Time-Cost Trade-Off

(Time Reduction = Time Compression)

(Time Shortening)

Durations:

- *To avoid late penalties* (*or avoid damaging the company's relationship*),
- *To realize incentive pay*, (monetary incentives for timely or early competition of a project,
- *To beat the competition to the market*, to fit within the contractually required time (*influences Bid price*)
- *To free resources for use on other projects*. (complete a project early & move on to another project)
- *To reduce the indirect costs* associated with running the project.
- *To complete a project when weather conditions make it less expensive* (Avoid temporary Heating, avoid completing site work during raining season).
- Many things make crashing a way of life on some projects (i.e. last minutes changes in client specification, without permission to extend the project deadline by an appropriate increment)

Shortening the duration is called project crashing

Methods to reduce durations

1. ***Overtime:*** Have the existing crew work overtime. This increase the labor costs due to increase pay rate and decrease productivity.

2. ***Hiring and/or Subcontracting:***

   a) Bring in additional workers to enlarge crew size. This increases labor costs due to overcrowding and poor learning curve.

   b) Add subcontracted labor to the activity. This almost always increases the cost of an activity unless the subcontracted labor is for more efficient.

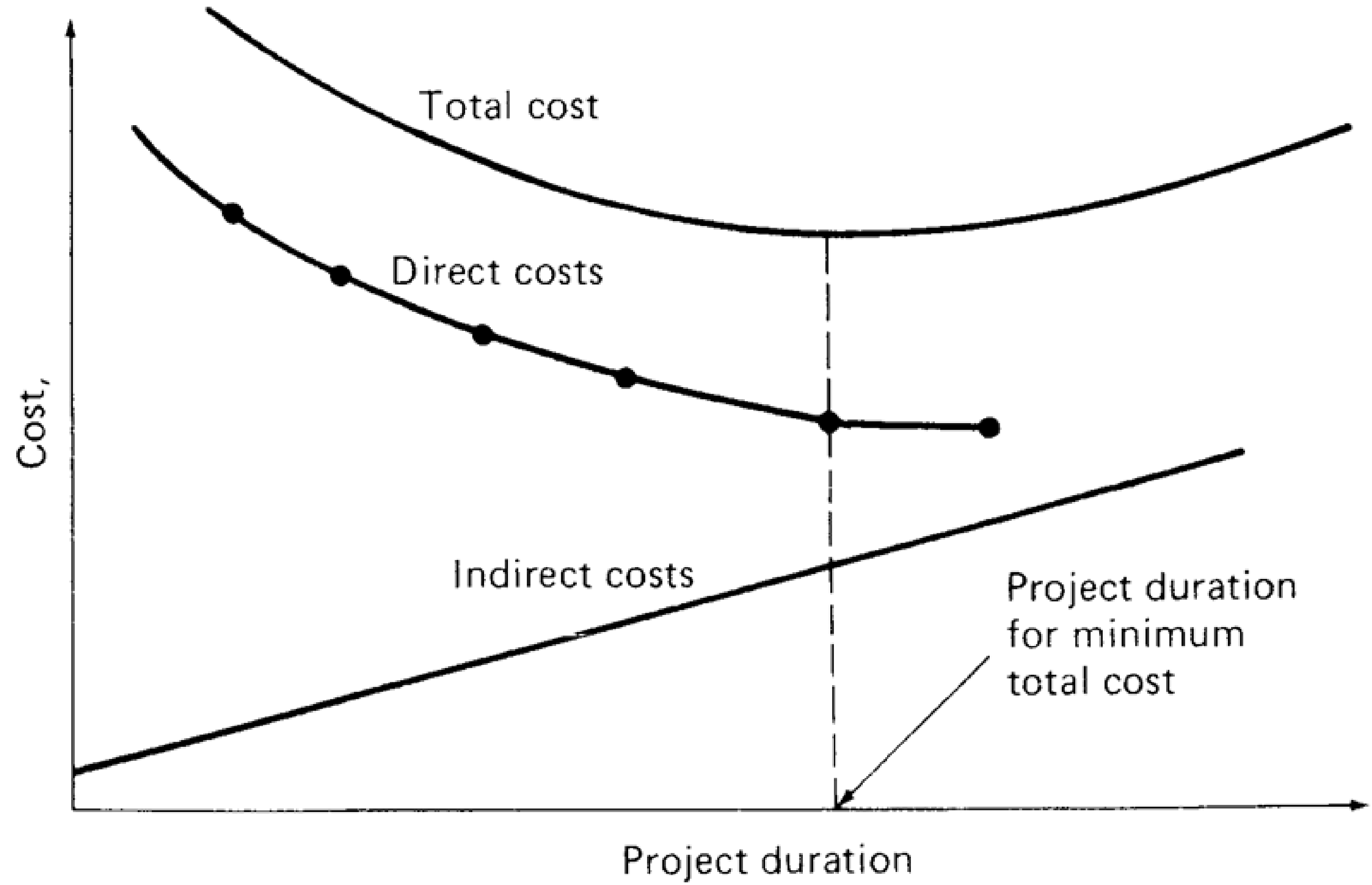
3. ***Use of advanced technology:*** Use better/more advanced equipment. This will usually increase costs due to rental and transport fees. If labor costs (per unit) are reduced, this could reduce costs.

How project cost is estimated?

Practices to Estimate the Project cost

- Some company assigns Overhead office as % of direct cost.
- Most companies don't consider profit as a cost of the job.
- Cost analysis are completed by using:
  - **[Direct costs + Indirect costs + Company overhead]** vs. Budgeted (estimated costs).
- Similar to each activity, the project as a whole has an ideal (Lease expensive) Duration.

How project cost is estimated?

