Week-5 Time-cost trade-offs.

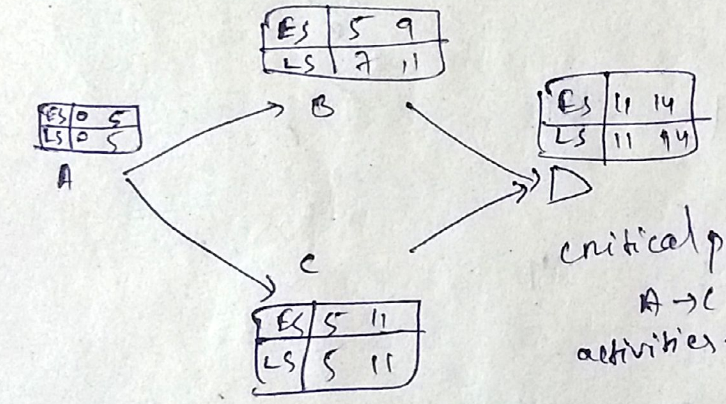
1. Fast tracking vs crashing.

Methods to reduce the time of ~~activity~~ overall project.

Fast tracking - Performing tasks in parallel to reduce time

Crashing - Reducing the time of individual activities for overall project time.

Activity	~~Activity~~ ND Durn	Predecessor	CD (min durn for an activity)	NC	CC	CD (days that can be reduced)	C/Day (expenditure of crashing a single day)	cost
A	5	–	3	250	300	2	25	
B	4	A	3	300	375	1	75	
C	6	A	3	350	875	3	175	
D	3	B, C	2	300	350	1	50	



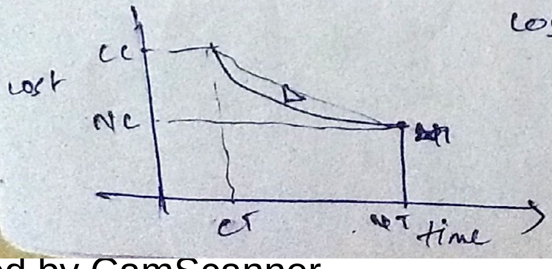
critical path
A → C → D
activities → A, C, D

~~expected durn = 14~~.
current compln durn = 14 d
expected = 10 d
How to do?

* Crashing - Reducing activity time ~~by~~ by ~~and~~ expending additional resources.

Normal durn - Usual/normal activity durn
Crash durn - minimized/reduced time durn
Normal cost - Cost incurred in completing activity in normal durn
Crash cost - " " to complete activity in crash/min durn.

$\text{Durn} \propto \frac{1}{\text{cost}}$ less durn - more cost (additional resources)
more " - less cost.



$\text{slope} = \frac{ND - CD}{NC - CC}$

Slope = $\frac{y}{x}$ = $\frac{\text{crash cost} - \text{normal cost}}{\text{Normal time} - \text{crash time}}$

Cost	
14	~~-25~~
13	+ 25/-

Final day

Cost	
14d	basic
13d	+ 25/-
12	+ 25/-
11	+ 50/-
10	+ 125/-
9	+ 125/-
8	+ 250/-

3 3 6
~~7~~ ~~4~~ ~~8~~ ~~7~~
~~8~~ ~~9~~
B

6 8
~~7~~ ~~9~~
~~8~~ 10
~~9~~ ~~11~~
10 ~~12~~
~~11~~ 13
14 ~~3~~ 14
D

~~3~~ 3
~~4~~ 4
0 ~~5~~ 8
A

3 6
3 ~~4~~ 9 ~~8~~ ~~7~~
4 ~~8~~ 10
8 ~~8~~ 11
C

Crashing details
1. A by 1 @ 25/-
2. A by 1 @ "
3. D by 1 @ 50/-
4. C by 1 @ 125/-

Task - ~~determi~~

Determine minimized cost when durn is reduced.

Critical activities - A, C, D

~~1. 13 days expected.~~

Task - 1. Choose the critical activity that has min. cost/day. Begin with that.

Here, A - 25/day C - 125/day D - 50/day.

~~Step 1 - reduce crash A.~~

~~those~~ A is chosen. A is crashed till crash durn is reached. Cost is calculated for each day. As $CD_A = 3$, ~~no~~ can't be crashed any more.

task - 2 Choose the next minimum costing crashing activity.

Here, D. CD = 2.

task - 3 ~~B~~ 1

Crashing details
1. A by 1 @ 25/-
2. "
3. D by 1 @ 50/-
4. C by 1 @ 125/-
5. C by 1 @ 125/-

Now, B is also critical. A & D fully crashed out.

6. B & C by 1 @

Cost table

normal durⁿ cost of all activities. Then sum up the extra for each of the below days.

Days	Addⁿ cost/day	Direct cost	Indirect cost	total
14	0	1200	1400	2600
13	25	1225	1300	2525
12	25	1250	1200	2450
11	50	1300	1100	$\boxed{2400}$
10	125	1425	1000	2425
9	175	1650	900	2550
8	250	1900	800	2700

this gives the min. possible cost.

constant @ 100/day.

Indirect costs

- salaries, temporary utilities like electricity, phone.
- site equipment, vehicle, office essentials. Rent, maintenance, etc.

* When project durⁿ is reduced, indirect cost will also decrease. They are not specific to any activity.

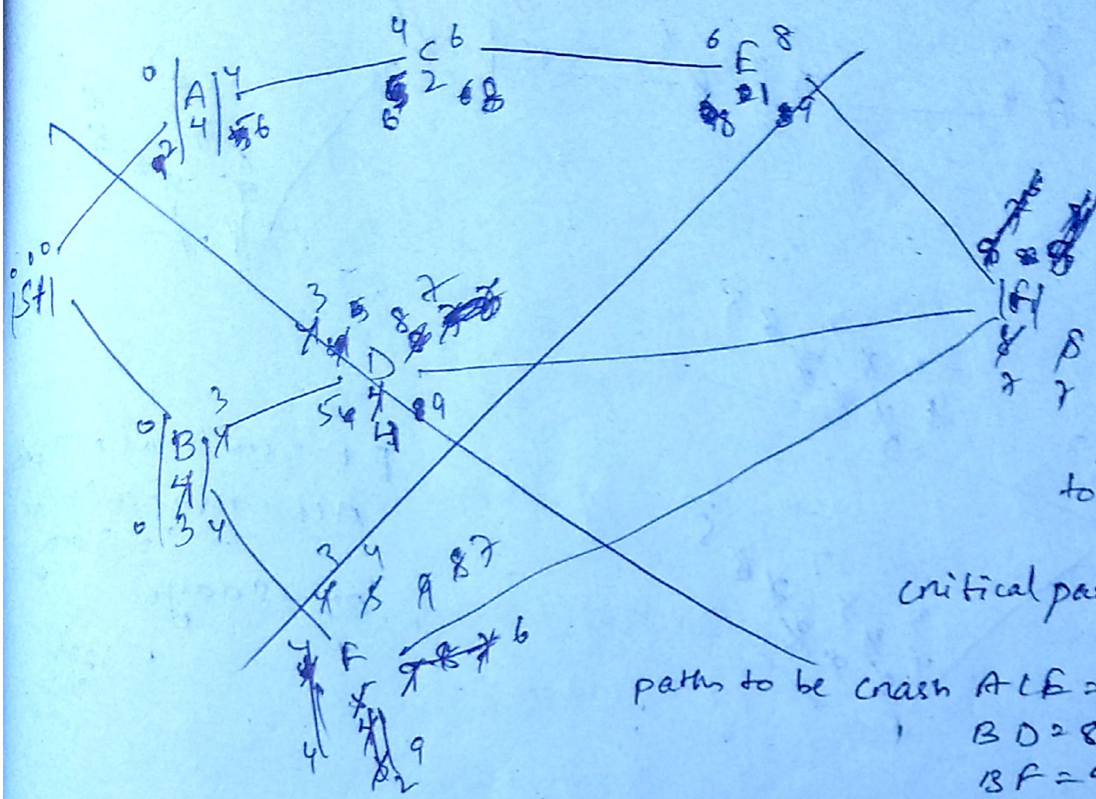
- Constant for each day, unlike direct costs that vary with activities.

$$\text{durⁿ} \propto \frac{1}{\text{direct cost}}, \quad \text{durⁿ} \propto \text{indirect cost}.$$

~~Total cost~~

Analysing the total cost shows that, initially with dec in durⁿ, cost decreases. Then it starts inc. with further decrease.

Here, 11 days is the min. total cost point. Reducing below it will incur larger costs. Thus reducing durⁿ from 14 to 11 will give optimum results.



total = 9 days

critical path = St BF Fi
= 9 days.

paths to be crash ACE = 7
BD = 8
BF = 9

Activity	ND	CD	NC	CC	$\frac{CC-NC}{ND-NC}$	
A	4	3	100	125	25	9
B	4	3	250	400	150	8 + 50/day
C	2					7 + 150
D	4	1	150	300	150	~~8 + 50~~
E	1	1	450	900	150	5 ~~+150~~
F	5	0.5	200	400	100	
		2	200	350	50	
		3				

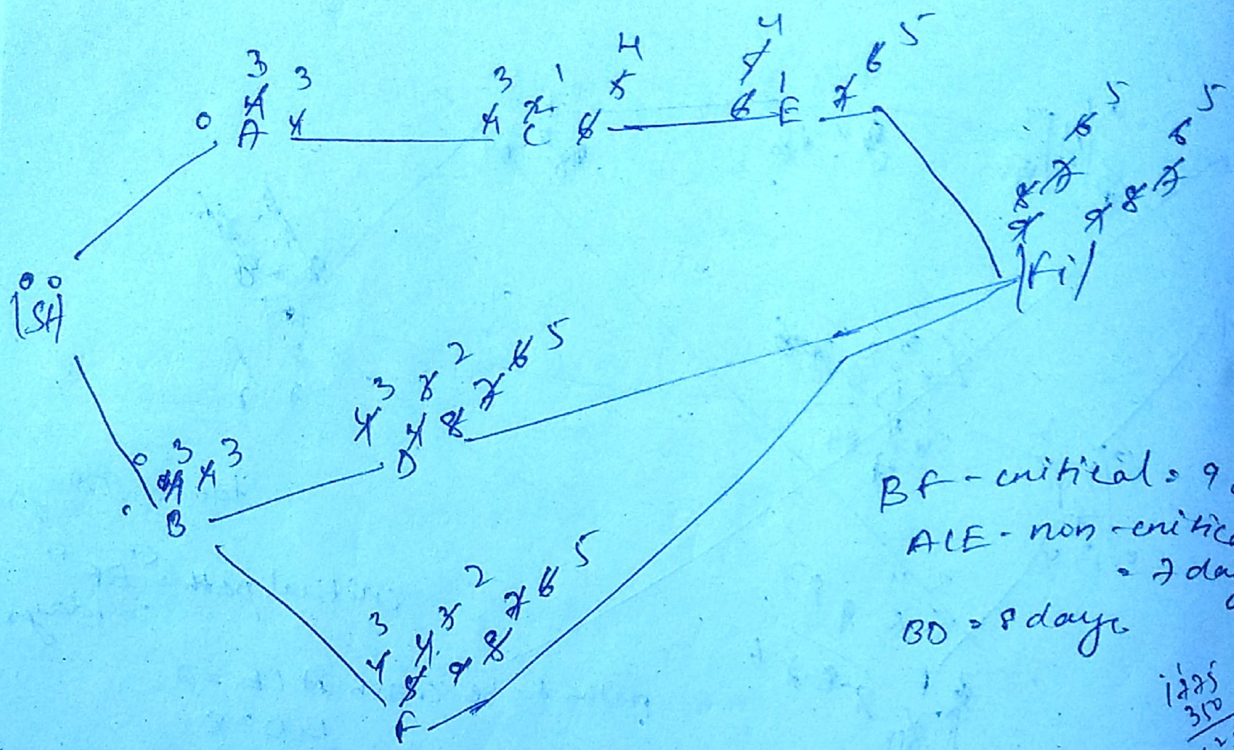
Cost table indirect - 125/day.

