.4793	0.4798	0.4803	0.4808	0.4812	0.4817
2.1	0.4821	0.4826	0.4830	0.4834	0.4838	0.4842	0.4846	0.4850	0.4854	0.4857
2.2	0.4861	0.4864	0.4868	0.4871	0.4875	0.4878	0.4881	0.4884	0.4887	0.4890
2.3	0.4893	0.4896	0.4898	0.4901	0.4904	0.4906	0.4909	0.4911	0.4913	0.4916
2.4	0.4918	0.4920	0.4922	0.4925	0.4927	0.4929	0.4931	0.4932	0.4934	0.4936
2.5	0.4938	0.4940	0.4941	0.4943	0.4945	0.4946	0.4948	0.4949	0.4951	0.4952
2.6	0.4953	0.4955	0.4956	0.4957	0.4959	0.4960	0.4961	0.4962	0.4963	0.4964
2.7	0.4965	0.4966	0.4967	0.4968	0.4969	0.4970	0.4971	0.4972	0.4973	0.4974
2.8	0.4974	0.4975	0.4976	0.4977	0.4977	0.4978	0.4979	0.4979	0.4980	0.4981
2.9	0.4981	0.4982	0.4982	0.4983	0.4984	0.4984	0.4985	0.4985	0.4986	0.4986
3.0	0.4987	0.4987	0.4987	0.4988	0.4988	0.4989	0.4989	0.4989	0.4990	0.4990
3.1	0.4990	0.4991	0.4991	0.4991	0.4992	0.4992	0.4992	0.4992	0.4993	0.4993
3.2	0.4993	0.4993	0.4994	0.4994	0.4994	0.4994	0.4994	0.4995	0.4995	0.4995
3.3	0.4995	0.4995	0.4995	0.4996	0.4996	0.4996	0.4996	0.4996	0.4996	0.4997
3.4	0.4997	0.4997	0.4997	0.4997	0.4997	0.4997	0.4997	0.4997	0.4997	0.4998

Difference between CPM and PERT

CPM	PERT
Deterministic tool with single estimate of duration	Probabilistic tool used with three estimate of duration
Activity oriented	Event oriented
Considers less uncertainty	Considers more uncertainty
Best suited for routine projects requiring accurate time and cost estimates	Best suited for research and development related projects where the project is performed for the first time and estimates of the duration is uncertain
Allows and explicit estimate of cost in addition to time, therefore CPM can control both time and cost	This tool is basically a tool for planning and controlling of time
The deterministic factor is more so values or outcomes are generally accurate and realistic	The probability factor is major in PERT so outcomes may not be accurate
Easy to maintain	Costly to maintain

Similarities between CPM and PERT

- Both tools lead to the same end : critical path and critical activities with slack time equal to zero
- Extensions of both PERT and CPM allow the user to manage other resources in addition to time and money, to trade off resources, to analyse different types of schedules and to balance the use of resources.

Probability of completing the projects in Given time

- It is assumed that the project completion time follows the normal distribution.
- The area under the normal curve between mean and any point x which is one standard deviation away from the mean is always same irrespective of the values of mean and standard deviation.
- The term one standard deviation can be replaced by any standard deviation and the statement still holds good.
- If z is the number of standard deviation away from the mean for an observation z can be represented as
- Z= [observed value- mean value]/ standard deviation

Resource Optimization

- Resource optimization is a tool/ technique used in the Develop Schedule process of Schedule Management knowledge area.
- Resource optimization is a schedule network analysis technique applied to a schedule that has already been analyzed by the Critical Path Method (CPM).

Resource Optimization

- Resource optimization is needed when resources have been over allocated, such as when a resource has been assigned to two or more activities during the same time period.
- It may also be needed when certain resources (eg. equipment or machinery) are available in limited quantities, while the CPM schedule demands more than the available quantities.

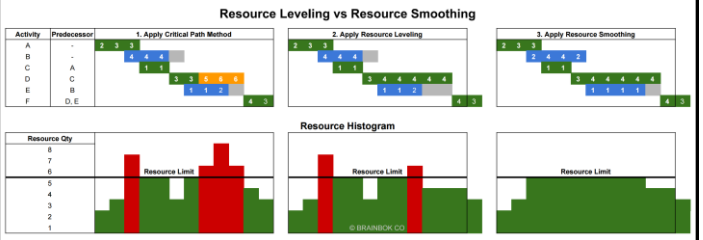
Resource leveling and resource smoothing

Planning with limited resources

- In real life project it is a common experience that the resources are frequently in a limited supply causing delay in completion of project.
- In some cases particular material or some machinery may not be available in the middle of the project.
- Availability of the fund may be restricted. Due to this following constraints are imposed
  - Starting of the activity is delayed
  - Non- critical jobs may be critical due to start in delaying
  - More than one type of resource may be scarce in the middle of performance of a particular job.

Resource leveling and resource smoothing

- Reduce peak resource requirement at undesirable times and smooth out period to period assignment is called resource leveling. It is done by moving project activities.
- If any **non critical activities are shifted** so that the **project duration does not increase** then it is called time limited resource leveling or simply resource leveling.
- But if **critical activities are also shifted** along the non critical activities it is called **resource smoothing**.
- Resource leveling is necessary to
  - Implement the project effectively
  - To reduce the cost of project