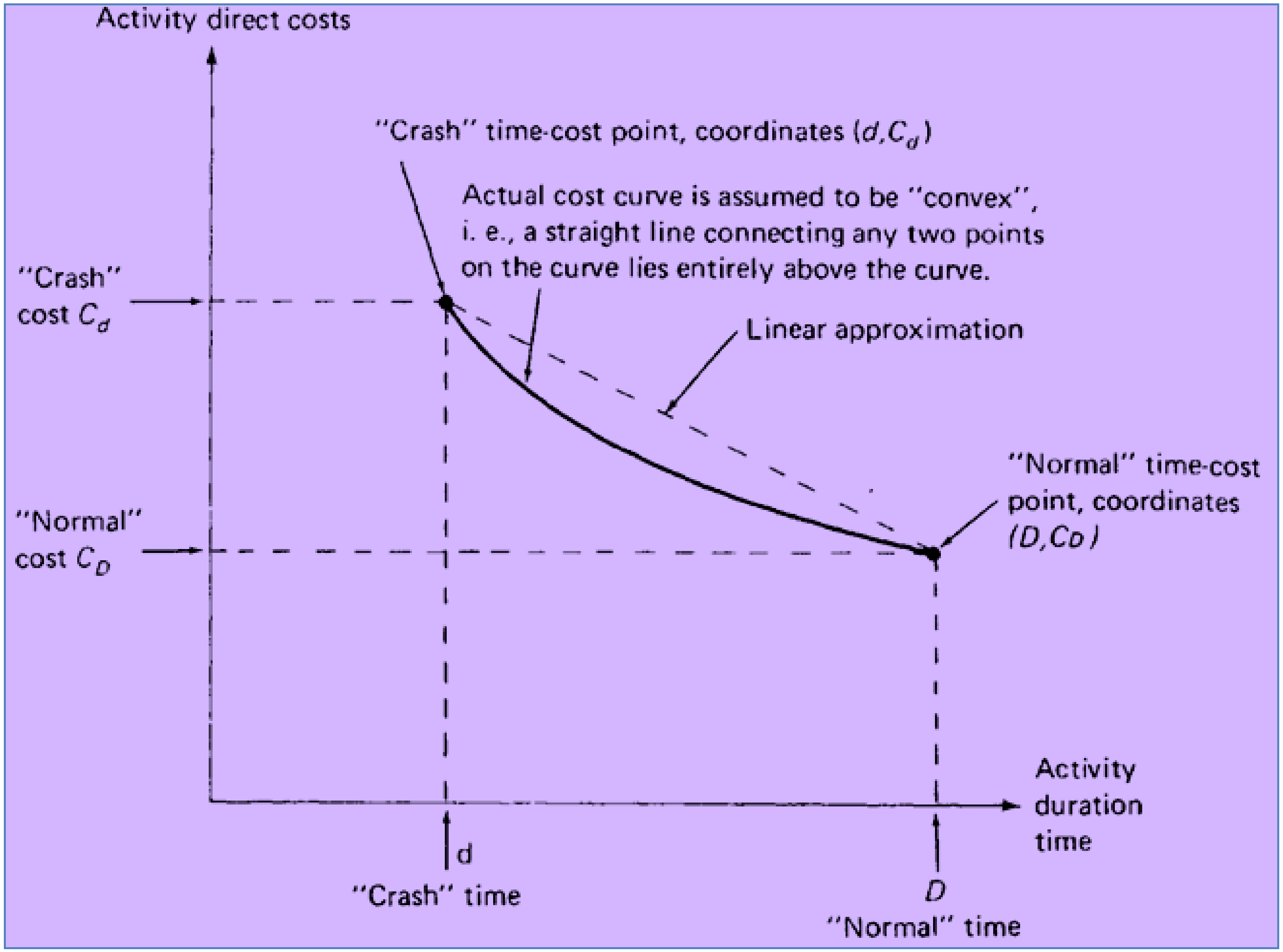


Determining project schedule for minimum total cost.

How project is crashed?

Specify 2 activity times and 2 costs

- 1st time/cost combination (D, C_D)- called ***normal*** [Normal – usual 'average' time, resources]
- 2nd time/cost combination (d, C_d)- called ***Crash*** [expedite by applying additional resources]



Steps in Project Crashing

Basic Steps

1. Compute the crash cost per time period. If crash costs are linear over time:

$$\textit{Crash Cost per priod} = \textit{Cost Slope} = \frac{(\textit{Crash cost} - \textit{Normal cost})}{(\textit{Normal time} - \textit{Crash time})}$$

2. Using current activity times, find the critical path and identify the critical activities

Steps in Project Crashing

3. If there is only one critical path, then select the activity on this critical path that (a) can still be crashed, and (b) has the smallest crash cost per period.

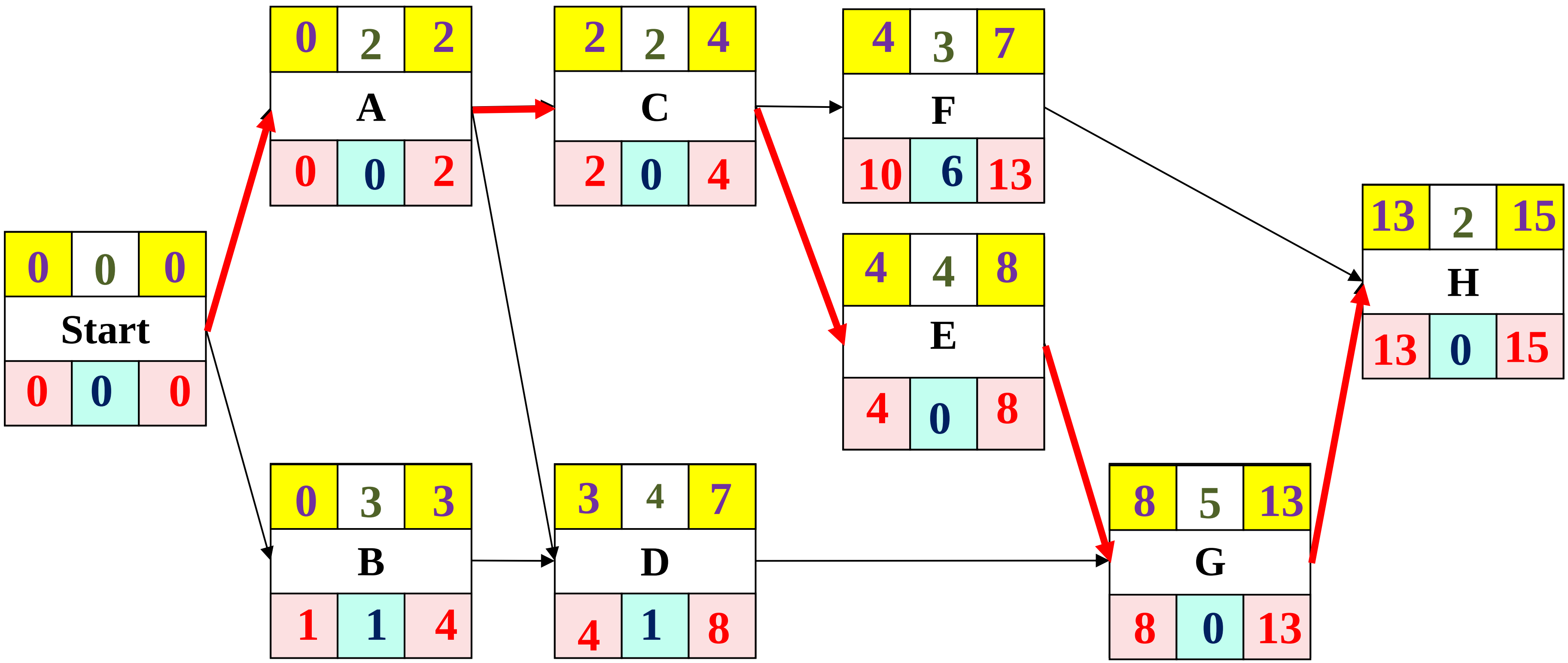
   If there is more than one critical path, *then select one activity from each critical path* such that (a) each selected activity can still be crashed, and (b) the total crash cost of all selected activities is the smallest.

   Note that the same activity may be common to more than one critical path.

4. Update all activity times. If the desired due date has been reached, stop. If not, return to Step 2.

Example1: Crashing The Project

Critical Path for Milwaukee Paper (A, C, E, G, H)