1. F by 1 @ 50/day → After this F & D have same values, 4 & 8, hence both are critical.
2. F by 1 @ 50/day
3. ~~F by 1 @ 50/day~~
4. ~~B by 1 @ 150/day~~

~~Redu~~ Crashing B - 150
Crashing D & F - 200.
So crash B.

2. ~~By~~ B by 1 @ 150
3.

9
8 + 50
7 + 150
6 + 225
5 + 350



BF - critical = 9 day

ACE - non-critical = 7 day.

BD = 8 days

1. ~~Crash~~ F by 1 @ 50/day

   Now both D & F are critical - Crashing B or crash D & F

   crashing B is cheaper than D & F combined.

2. B by 1 @ 150/day

   E, D, F end at the same time. So A, C, E is also critical now.

3. Possible crashes - DF along with ACE.

   DF will be definitely crashed as both are critical.

   Form combinations of DF with A, C, E.

cost → ~~Crash~~ DF A ~~by 1~~ - 225

DF C - 350

DF E - 300

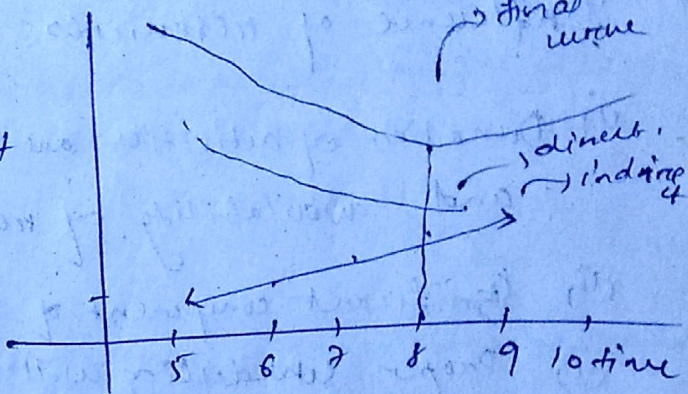
• ~~Crash~~ DFA by 1 @ 225/-

4. ~~DFE~~ DFC by 1 @ 350/-

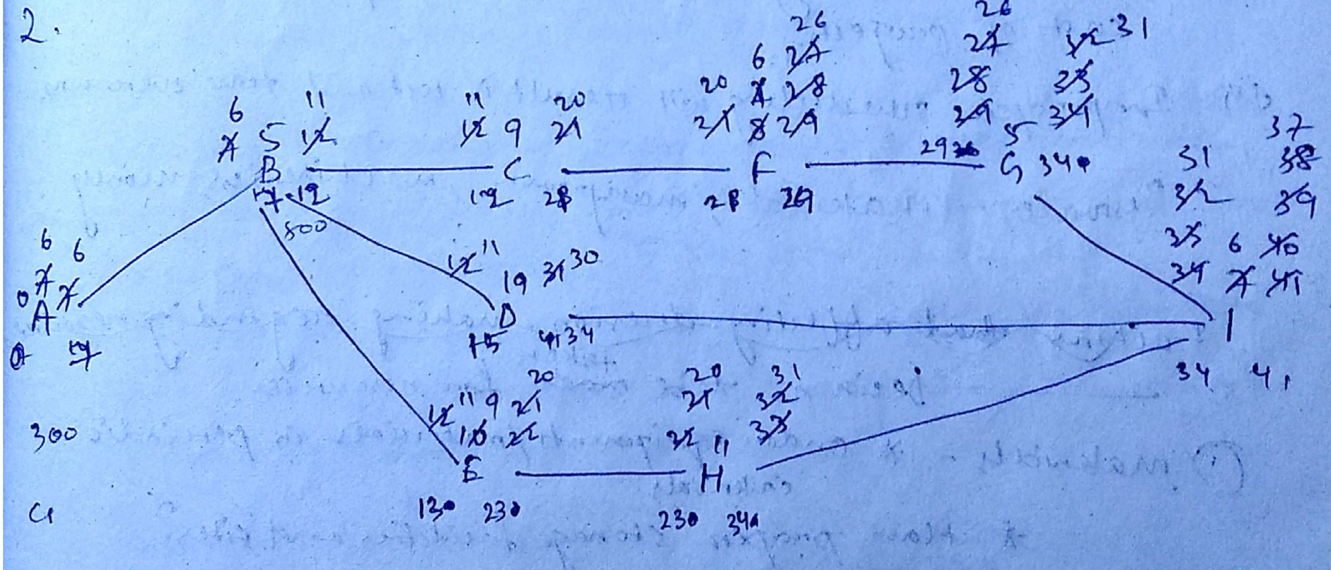
Cost table

Duration	Direct cost	Indirect cost (dur^n x cost/day)	Total
9	1350	1125	2470
8	1400	1000	2400 ✓
7	1550	875	2425
6		750	2525
~~5~~	1775		2750
5	2125	625	

8 days - optimum



2.



Critical path - ~~None~~ ABCFGI

ABCFGI - 41 days.

ABDI - ~~31 days~~ 38 days

ABEHI - ~~33 days~~ 40 days

Crash activities on ABCFGI.

1. I by 1 @ 200
2. F by 1 @ 250

~~BEH~~ E, H also critical.

Combinations possible - A, B, CE, CH, FE, FH
300 500 575 1025 400 850

3. A by 1

Critical path = ABCFGI = 41 days

Other paths = ABDI = 38 days

ABEHI = 40 days.

Critical path will change while crashing only when activities on the parallel lines are crashed.

Procurement management

Failure mode analysis.

various possibilities of failure, probabilities of failure,
How severe is the failure.

Week-6 Resource Scheduling.

Influence of resources on schedule.

(i) Duration of activities are dependant on the usage and availability of resources.

(ii) Significant component of project cost.

(iii) Proper scheduling will have the impact on time and cost of projects.

(iv) Improper scheduling will result in cost and time overruns.

Resources - material, manpower, machineries, money.

~~Factors that affecting decision making regarding resources~~

Decisions to be ~~made~~ taken for resources.

1. materials - * order equipments/materials in periodic intervals.
    * Have proper storage facilities and sites?
    * Negotiate with multiple vendors. Large quantities may give a discount?
    * Custom ~~delivery~~ of equipments delivery?

2. manpower - * Skill requirements. Find highly-skilled manpower for current work.
    * Welders, masons, carpenters.

If skilled people are unavailable, ~~new~~ substitutes have to be found or work has to be relocated.

3. Machinery - * when special equipment is needed on site.

* certain ~~eqy~~ machineries like cranes, customized crane, etc aren't easily or widely available.

* Preparatory work for equipment requirements.
  - ~~For a~~ To move a heavy-lift crane into a site, foundation ~~prey~~ has to be prepared.

* Sharing equipment with other sites.

4. Money - * Cash flow prediction.
  - Whatever amount of money is invested, it has to be received back. There has to be returns for the investment. This is cash flow. ~~Bt~~ Lack of cash flow will screw up the project.

* Credit planning.
  - Borrowing money for project progress. Proper planning should be done in order to avoid negative cash flow.

*

To visually understand requirement of resource ~~per~~ for each activity per day, gantt chart, Histogram and other bar charts are required. Time and cumulative resource per day will vary with early ~~start~~ and late start times. All the bars and charts show cumulative resources over ~~a~~ time.

Projects (P) & Resources (R)

~~single P - single R~~
~~" - multiple R~~
~~multiple P - "~~
~~" - single R~~

Single P - ~~multiple~~ single R
" - multiple R ✓ usual
multiple P - single R
" - multiple R) Large companies

In the gantt chart, for every activity 2 resources are required. Resources are added up separately.

In histogram, for every activity/day two bars will be plotted to show two diff resources.

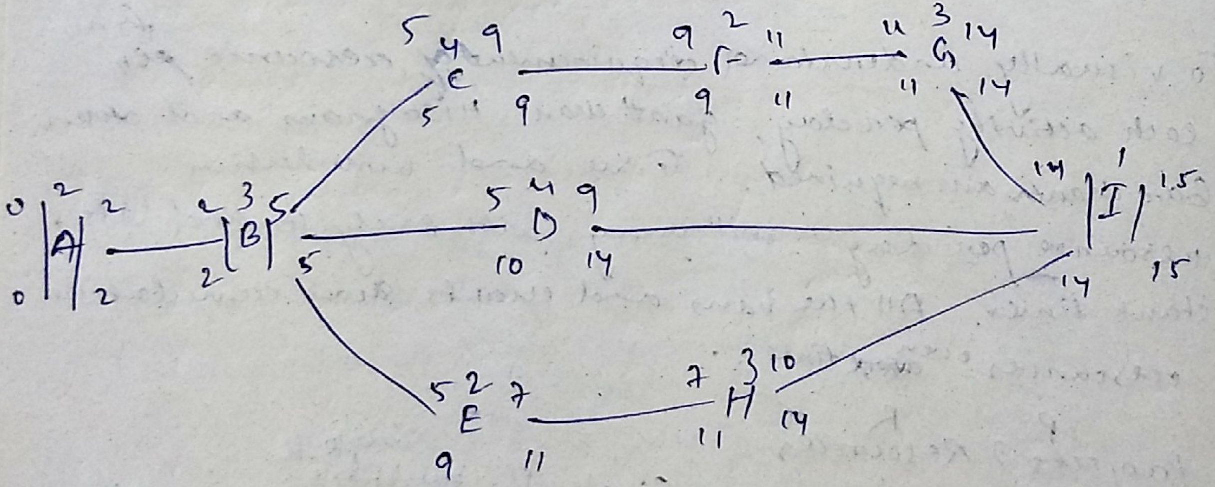
Exercise.

Activity	Preceded by	Dur^n	trucks
A	–	2	2
B	A	3	1
C	B	4	6
D	B	4	4
E	B	2	4
F	C	2	2
G	F	3	2
H	E	3	1
I	D, G, H	1	1

equipment resource.

1. Plot resource histogram.
2. What if only 10 trucks are available?

Critical – ABCFGI.



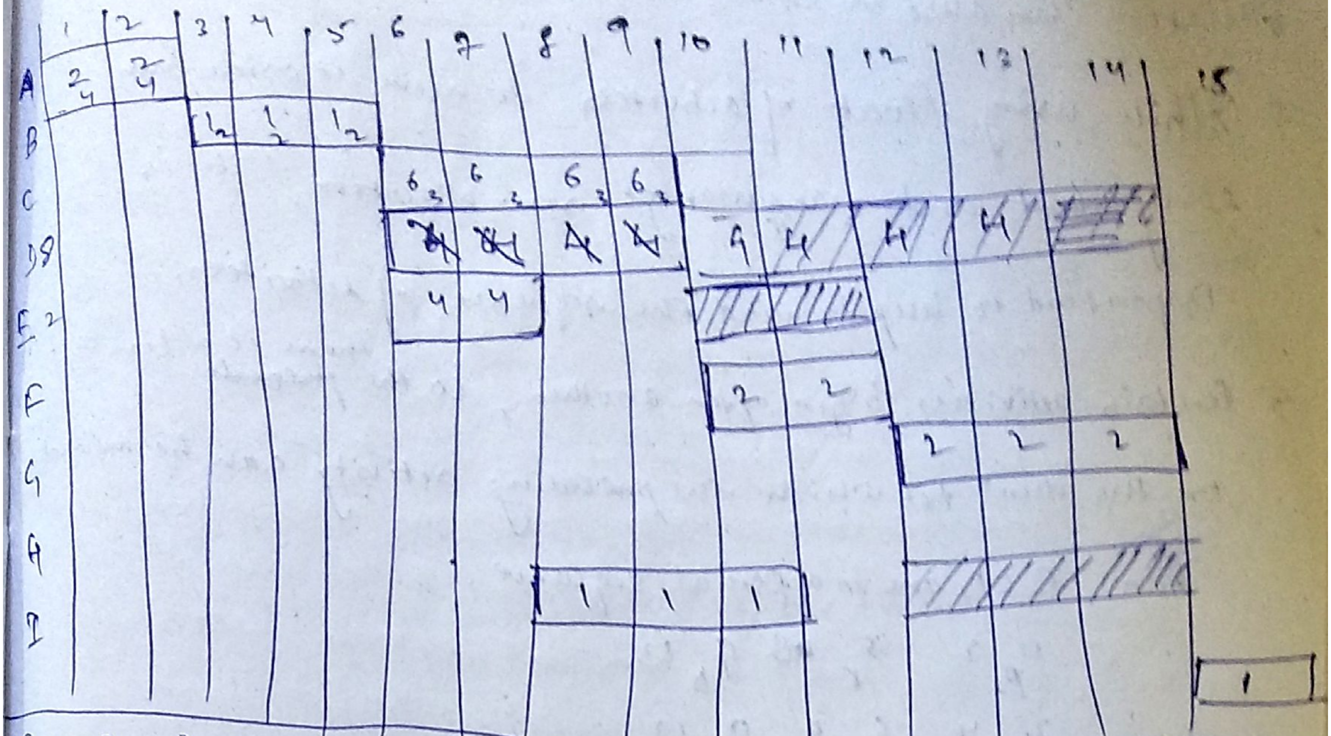
*. Critical activities do not have float/slack.