Resource Leveling vs smoothing

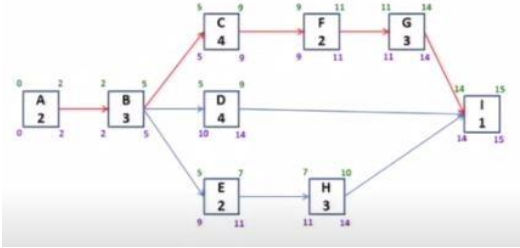
	Resource leveling	Resource smoothing
1	Resource limited scheduling technique; Importance is given to the limited resources	Time limited scheduling technique; Importance is given to the duration of the project
2	Removes all resource conflicts	Removes as much resource conflicts as possible; but, may not remove all resource conflicts
3	May not require additional resources	May require additional resources to address left over resource conflicts
4	Activities may be shifted beyond the float available while rescheduling the activities	Activities are shifted only to the extent of the float available
5	Generally, the project duration gets extended	The project duration remains the same
6	May change the critical path	No change in critical path

Numerical on Resource Leveling

Activity	A	B	C	D	E	F	G	H	I
Pre Act	-	A	B	B	B	C	F	E	D,G,H
Duration	2	3	4	4	2	2	3	3	1
Trucks	2	1	6	4	4	2	2	1	1

Plot a Resource Histogram
What if only 10 trucks are available at site.

Step 1: First draw a Network Diagram and determine the critical path



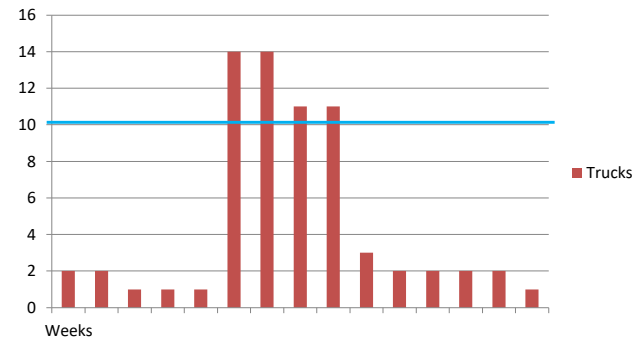
Here, Critical Path is : A-B-C-F-G-I with duration = 15 days

- Step 2: Now plot the bar diagram using EST (also you can draw using LST)

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
2	A	2	2													
1	B			1	1	1										
6	C						6	6	6	6						
4	D						4	4	4	4						
4	E						4	4								
2	F										2	2				
2	G												2	2	2	
1	H								1	1	1					
1	I															1
Sum =		2	2	1	1	1	14	14	11	11	3	2	2	2	2	1

- Check for the resources allocation number which needs to be leveled

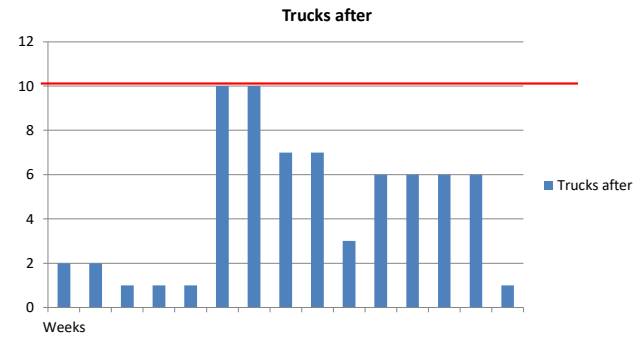
Step 3: Draw Resource Histogram



- Step 4: Now Check for the floats available and shift the non critical activities. And check for resources availability.

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
2	A	2	2													
1	B			1	1	1										
6	C						6	6	6	6						
4	D											4	4	4	4	
4	E						4	4								
2	F										2	2				
2	G												2	2	2	
1	H								1	1	1					
1	I															1
Sum =		2	2	1	1	1	10	10	7	7	3	6	6	6	6	1

Resource after leveling

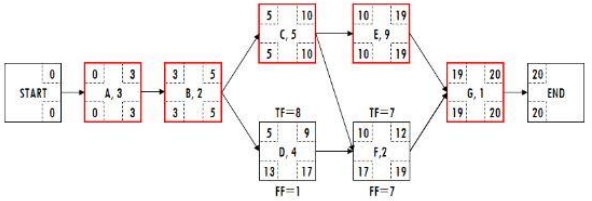


Numerical Example

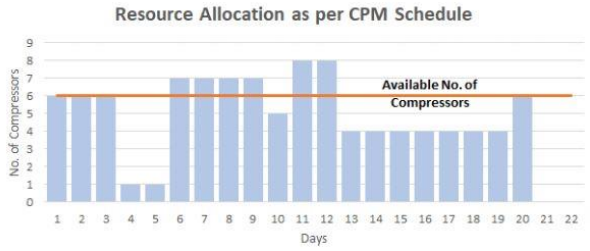
Consider a project with 7 activities as shown in the table below. The number of compressors (consider it as a resource) required by each activity is also listed. The organization has only 6 compressors available with them.

Activity	Predecessors	Duration (days)	No. of compressors needed
A	-	3	6
B	A	2	1
C	B	5	5
D	B	4	2
E	C	9	4
F	C, D	2	4
G	E, F	1	6

Solution:



Activity	Duration (days)	No. of compressors needed	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
A	3	6																						
B	2	1																						
C	5	5																						
E	9	4																						
G	1	6																						
D	4	2																						
F	2	4																						



Applying Resource Leveling

Activity	Duration (days)	No. of compressors needed	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
A	3	6																						
B	2	1																						
C	5	5																						
E	9	4																						
G	1	6																						
D	4	2																						
F	2	4																						

(the light blue color bars show the original schedule based on CPM)

Activity	Duration (days)	No. of compressors needed	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
A	3	6																						
B	2	1																						
C	5	5																						
E	9	4																						
G	1	6																						
D	4	2																						
F	2	4																						

Applying Resource Smoothing

Activity	Duration (days)	No. of compressors needed
A	3	6
B	2	1
C	5	5
E	9	4
G	1	6
D	4	2
F	2	4

Assignment

- As usual
- Also include at least 3-3 different numerical problem from the old questions and/or books (CPM, PERT and Resource Optimization)