Example1: Crashing The Project

CALCULATION OF CRAH COST/PERIOD

Crash and Normal Times and Costs for Activity B

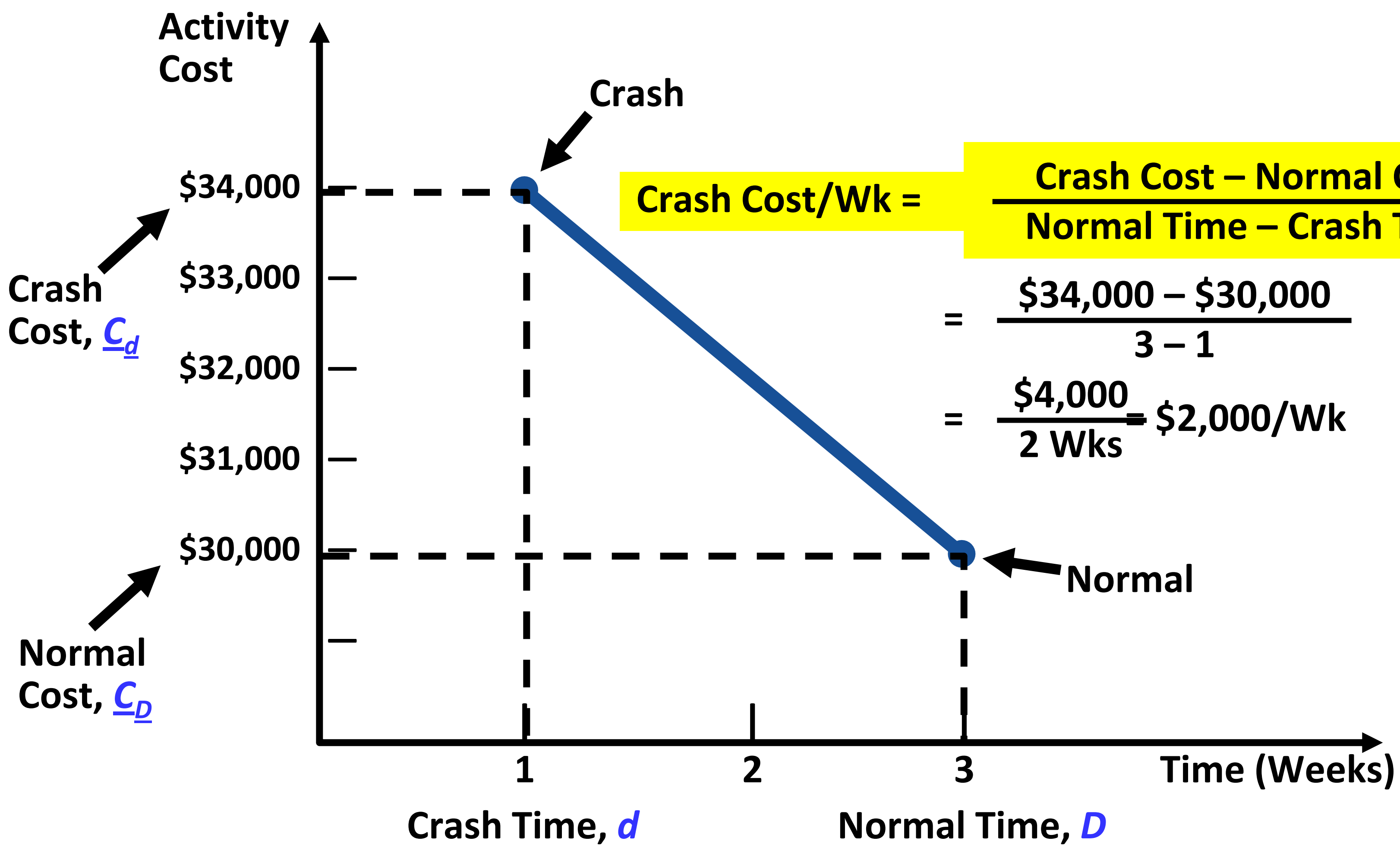


Table 3.16 (Frome Heizer/Render; Operation Management)

Example1: Crashing The Project

Activity	Time (Wks)		Cost ($)		Crash Cost Per Wk ($)	Critical Path?
	Normal	Crash	Normal	Crash		
A	2	1	22,000	22,750	750	Yes
B	3	1	30,000	34,000	2,000	No
C	2	1	26,000	27,000	1,000	Yes
D	4	2	48,000	49,000	1,000	No
E	4	2	56,000	58,000	1,000	Yes
F	3	2	30,000	30,500	500	No
G	5	2	80,000	84,500	1,500	Yes
H	2	1	16,000	19,000	3,000	Yes

Table 3.5 (Frome Heizer/Render; Operation Management)

Example2: Crashing Project (123)

For the small project shown in the table, it is required reduce the project duration.

A) Reduce by 2 periods.

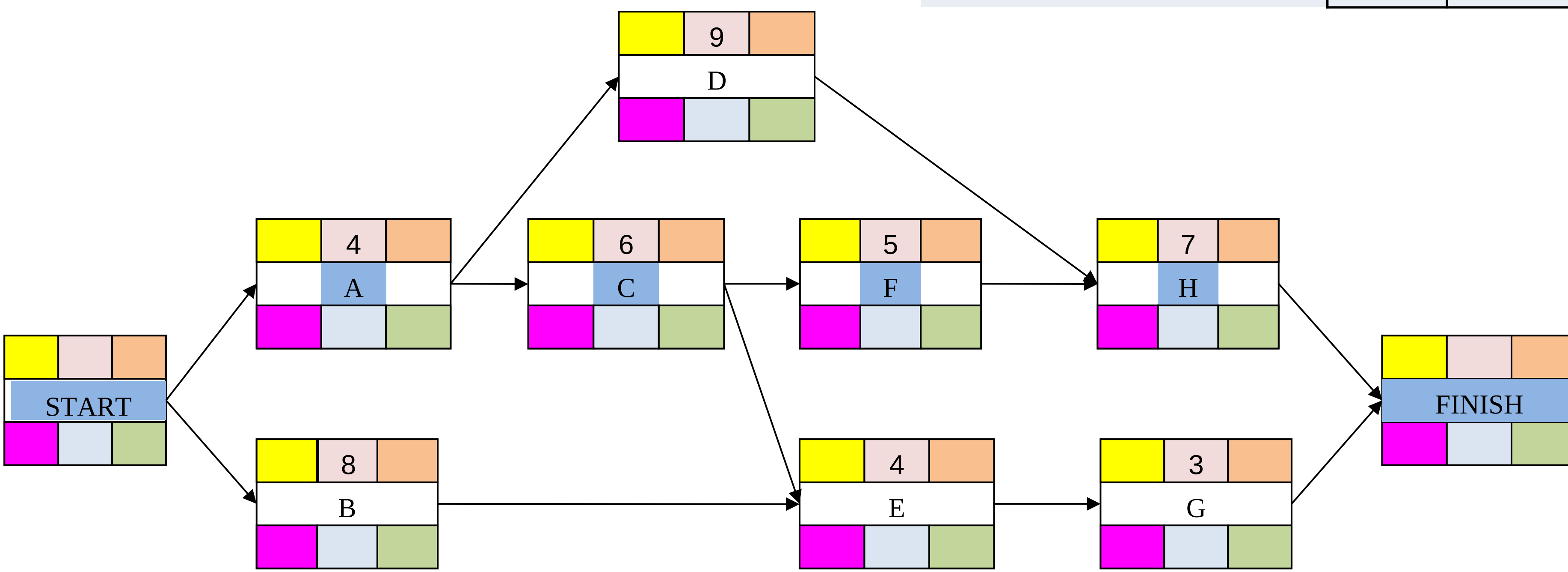
B) Reduce by 5 periods.

Activity	Precedence	Normal		Crash	
		Time, day	Cost, $	Time, day	Cost, $
A	-	4	210	3	280
B	-	8	400	6	560
C	A	6	500	4	600
D	A	9	540	7	600
E	B,C	4	500	1	1100
F	C	5	150	4	240
G	E	3	150	3	150
H	D,F	7	600	6	750
		Σ	3050		4280

Example2: Crashing Project (123)