Here – A, B, C, F, G, I.

To have separate early start and late start profiles, only D, E and H can be varied in days.

In the graph – → Late start profile of activities after considering their floats.

* Overallocation of resources can be resolved by using float of an activity.



Res | 2 | 2 | 1 | 1 | 1 | ~~14~~ 10 | ~~14~~ 10 | ~~11~~ 7 | ~~11~~ 7 | ~~8~~ 7 | ~~2~~ 6 | ~~8~~ 6 | ~~8~~ 6 | 2 | 1

i) Moved D out of C's space.

This is required because the question ~~states~~ puts a constraint ~~of~~ on the # of trucks available. As the # trucks is 10, no day can have resources exceeding that value.

For days 6, 7, 8, 9, ~~10~~ resources summed up to 14 and 11.

~~Hence~~ As D has float time, it was moved out to bring resources within constraint. Two possible solutions with D. ~~None~~ Start from day 10 or 11.

Cash as a Resource

Total value/cash required for an activity is given for the entire durn - maybe days/months/years. Find a ~~total~~ value for a single day/month/year. Divide it equally.

How to manage cash overflow?

~~By~~ There is always a constraint ~~of~~ on usage of resource (total) for each day. If ~~the~~ resources allocated to activities exceed the given limit, it's called over-allocation of resources. As the resource here is only cash, over-allocation can also be called cash overflow.

* While using float of activities to move it aside from early start and ~~maag~~ manage over-allocation, it is important to keep in mind the sequence of activities.

* Certain activities begin after another, so ~~the preced~~ there is a limit on the durn till which the preceding activity can be moved.

For B C D are in a serial sequence.

0	2	5	~~10~~ 8	9	13
B		C		D	
2	4	6	9	9	13

has a float of 3 unit. But ~~can~~ has to be completed before 9th day ~~doses~~ i.e. before early start of D.

* Here, there is only one decision variable - How ~~to~~ much to ~~much~~ move each activity?

Two Resources in a single Project

Activi	Preced	Durn	Truck R-1	Workers R-2
A	-	2	2	4
B	A	3	1	2
C	B	4	6	3
D	B	4	4	8
E	B	2	4	2
F	C	2	2	3
G	~~D~~F	3	2	8
H	E	3	1	1
I	DGH	1	1	3

Q- 10 truck, 15 workers constraint.

* For multiple resources, same method of charts will is followed. Draw alloc^n charts separately for each of the resources. Then draw a single ~~b~~ histogram for both.
* Then look for over-allocation.
* Use float of activities to find a balanced use and allocation of both resources so that overall allocation of both resources ~~meets the~~ doesnot exceed limit.

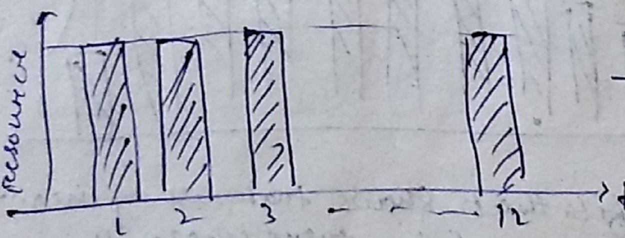
Resolving over-allocation of one resource might ~~resul~~ lead to over-allocation of the other.

Levelling Resources

* ~~Requirements~~ Resource level requirements on projects.
* Simplifying resource profile.

Levelling approaches - minimum movement algo.

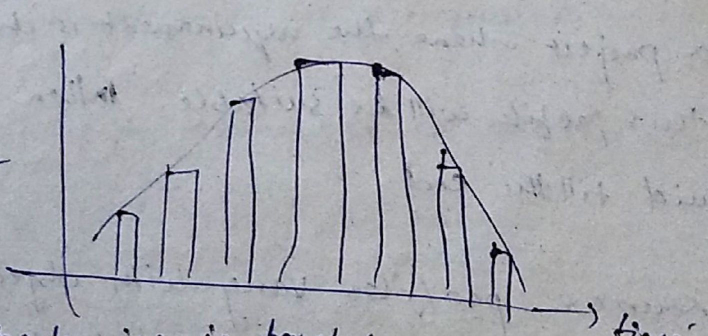
✓ Perfectly leveled resource / Ideal ~~case~~ case - Fixed amount of resources for the entire duration.



- ideal case. ~~This is~~ Aim is to achieve this perfectly levelled resource histogram.

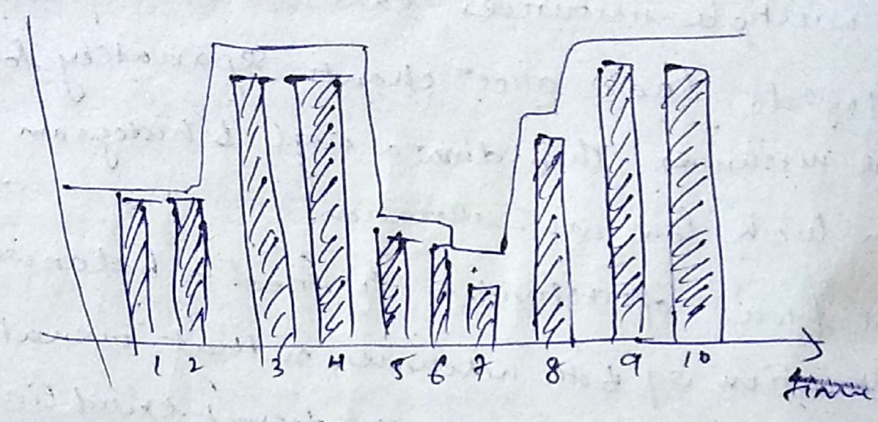
✓ another possible ~~lo~~ histogram -

A very commonly observed profile. (A practical case)



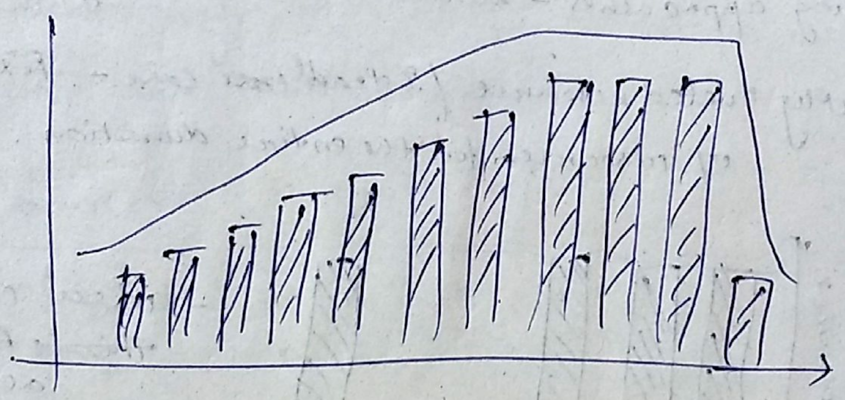
a steady inc. in demand of resources as the project proceeds. A ~~pe~~ peak of resource requirement. then a steady decrease.

3)



This can be resource profile or progress of graph of a project where weather/climatic conditions affect the working. Let's say it's for each month. In the initial months of a year - Jan/Feb, ~~there isn't~~ weather cond^n isn't very favourable. Then around march and April, weather is favourable and project progress is high. Proceeding to summer season, project progress reduces further.

4.



This ~~is~~ is a profile that shows that use of resources inc, reaches a peak point ~~for season~~ and stays there constantly till the project completes.

For a project where the requirement is changing continuously, this profile will be suitable. When requirements are fluid till the end.

Resource profiles vary with objective & demand of project. Can be as different in many different cases. But first one is the ideal ~~an~~ case.

Reason behind resource leveling - manage over-allocation.

* Apart from ~~ov~~ resolving over-allocation, resource levelling is also required to remove abrupt or random variations in need of resources. the variation over time should be smooth and not abrupt. Hence, to achieve that ~~al~~ also resource leveling is required.

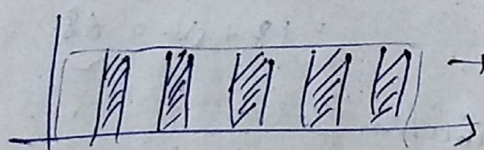
* Resource leveling can be done ~~usin~~ by exploiting the float of non-critical activities. For ~~a~~ all the possible shifts in the ~~no~~ " " , find the best ~~comb~~ combo. that results in total usage of resources which looks levelled and stays within ~~co~~ constraints.

Minimum moment concept

A mathematical method to find out the levelled profile.

→ The moment of the shape about horizontal axis is minimum only when the profile of the resources is rectangular.

The ideal case of levelled resources is -



→ this is called rectangular profile. ~~So~~ Only in this case, moment is minimum.

Objective - Given any profile of resources, ~~somehow~~ bring it as close as possible to this rectangular shape., So that there is less variation in use of resources.

Moment of a resource histogram is calculated as -

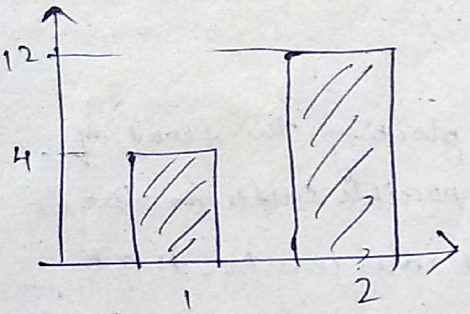
$$\boxed{M = \Sigma (Y * Y/2)}$$ on x-axis.

Sum of $(Y * Y/2)$ of all bars given in a histogram.

Y is the height of the bar.

In a resource histogram, x-axis ~~denoted~~ denotes duration of project in days/months. Y- axis denotes units/no. of resources utilized i.e. weight of a bar in the histogram denotes that.

Lets say, a resource profile of 2 days that utilizes 16 resource units is as below.



1 → 4 units
2 → 12 units.