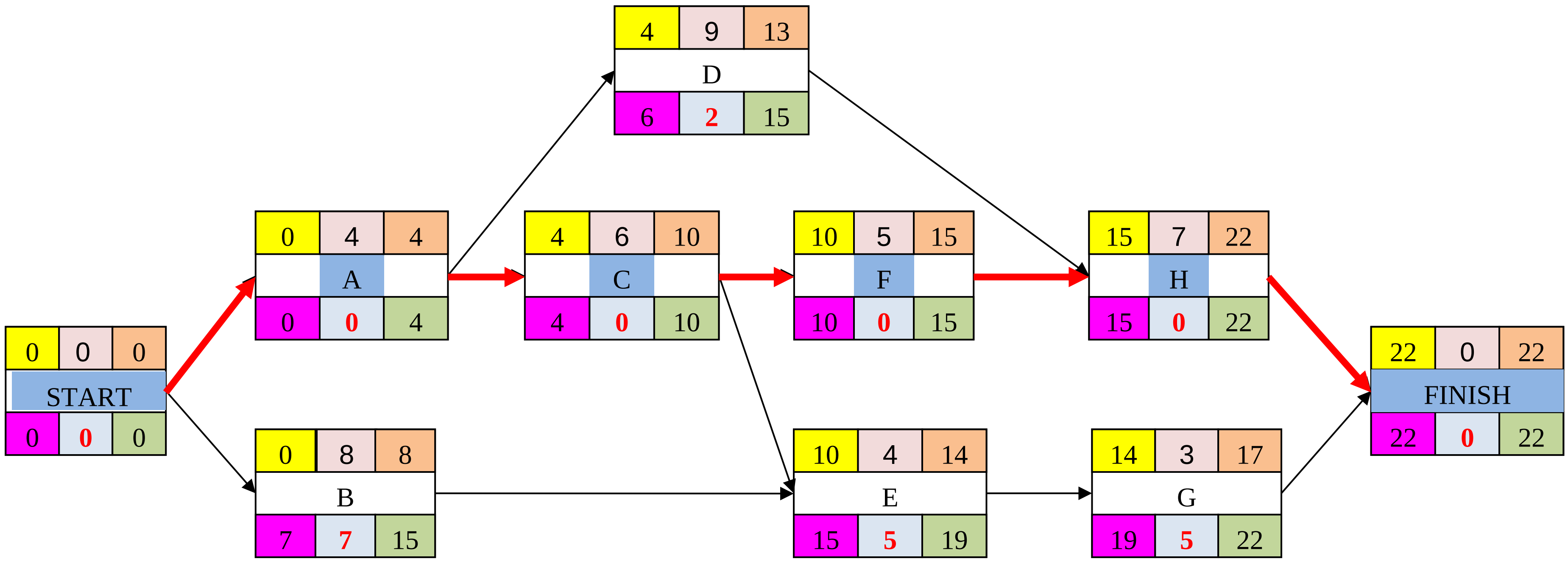
1- develop network

Activity	Precedence	Normal		Crash	
		Time, day	Cost, $	Time, day	Cost, $
A	-	4	210	3	280
B	-	8	400	6	560
C	A	6	500	4	600
D	A	9	540	7	600
E	B,C	4	500	1	1100
F	C	5	150	4	240
G	E	3	150	3	150
H	D,F	7	600	6	750
		Σ	3050		4280



Example2: Crashing Project (123)

2- calculate times, find critical path



- Project completion time = 22 working days
- Critical Path: A, C, F, H.

Activity	A	B	C	D	E	F	G	H
Total float	0	7	0	2	5	0	5	0
Free float	0	2	0	2	0	0	5	0

Example2: Crashing Project (123)

3- calculate cost slope

Activity	Precedence	Normal		Crash		Cost Slope, $/day
		Time, day	Cost, $	Time, day	Cost, $	
A	-	4	210	3	280	70
B	-	8	400	6	560	80
C	A	6	500	4	600	50
D	A	9	540	7	600	30
E	B,C	4	500	1	1100	200
F	C	5	150	4	240	90
G	E	3	150	3	150	**
H	D,F	7	600	6	750	150
		Σ	3050		4280	

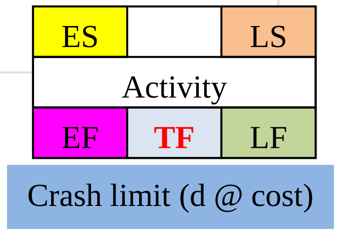
Remarks

1- [G can not expedite]

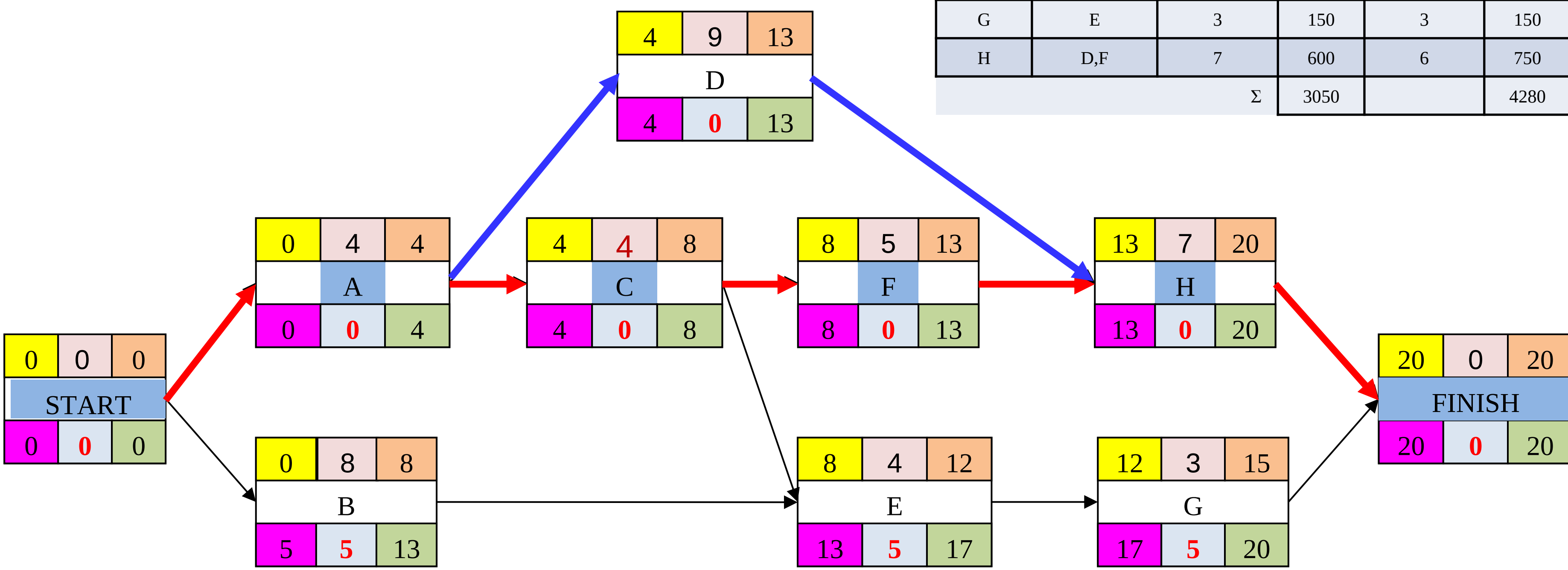
2- lowest slope and can be expedited on critical path is activity (C) WITH 2 periods

Example2: Crashing Project (123)

Reduce 2 periods of activity (C) with increase of cost (2*50) =100



Activity	Precedence	Normal		Crash		Cost Slope,
		Time, day	Cost, $	Time, day	Cost, $	$/day
A	-	4	210	3	280	70
B	-	8	400	6	560	80
C	A	6	500	4	600	50
D	A	9	540	7	600	30
E	B,C	4	500	1	1100	200
F	C	5	150	4	240	90
G	E	3	150	3	150	**
H	D,F	7	600	6	750	150
	Σ		3050		4280	



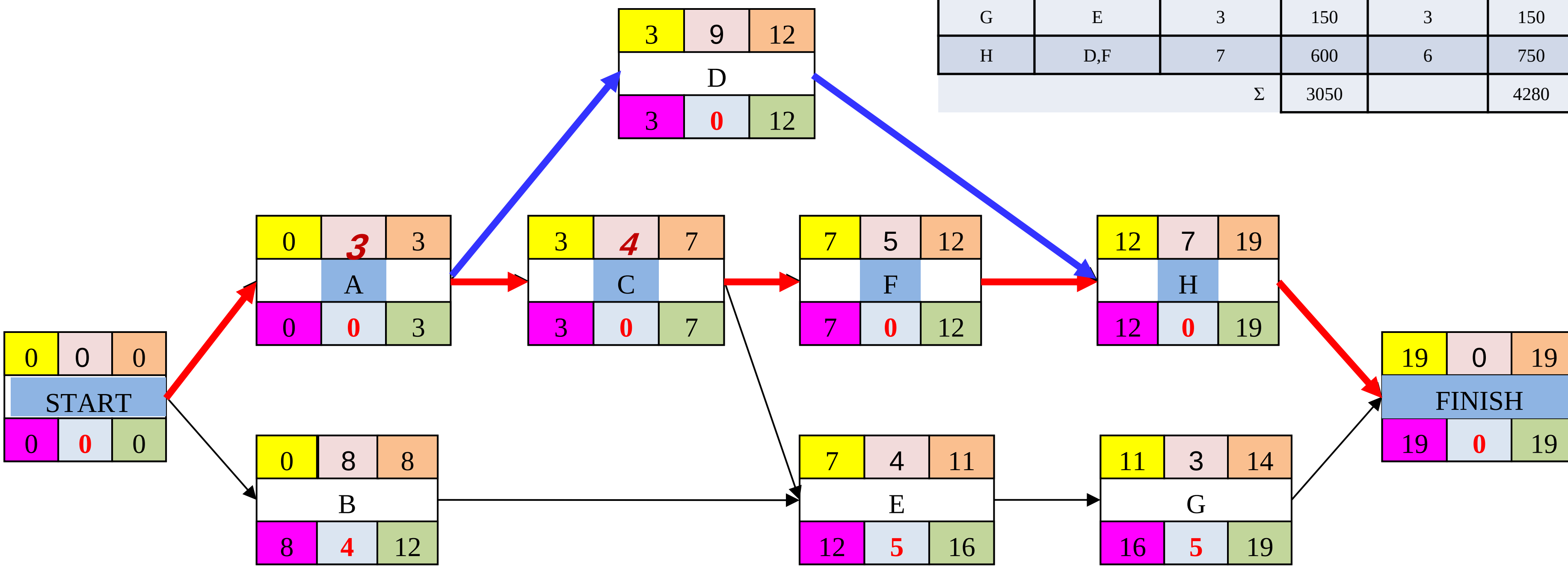
- Project completion time = 20 working days
- Critical Path: ***A, C, F, H.*** & ***A, D, H***

Activity	A	B	C	D	E	F	G	H
Total float	0	5	0	0	5	0	5	0
Free float	0	0	0	0	0	0	5	0

Example2: Crashing Project (123)

Reduce 1 period of activity (A) with increase of cost =70

Activity	Precedence	Normal		Crash		Cost Slope,
		Time, day	Cost, $	Time, day	Cost, $	$/day
A	-	4	210	3	280	70
B	-	8	400	6	560	80
C	A	6	500	4	600	50
D	A	9	540	7	600	30
E	B,C	4	500	1	1100	200
F	C	5	150	4	240	90
G	E	3	150	3	150	**
H	D,F	7	600	6	750	150
	Σ		3050		4280	



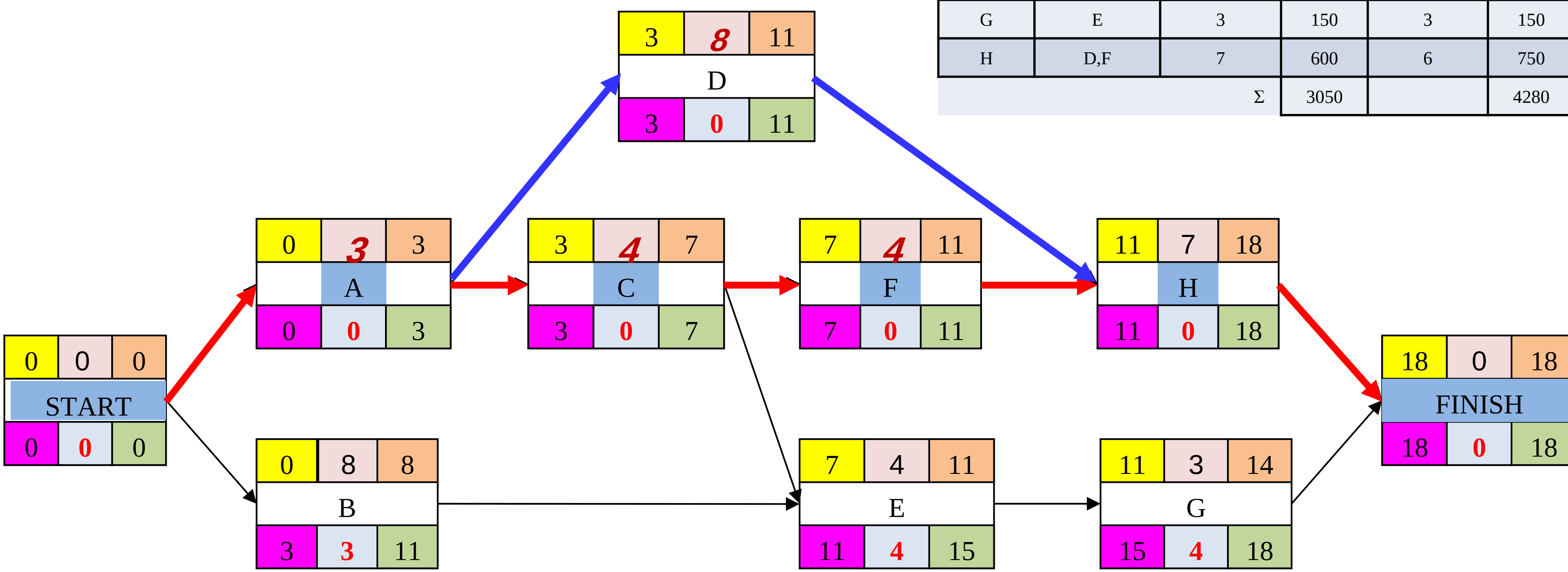
- Project completion time = 19 working days
- Critical Path: ***A, C, F, H.*** & ***A, D, H***

Activity	A	B	C	D	E	F	G	H
Total float	0	4	0	0	5	0	5	0
Free float	0	0	0	0	0	0	5	0

Example2: Crashing Project (123)

Reduce farther 1 period of 2 activities (D,F) with increase of cost (30+90) =120

Activity	Precedence	Normal		Crash		Cost Slope,
		Time, day	Cost, $	Time, day	Cost, $	$/day
A	-	4	210	3	280	70
B	-	8	400	6	560	80
C	A	6	500	4	600	50
D	A	9	540	7	600	30
E	B,C	4	500	1	1100	200
F	C	5	150	4	240	90
G	E	3	150	3	150	**
H	D,F	7	600	6	750	150
		Σ	3050		4280	