Moment of the profile

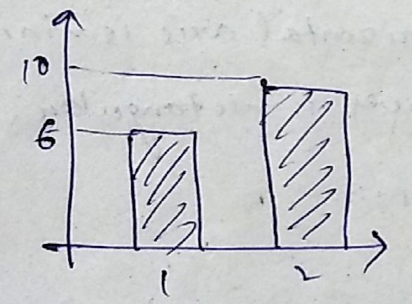
$= (4 * 4/2) + (12 * 12/2)$

$= (4 \times 2) + (12 \times 6)$

$= 8 + 72 = 80$

~~The same profile is a modified as below~~

• The same no. of resource units with a different distribution



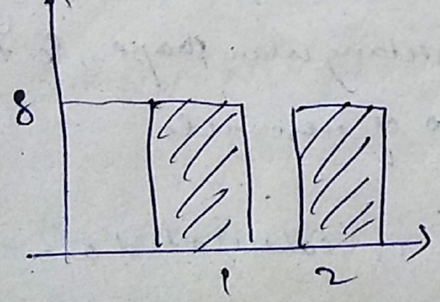
1 → 6 2 → 10 units

$M = (6 \times 6/2) + (10 \times 10/2)$

$= (6 \times 3) + (10 \times 5)$

$= 18 + 50 = 68$

Another possible distribution -



1 - 8 2 - 8

$M = (8 \times 8/2) + (8 \times 8/2)$

$= 2 \times 8 \times 4$

$= 64$

~~Hence the minimum moment~~

Minimum moment is obtained in the third case, where resources are equally levelled on both days. With the same no. of resource units and days, moment can vary widely with distribution and levelling.

From the above it is also observed that rectangular profile truely gives the least moment.

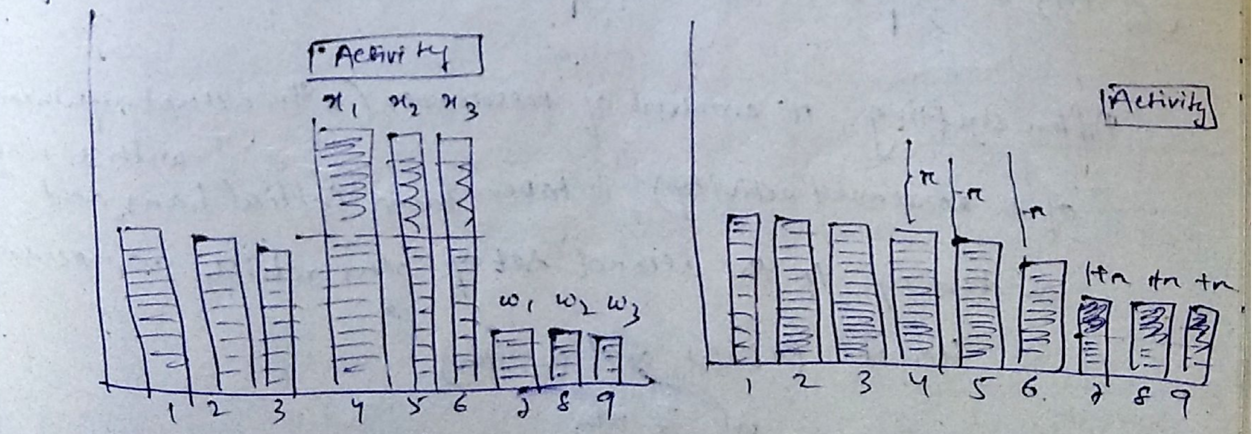
* The concept is to reduce the moment of histogram in a systematic way and that profile obtained is the most levelled and as closest ~~to~~ possible to a rectangular profile.

* Possible procedure to calculate the optimum level -

i) Find all possible combinations of floats/shifts of non-critical activities. Find moment for each ~~of~~ one of them. And figure out the min. moment. ~~But this~~ But this method ~~is~~ gets tedious when there are higher no. of resources and complex network of activities.

ii) An improvement function.
Each time an activity shifts towards late start profile by certain days/~~unit~~ time units, whether there is an inc. in moment of histogram or a decrease in moment (i.e. improvement) in histogram.

$\boxed{3}$ → denotes shifts/extras.



When activity happened on days 4, 5, 6 there was a certain extra load of resources on that day. Moving it to days 7, 8, 9 using its float has created a certain kind of balance. ~~Ex~~ Extra of day-4, 5, 6 was removed and added up to day - 7, 8, 9.

- x_i – resource level from which resource are moved for m days.

w_i – resource level to which the m days of resources are moved.

m – no. of days when resources are removed/added.

~~(no. of days of activity affecting those resources)~~

not necessary to shift the entire activity. x_i – initial level w_i – final level of a histogram

r → resource load of the activity.

For Histogram 1,

$$M_1 = \frac{1}{2}\sum_{i=1}^{m}(x_i^2) + \frac{1}{2}\sum_{i=1}^{m}(w_i^2) \quad \left[\text{moment} = \frac{x \times x}{2} = \frac{x^2}{2}\right]$$

- ~~Each bar~~ Before shifting, the initial bars which had extra resources are denoted by $x_1, x_2 \ldots x_m$. And the days which lacked resources are $w_1, w_2 \ldots w_m$.

For histogram 2,

$$M_2 = \frac{1}{2}\sum_{i=1}^{m}(x_i - r)^2 + \frac{1}{2}\sum_{i=1}^{m}(w_i + r)^2$$

After shifting, r amount of resources (the actual requirement of the concerned activity) is taken from initial bars with x_i resources and added up to the second set of bars which w_i resources

Hence $(x_i - r)$ and $(w_i + r)$.

* Now compare M_1 & M_2.

$M_1 = M_2$ → shifting did not bring up any benefit.

$M_1 < M_2$ → shifting increased the moment. Should not be shifted then.

$M_1 > M_2$ → shifting reduced the moment. Hence, desirable.

$$IF_{A,d} = \pi\left(\sum_{i=1}^{m} x_i - \sum_{i=1}^{m} w_i - mn\right)$$

$IF_{A,d}$ = improvement factor for shifting activity A, d days out in time.

IF > 0, implies reduction in moment due to shift.

m = min # days that the activity is shifted, or durn of activity

x_i = daily resource sum of activity for the current time frame, over which resources will be removed.

w_i = daily resource sum of activity for the ~~current~~ time frame over which resources will be added.

π = ~~ditto~~ daily resource load for the activity.

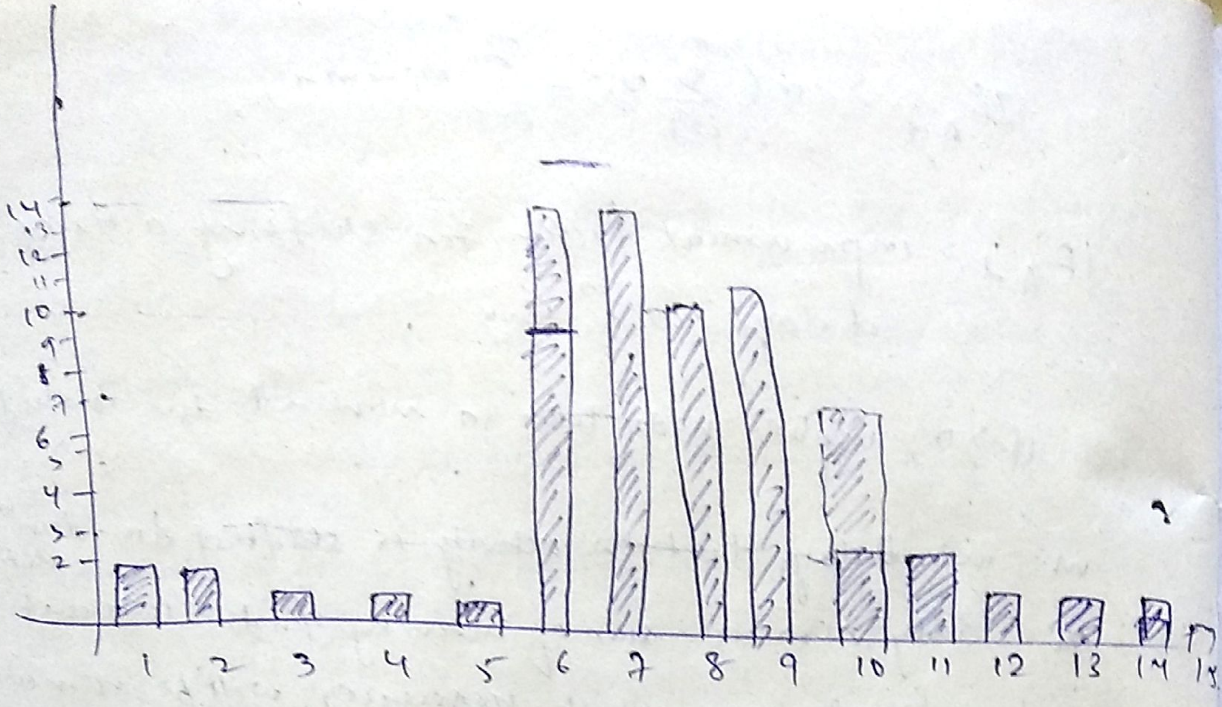
Ex– Problem on minimum moment concept.

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

If Activities D, E, H can be shifted. Calculate moment at each step.

Start – (i) shift D by 1.

IF (D, 1) =



Step-1 Shift D by 1. It will move from Day 6 to Day 10.

x_1 = resource at Day 6 = 14

w_1 = " " " 10 = 3

$n = 4$

$m = 1$

① $IF(D,1) = 4(\cancel{- 6 - 10 - 4\times1}) = 4(14-3-4)$

$= 4\times7 = 28 > 0$

∴ moment reduced. This means move D by 1. Now it ranges from Day ~~7~~ to Day 10. Da

change in Histogram - Day 6 = 10 (earlier 14)

Day 10 = 7 (earlier 3)

Step-2

~~IF(D,2)~~ = IF(D,2)

As $n = 4$, $m = 2$, $x_1 = 14$, $x_2 = 14$, $w_1 = 3$, $w_2 = 3$

(~~10~~) D-6, ~~14~~ D-7, (D-10), (D-11)

$IF(D,2) = 4((14+14) - (3+3) - 2\times4)$

$= 4(28-6-8) = 4\times14 = 56 > 0$

∴ moment reduced again. As value is higher than Step 1, this is a better option.

shifting D by 3 days - $n=4$, $m=3$, $x_1=14$ $x_2=14$ $x_3=10$
D6 D7 D8

step-3

$w_1=3$ $w_2=3$ $w_3=2$
D10 D11 D12

$IF(D,3) = 4((14+14+10)-(3+3+2)-4\times3)$
$= 4\{38-8-12) = 4(38-20) = 4\times18 = 72>0$

∴ moment reduced even better.

shifting D by 4 days - $n=4$, $m=4$, $x_1=14$ $x_2=14$, $x_3=10$
$x_4=11$

step-4

$w_1=3$, $w_2=3$, $w_3=2$, $w_3=2$

~~$IF(D,4) = 4(38+$~~
~~$= 4[(14+14+10+11)-(3+3+2+2)-(4\times14)]$~~
~~$= 4[49-10-56] = 4\times(59-66)$~~
~~$= 4\times-7 = -28<0$~~

~~∴ Not a desirable shift.~~

$IF(D,4) = 4[(14+14+10+11)-(3+3+2+2)-(4\times4)]$
$= 4[49-10-16] = 4[49-26] = 4\times23 = 92>0$

∴ Even better.

step-5 shifting D by 6 days.

$IF(D,5) = n=4$, $\boxed{m=5}$, $x_i = 14, 14, 10, 11, 3$ $w_i = 3\ 2\ 2\ 2$
$m=4$. ↳ will remain 4.
Because 4 days of resources are being shifted. Durn of D is 4 days, it assigned resources for 4 days. Hence m can never exceed total durn of an activity.

$IF = 4(49 - 9 - 16) = 4(49-25) = 4\times24 = 96>0$

∴ Best option.

Hence, to level the resource histogram closer to a rectangular profile. D should be moved by 5 days.

Shifting Activity H

1. IF(H,1) = $r = 1$, $m = 1$, $x_1 = 4$ $w_1 = 2$

~~IFF~~ = 1(11 - 2 - 1) = 11 - 3 = 8 > 0

2. IF(H,2) = $r = 1$, $m = 2$ $x_1 = 11, 11$ $w = 13, 2$

1 ((11+11) - (13+2) - 2×1) = 1[22 - 15 - 2]
= 22 - 17 = 5 ≥ 0

3. IF(H,3) = $r = 1$, $m = 3$, $x = 11, 11, 3$ $w = 2, 13, 13$

[(11 + 11 + 3) - (2+13+13) - 3]
= 25 - 28 - 3 = 25 - 31 = -6 < 0 → moment increased.

∴ option 1 ~~was~~ is the best. Shifting H by 1 will give best results.

Shifting Activity E

1. IF(E,1) = $r = 4$, $m = 1$, $x_1 = 14$, $w_1 = 10$

4(14 - 10 - 4) = 4(0) = 0

2. IF(E,2) = $r = 4$, $m = 2$, $x_1 = 14, 14$ $w = 10, 11$

= 4(28 - 21 - 8) = 4(28 - 29) = 4 × -1 = -4 < 0

moment increased.

3. IF(E,3) = $r = 4$, $m = 2$, $x = 14, 14$, $w = 11, 3$

4(28 - 14 - 8) = ~~28~~ (4 (28 - 22) = 4 × 6 = 24 > 0

4. IF(E,4) = $r = 4$, $m = 2$, $x = 14, 14$ $w = 3, 3$

4(28 - 6 - 8) = 4(28 - 14) = 4 × 14 = 56 > 0

∴ moving E by 4 days will give least moment.

Week 7

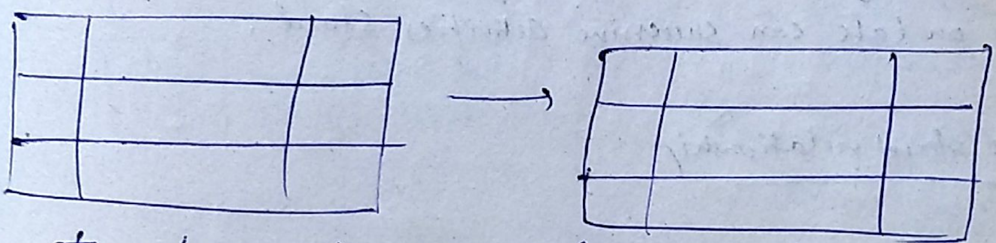
Precedence Diagramming method (PDM). - Module-2

AOA → Activity on Arrow   O —Act→ O
AON → " " Node   (Act) — (Act)

→ PDM utilises event-based approach of AoA but flow of AON.
→ It is a popular method of representation in almost every scheduling method ~~as~~ given by Project management software.

PDM Notation

1. AON Type Notation.



These boxes will contain information about activities. Activity name, duration, ~~float~~ and maybe resources info too. early & late start time, early & late finish time, float.

2. 4 types of relationships:

- Start to start relⁿ
- Finish to start " ✓ - so far only this representation is being used. Notation shows sequence as end of activity ↓ start of next activity.
- Start to finish "
- Finish to finish "

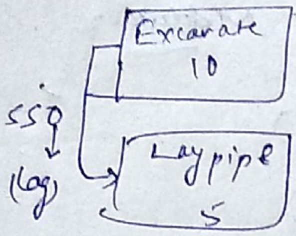
3. Leads and Lags.

This shows the gap betⁿ start or finish of 2 following activities in a sequence.

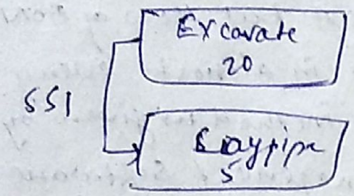
Finish to start with 2 day lag.

that ~~mean~~ means, an activity will start 2 days after the preceding activity has finished its execution.

Start to start



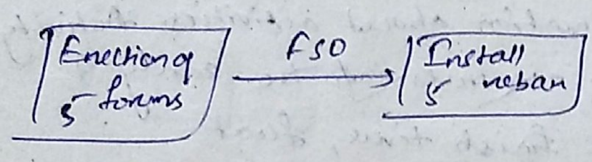
Zero lag: Lay pipe cannot start before Excavate starts.



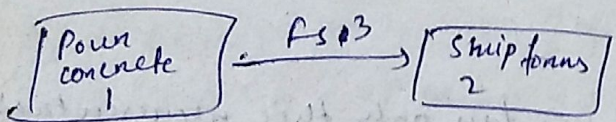
Positive lag: Lay pipe can start no earlier than one day after excavation starts.

Here the diagram shows start of activities only. And how early or late can successive activities start.

Finish to start relationship

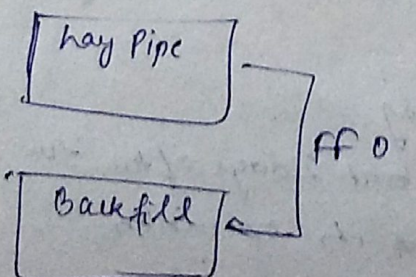


~~2000~~ Zero lag: Installation of forms can start only after the erection of forms (1st activity) is completed.

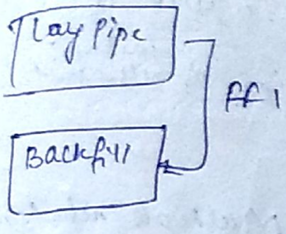


Positive lag: Strip forms activity will start 3 days after completion of pour concreate activity. ~~Cannot start~~ wait for 3 days after completion of Activity 1, then only start Act 2.

Finish-finish relationship



Zero lag: Back fill (Act 2) can be completed only after Lay pipe (Act 1) is completed.
Act 2 cannot be completed before Act 1 is completed.



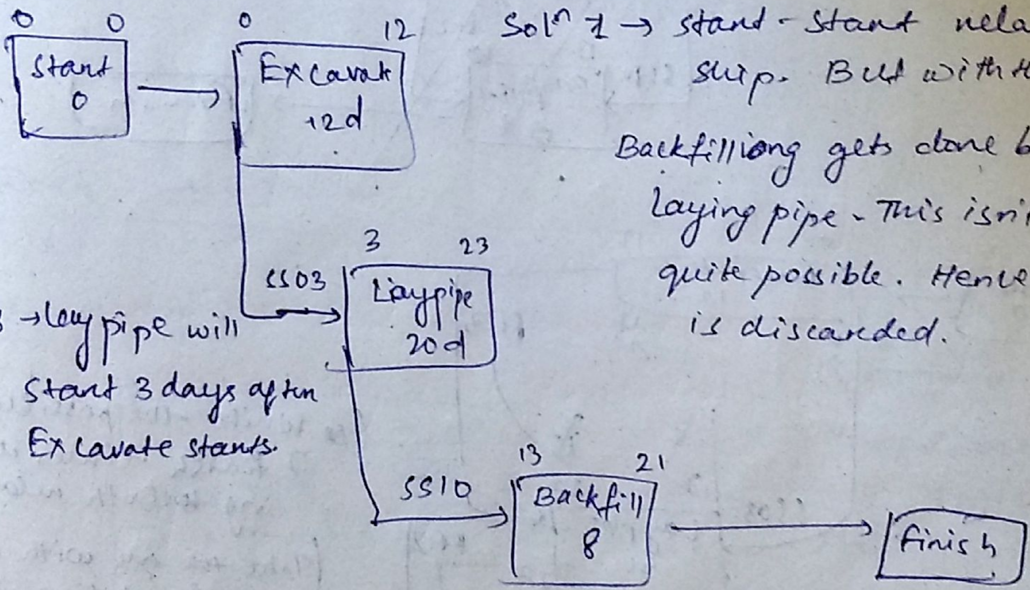
Positive lag: Backfilling can be completed no earlier than 1 day ~~before~~ after Lay pipe activity is completed.
~~It can be finished only at day after lay pipe~~

Act 2 can be finished 1 day after Act 1 is finished. Not before 1 day.

+ → delay (lag)

- → lead

PDM analysis

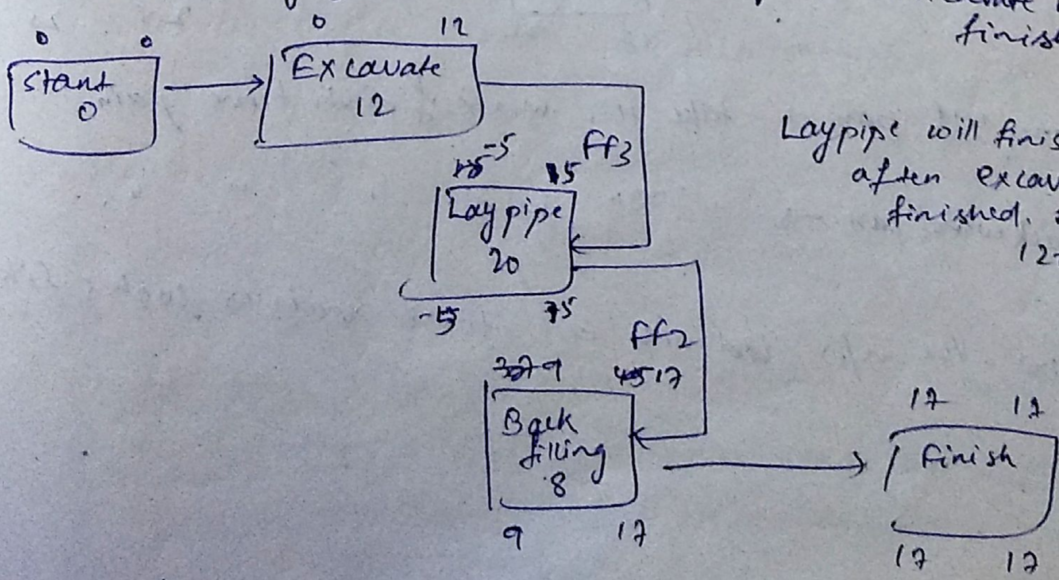


Soln 1 → start - start relationship. But with this, Backfilliong gets done before laying pipe - This isn't quite possible. Hence this is discarded.

SS 03 → lay pipe will start 3 days after Excavate starts.

Soln-2 Finish-finish relationship. An activity will finish after some days of ~~finishing~~ completion of the preceding activity.

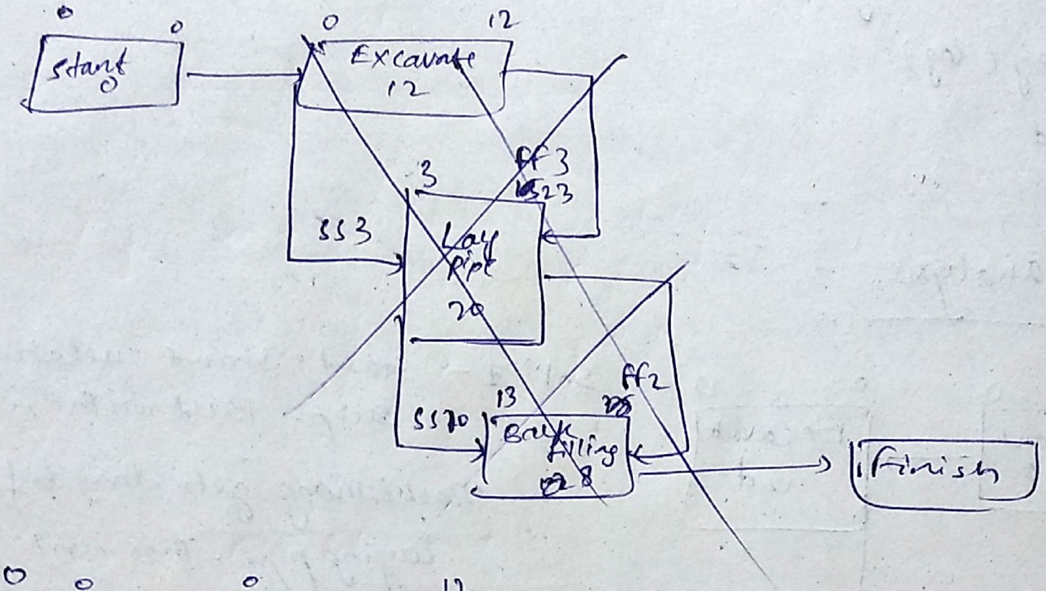
FF3 → Laying pipe will finish 3 days after Excavate has finished.