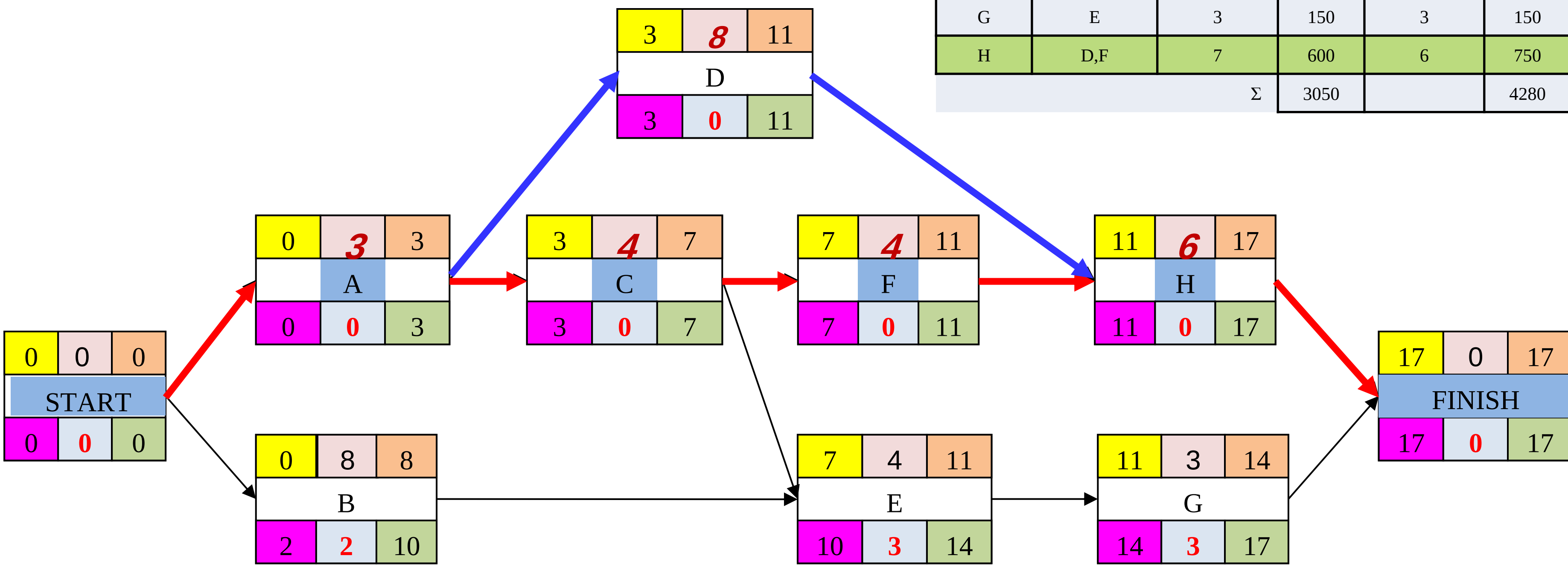
- Project completion time = 19 working days
- Critical Path: ***A, C, F, H.*** & ***A, D, H***

Activity	A	B	C	D	E	F	G	H
Total float	0	3	0	0	4	0	4	0
Free float	0	0	0	0	0	0	4	0

Example2: Crashing Project (123)

Reduce farther 1 period of activity (H) with increase of cost =150

Activity	Precedence	Normal		Crash		Cost Slope,
		Time, day	Cost, $	Time, day	Cost, $	$/day
A	-	4	210	3	280	70
B	-	8	400	6	560	80
C	A	6	500	4	600	50
D	A	9	540	7	600	30
E	B,C	4	500	1	1100	200
F	C	5	150	4	240	90
G	E	3	150	3	150	**
H	D,F	7	600	6	750	150
	Σ		3050		4280	



- Project completion time = 19 working days
- Critical Path: ***A, C, F, H.*** & ***A, D, H***

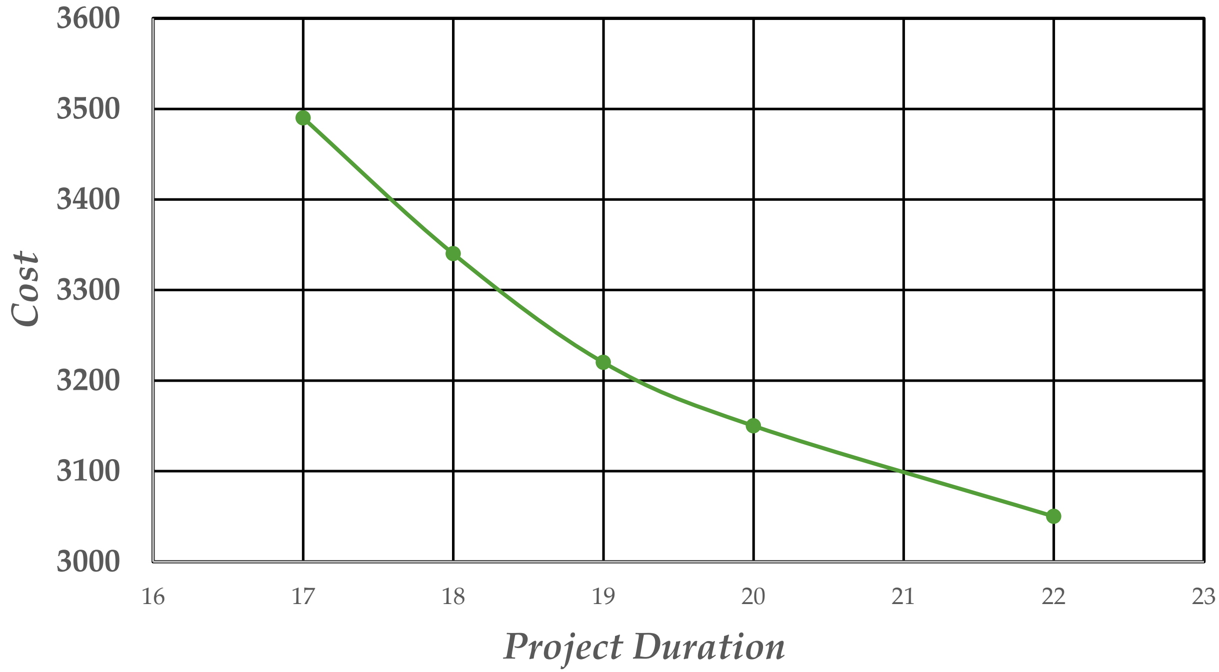
Activity	A	B	C	D	E	F	G	H
Total float	0	2	0	0	3	0	3	0
Free float	0	0	0	0	0	0	3	0

Example2: Crashing Project (123)

Reduction from 22 to 17 increase to 3490

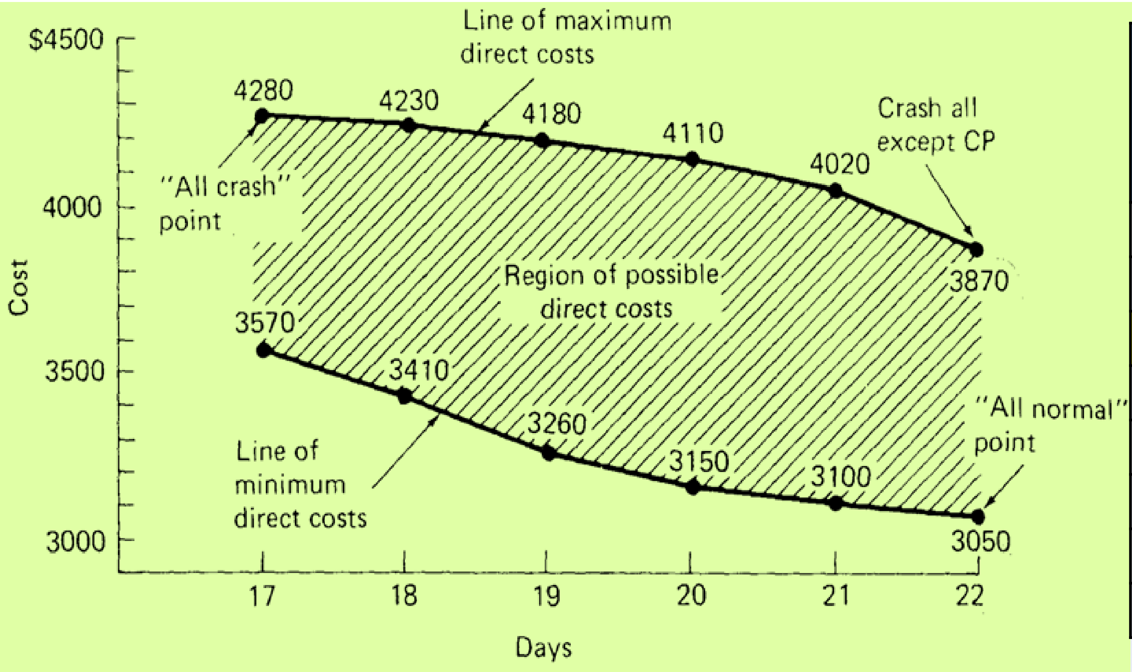
Cycle	Activity	Time	cost	Total cost	Duration
0	-			3050	22
1	C	2	100	3150	20
2	A	1	70	3220	19
3	D,F	1	30+90	3340	18
4	H	1	150	3490	17

Activity	Precedence	Normal		Crash		Cost Slope,
		Time, day	Cost, $	Time, day	Cost, $	$/day
A	-	4	210	3	280	70
B	-	8	400	6	560	80
C	A	6	500	4	600	50
D	A	9	540	7	600	30
E	B,C	4	500	1	1100	200
F	C	5	150	4	240	90
G	E	3	150	3	150	**
H	D,F	7	600	6	750	150
	Σ		3050		4280	



Example2: Crashing Project (123)

Accelerating the Critical and Noncritical path



Project duration vs. direct cost for sample network

Activity	Precedence	Normal		Crash		Cost Slope,
		Time, day	Cost, $	Time, day	Cost, $	$/day
A	-	4	210	3	280	70
B	-	8	400	6	560	80
C	A	6	500	4	600	50
D	A	9	540	7	600	30
E	B,C	4	500	1	1100	200
F	C	5	150	4	240	90
G	E	3	150	3	150	**
H	D,F	7	600	6	750	150
	Σ		3050		4280	

How project is crashed?

Network Compression Algorithm

- Determine Normal project duration, and cost.
- Identify Normal duration Critical Path.
- For large network, using CRITICALITY THEORM to eliminate the noncritical paths that do not need to be crashed.
- Compute the cost slop

$$\text{Crash Cost per priod} = \text{Cost Slope}$$
$$= \frac{(\text{Crash cost} - \text{Normal cost})}{(\text{Normal time} - \text{Crash time})}$$

How project is crashed?

Network Compression Algorithm

- shortening the CRITICAL ACTIVITIES beginning with the activity having the lowest cost-slope
- Determine the compression limit (Nil)

$$Nil = Min \begin{cases} \text{- Crash Limit, or} \\ \text{- Free Float of any of the non critical activities} \\ \text{in the parallel paths competing for critical path.*} \end{cases}$$

- Organize the data as in the following table:

Cycle #	Activity to Shorten	Can Be Shortened	Nil	Days Shortened	Cost per Day	Cost for Cycle	Total Cost	Project Duration
0								
1								
2								
3								

How project is crashed?

Network Compression Algorithm

- Update the project network
- When a new Critical path is formed:
  - Shorten the combination of activity which Falls on Both Critical Paths, OR
  - Shorten one activity from each of the critical paths. Use the combined cost of shortening both activities when determining if it is cost effective to shorten the project.
- At each shortening cycle, compute the new project duration and project cost
- Continue until no further shortening is possible

How project is crashed?

Network Compression Algorithm

- Tabulate and Plot the Indirect project Cost on the same time-cost graph

Cycle #	Project Duration	Direct Cost	Indirect Cost	Total Cost
0				
1				
2				
3				

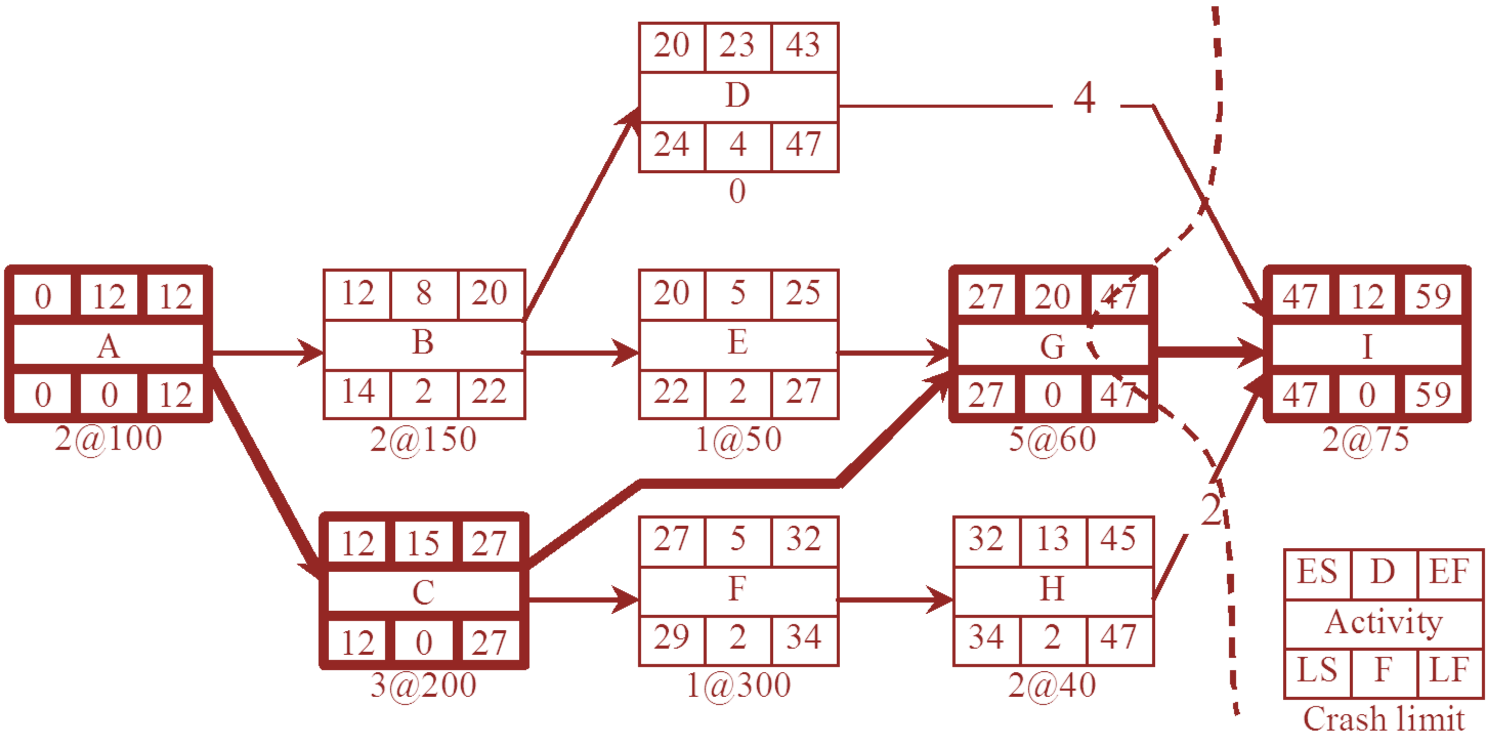
- Add direct and indirect cost to find the project cost at each duration.
- Use the total project cost-time curve to find the optimum time.

Example 3

The durations and direct costs for each activity in the network of a small construction contract under both normal and crash conditions are given in below Table. Establish the least cost for expediting the contract. Determine the optimum duration of the contract assuming the indirect cost amounts to SR 125/week.