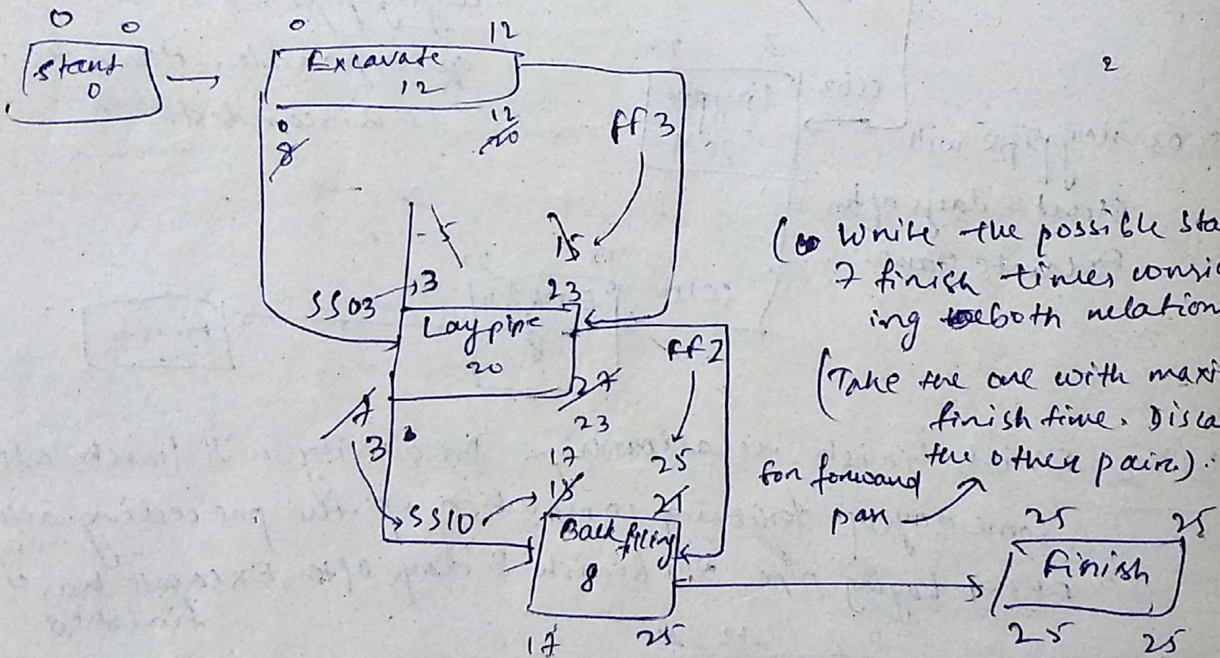


Laypipe will finish 3 day after excavate has finished. Hence 12+3 = 15 ✓.

As the early finish of Laypipe is negative which is practically not possible, ff relationship is also not failed.

Sol^n 3 → Using both SS & ff relationships. Multiple relationship on activities.





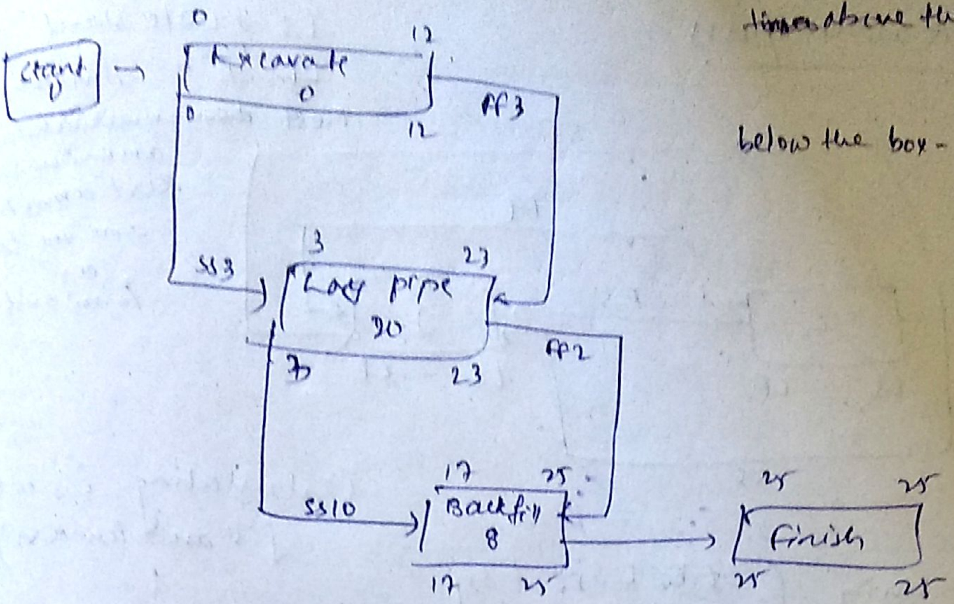
(Write the possible start & finish times considering both relationships.
(Take the one with maximum finish time. Discard the other pair).

for forward pass

Forward pass → take the max finish time pair.

Backward pass → " " min " " ".

Now the n/w with all time values looks like-



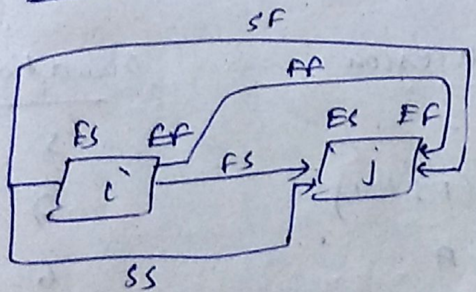
times above the box - early times (start & finish)

below the box - late times (start & finish)

* PDM may require multiple relationships between activities. But they should form a loop.

Network Calculations

* Forward pass



D_j → Duration of activity j

ES → Early start

EF → " finish

SS → Start start

SF → " finish

FF → Finish "

FS_{ij} → " - start. lead/lag of activity i, j

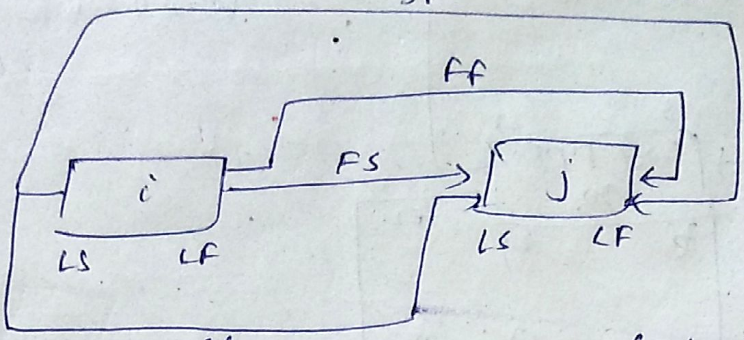
$$ES_j = \max \begin{cases} EF_i + FS_{ij} & \text{(FS relationship)} \\ ES_i + SS_{ij} & \text{(SS relationship)} \\ EF_i + FF_{ij} - D_j & \text{(FF relationship)} \\ ES_i + SF_{ij} - D_j & \text{(SF ")} \end{cases}$$

$$EF_j = \max ES_j + D_j$$

FS_{ij}, FF_{ij}, SF_{ij}, SS_{ij} are the lead/lag values for the different possible relationships.

* Backward pass

LS → Late start
LF → " finish
~~Rest der conventions are the same.~~
Rest annotation are the same as forward pass.



(Calculating i's when j's are known).

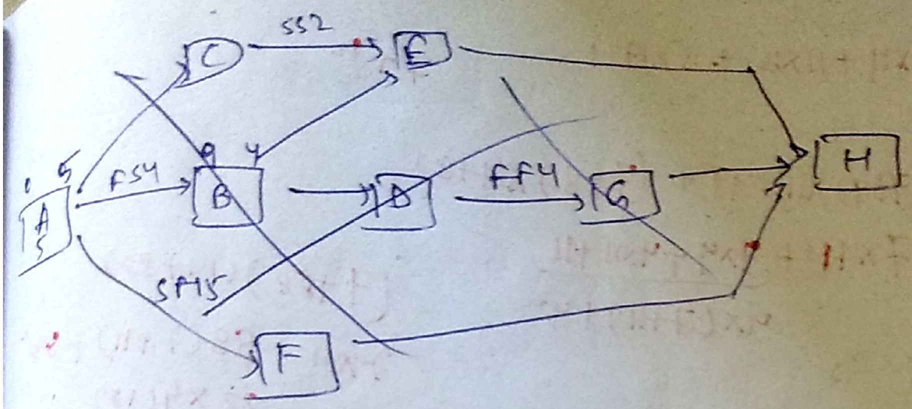
$$LF_i = \min \begin{cases} LS_j - FS_{ij} \\ LF_j - FF_{ij} \\ LS_j - SS_{ij} + D_i \\ LF_j - SF_{ij} + D_i \end{cases}$$

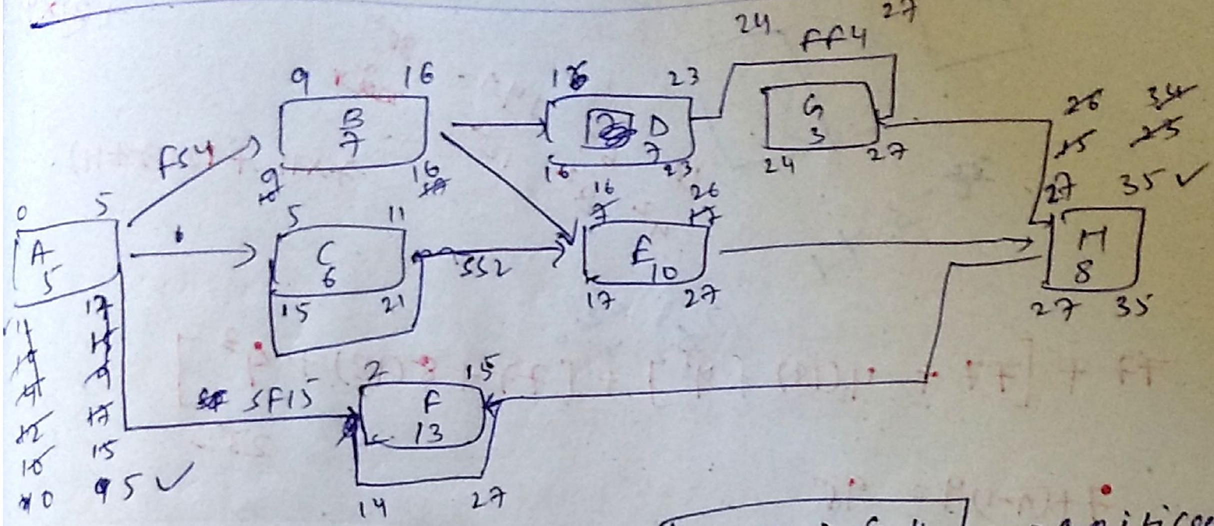
$$LS_i = \min LF_i - D_i$$

Problem

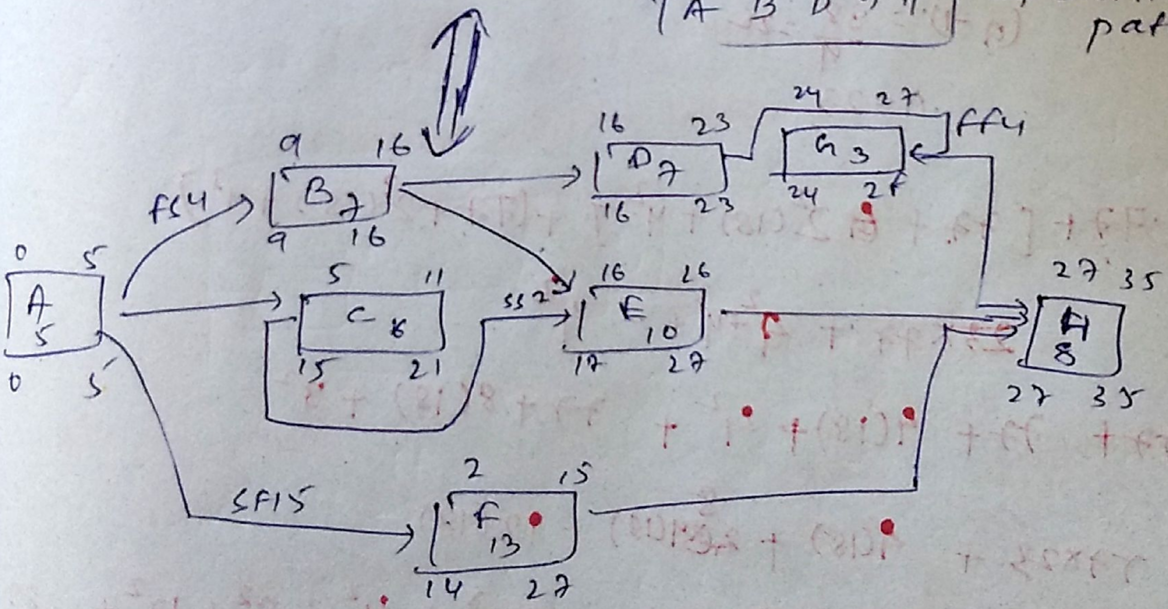
Activity	Predecessor	Duration
A	–	5
B	A(FS+4)	7
C	A	6
D	B	7
E	C(SS+2), B	10
F	A(CF+15)	13
G	D(FF+4)	3
H	E, F, G	8

Q– Draw PDM network. Find ES, EF, LS, LF & critical path.



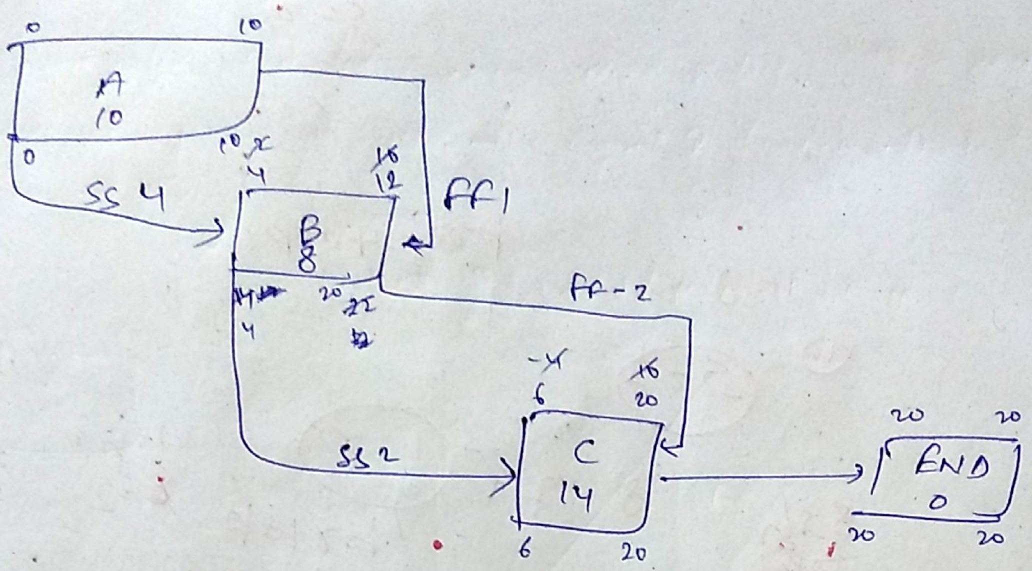


A B D G H → critical path



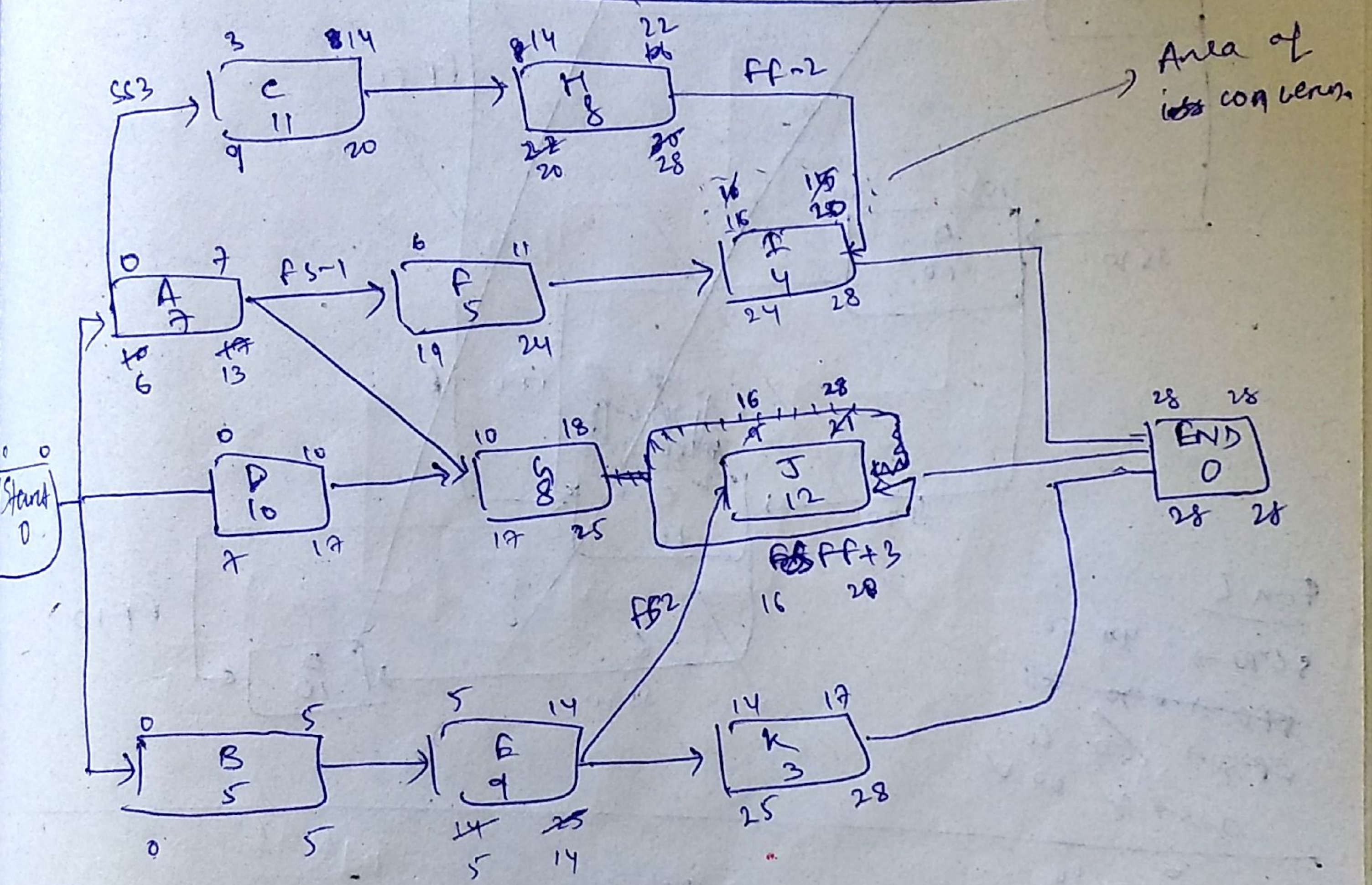
Final network

PDM network

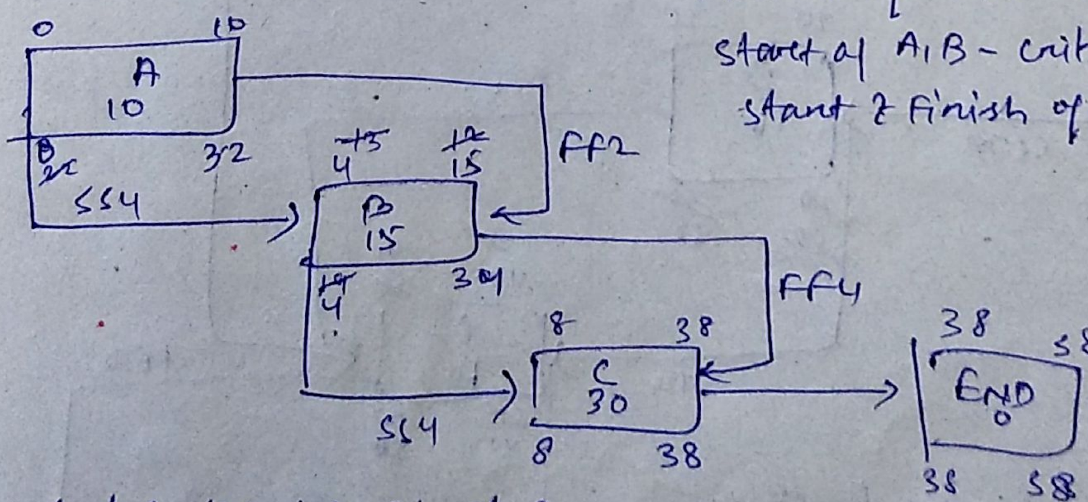


Due to negative lag, there is an inconsistency in the late start & finish times of B. Taking FF-2 from C, late start of B comes as 22, but as the entire durn of project is 20, 22 isn't possible. So truncated to 20. With SS2 reln, early start of B = 4. This creates an inconsistent situation. B, late start = 4 ∴ finish = 20 durn = 8. ?? Not quite possible.

Activity	Predecessor	Duration
Start	-	0
A	Start	7
B	"	5
C	A(SS+3)	11
D	Start	10
E	B	9
F	A(FS-1)	5
G	A, D	8
H	C	8
I	F, H(FF-2)	4
J	E(FS+2) G(FF+3)	12
K	E	3
End	I, J, K	0



Another Example.



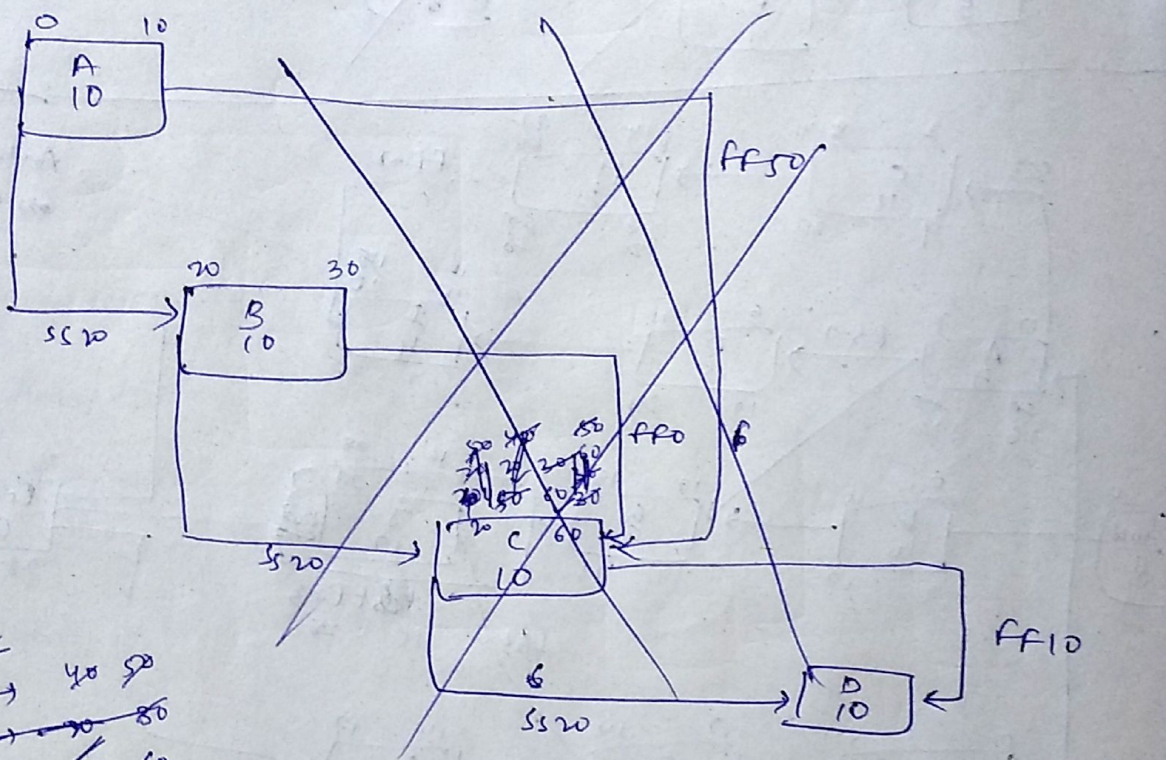
Finish of A, B - flexible
Start of A, B - critical
Start & Finish of C → critical.

Here, we calculate the late start & finish times of activities taking both relationships. Then we are considering min start & max finish time. (late). This results in critical start times but flexible finish times.

~~min of late start~~ when you have a couple of start & finish time pair options, ~~take~~; for the starts, choose min value, for finish choose max value. This ~~min~~ min-max pair will form the start & finish times for the activity.

~~25~~ 30
50 ~~60~~

where Extract(MONTH FROM "Date") ==6



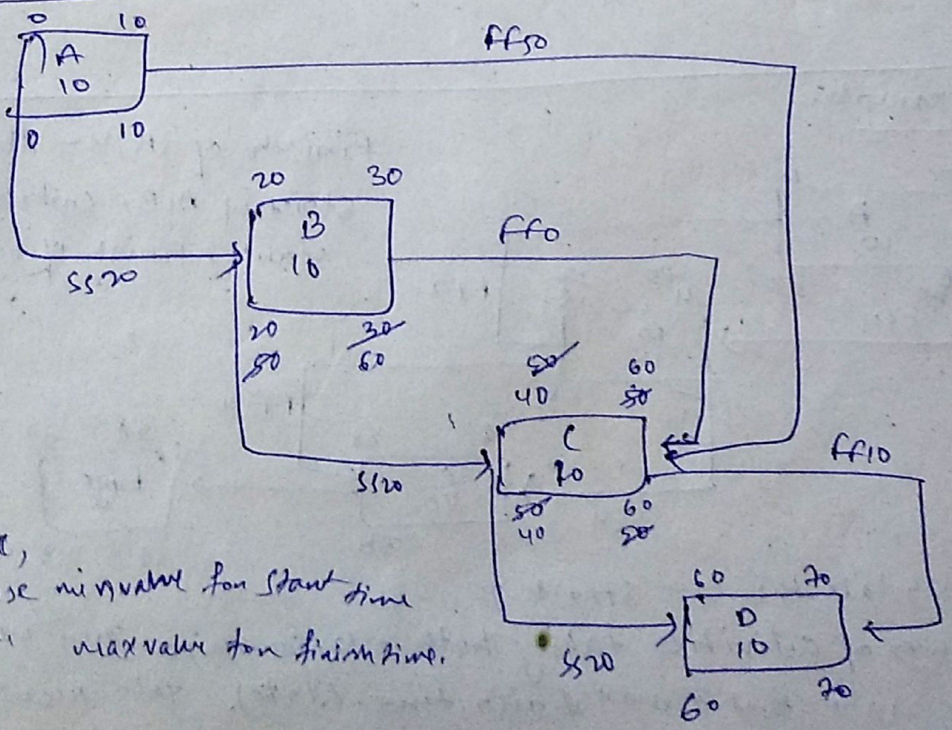
For C

SS20 → 40 50

~~ff0 → 20 80~~

ff50 → ~~50~~ 60

ans → 20 60 ✓



For C,

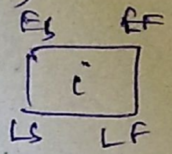
choose min value for start time

" max value for finish time.

With this, Activity A is critical, Start of B is critical, C & D are critical.

Alternate floats are defined for PDM - start float, finish float, relation float, activity float.

~~Est~~ Floats in PDM (Non-continuous dur^n)



1. Task Float

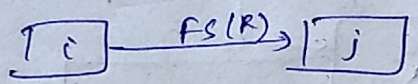
   i) total float (i) = ~~tf~~ LF(i) − ES(i) − Dur(i)

   ii) start float (i) = LS(i) − ES(i)

   iii) finish float (i) = LF(i) − EF(i)

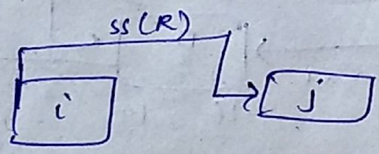
2. Relationship Float.

   i) FS.



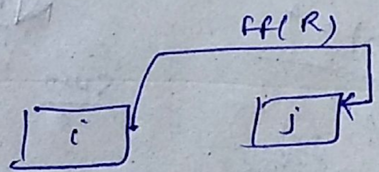
   RF(FS) = LS(j) − EF(i) − Lag(R) ✓

   ii) SS



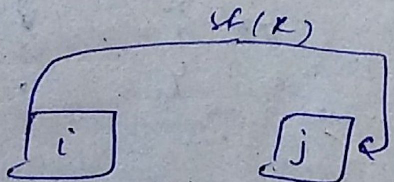
   RF(SS) = LS(j) − ES(i) − lag(R) ✓

   iii) FF

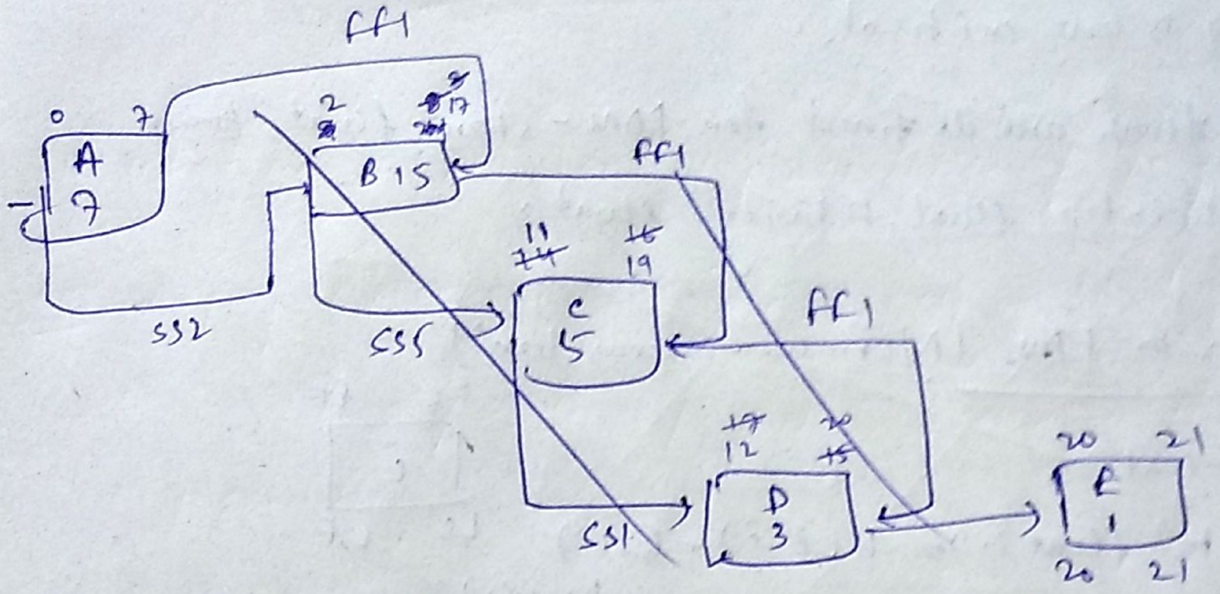


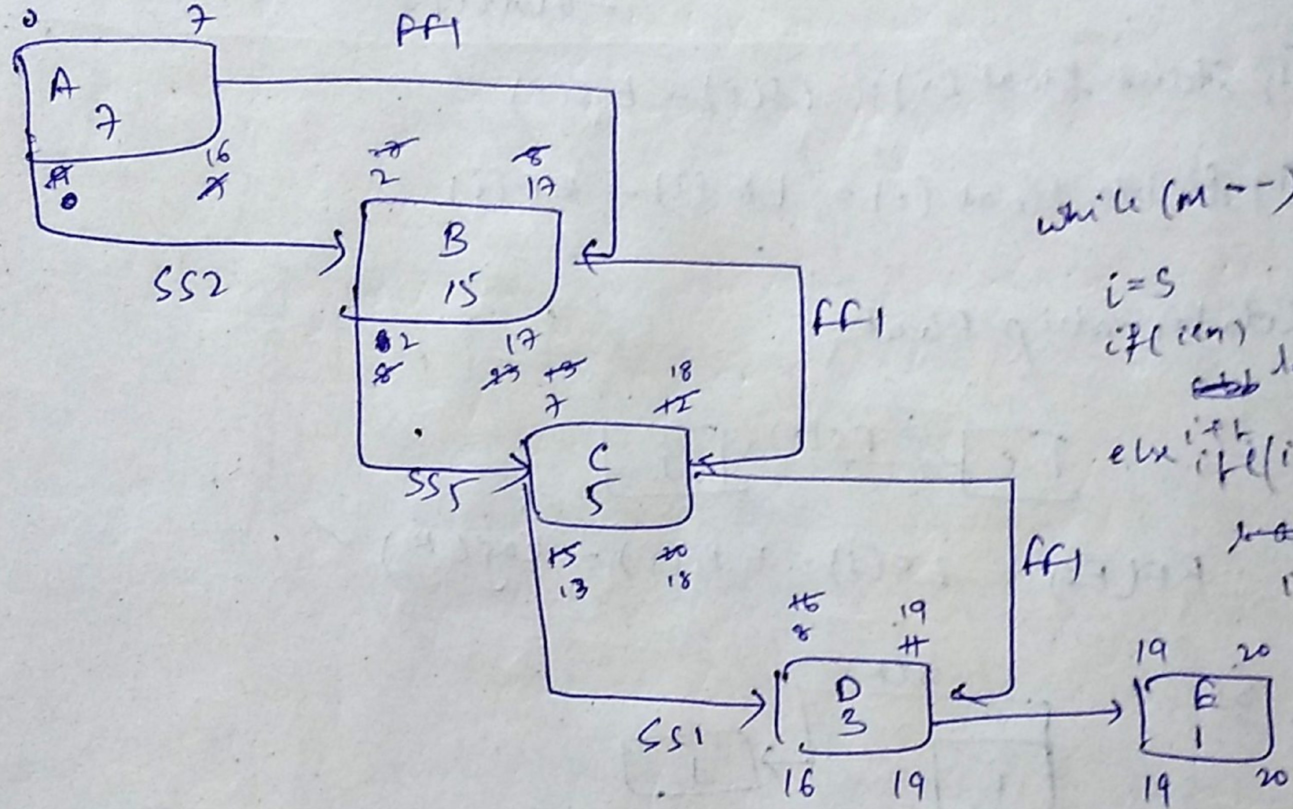
   RF(FF) = LF(j) − ~~Ef~~ EF(i) − lag(R) ✓

   iv) SF



RF(SF) = LF(j) − ES(i) − Lag(R) ✓





while (n--)

i=5

if(i<n)

~~l.append i~~

else if(i==n)

~~l.append(i)~~

i=1