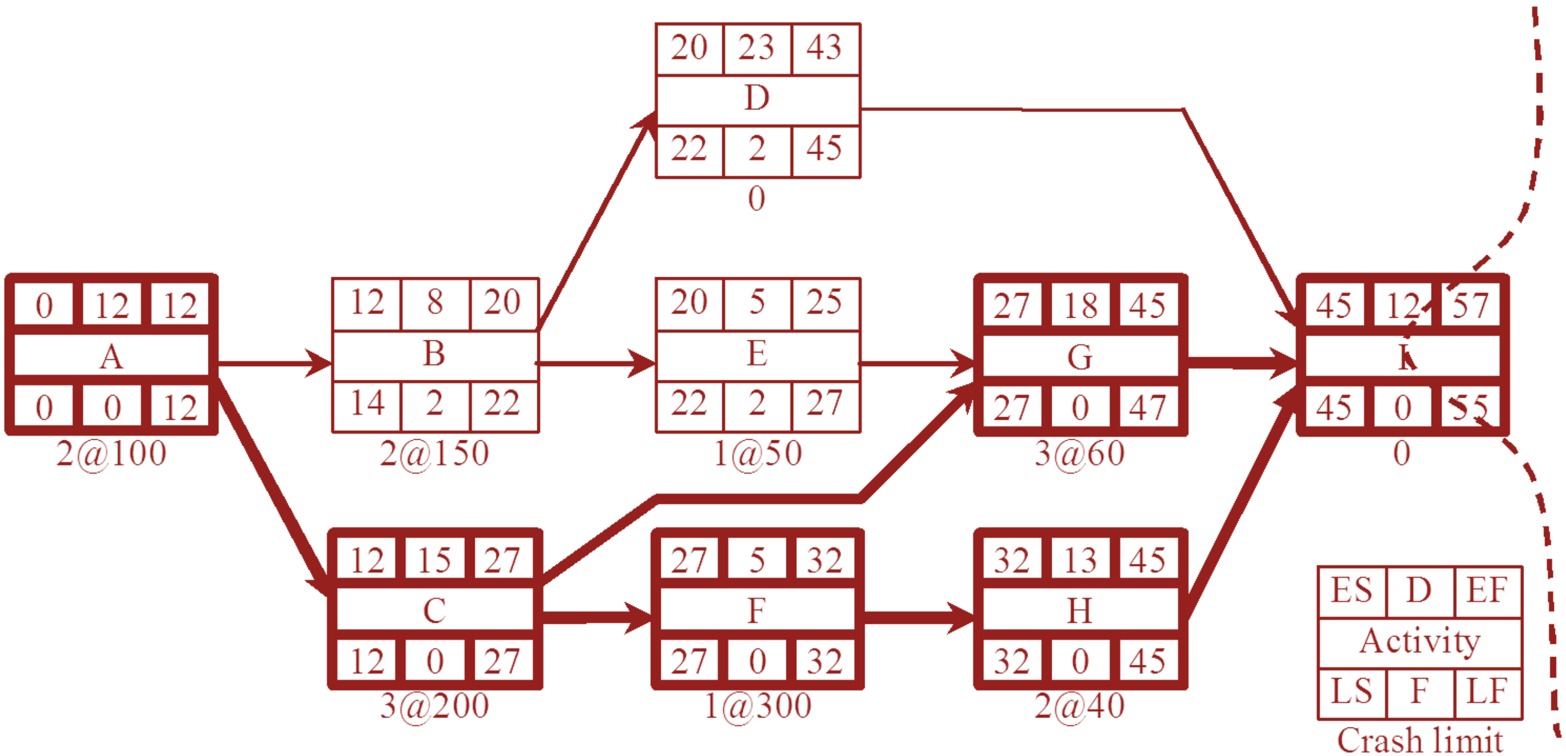
Activity	Preceded by	Normal		Crash	
		Duration (weeks)	Cost (SR)	Duration (weeks)	Cost (SR)
A	—	12	7000	10	7200
B	A	8	5000	6	5300
C	A	15	4000	12	4600
D	B	23	5000	23	5000
E	B	5	1000	4	1050
F	C	5	3000	4	3300
G	E,C	20	6000	15	6300
H	F	13	2500	11	2580
I	D, G, H	12	3000	10	3150
			∑36,500		38470

Example 3



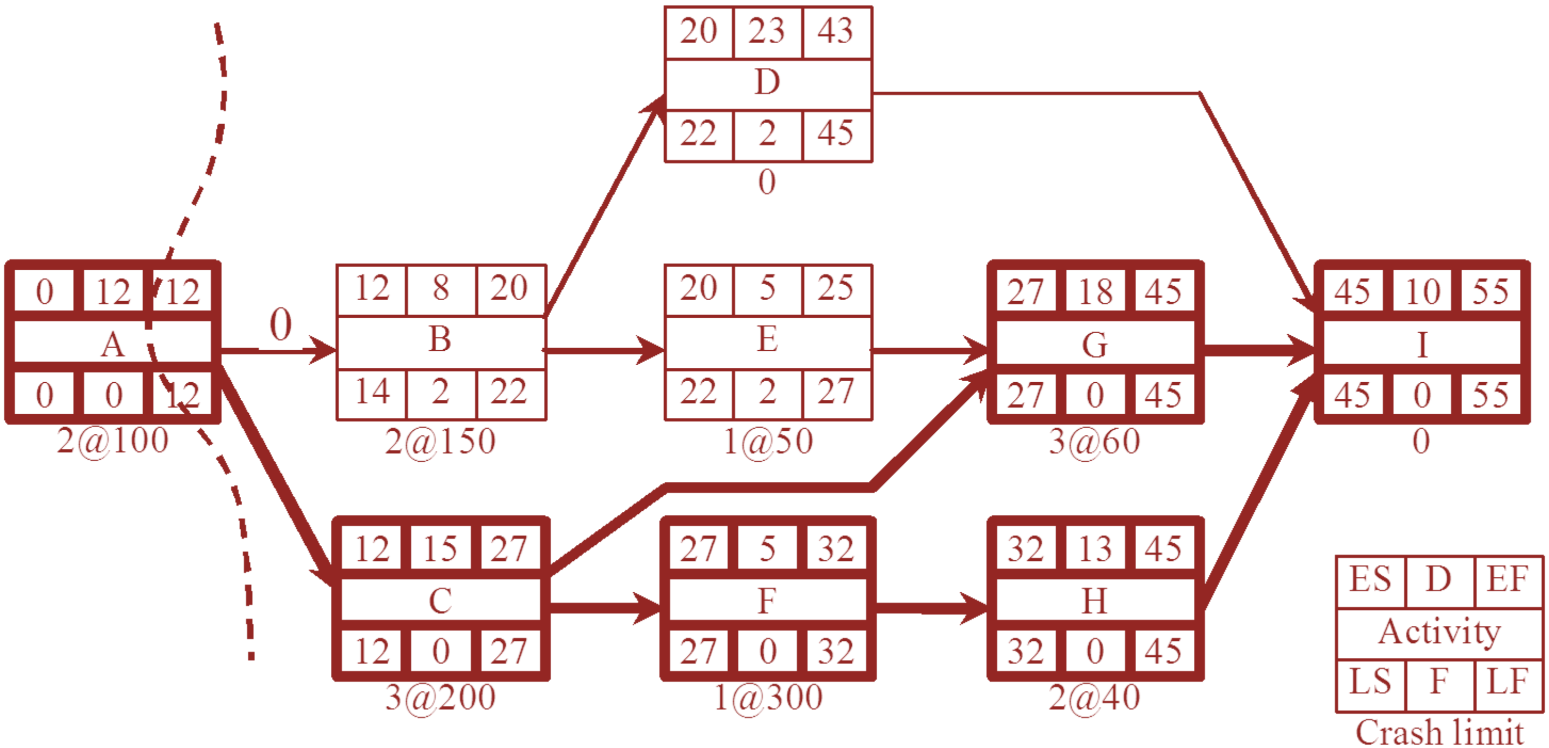
Cycle #	Activity to Shorten	Can Be Shortened	Nil	Days Shortened	Cost per Week	Cost for Cycle	Total Cost	Project Duration
0	–	–	–	–	–	–	36,500	59
1	G	5	2	2	60	120	36,620	57

Example 3



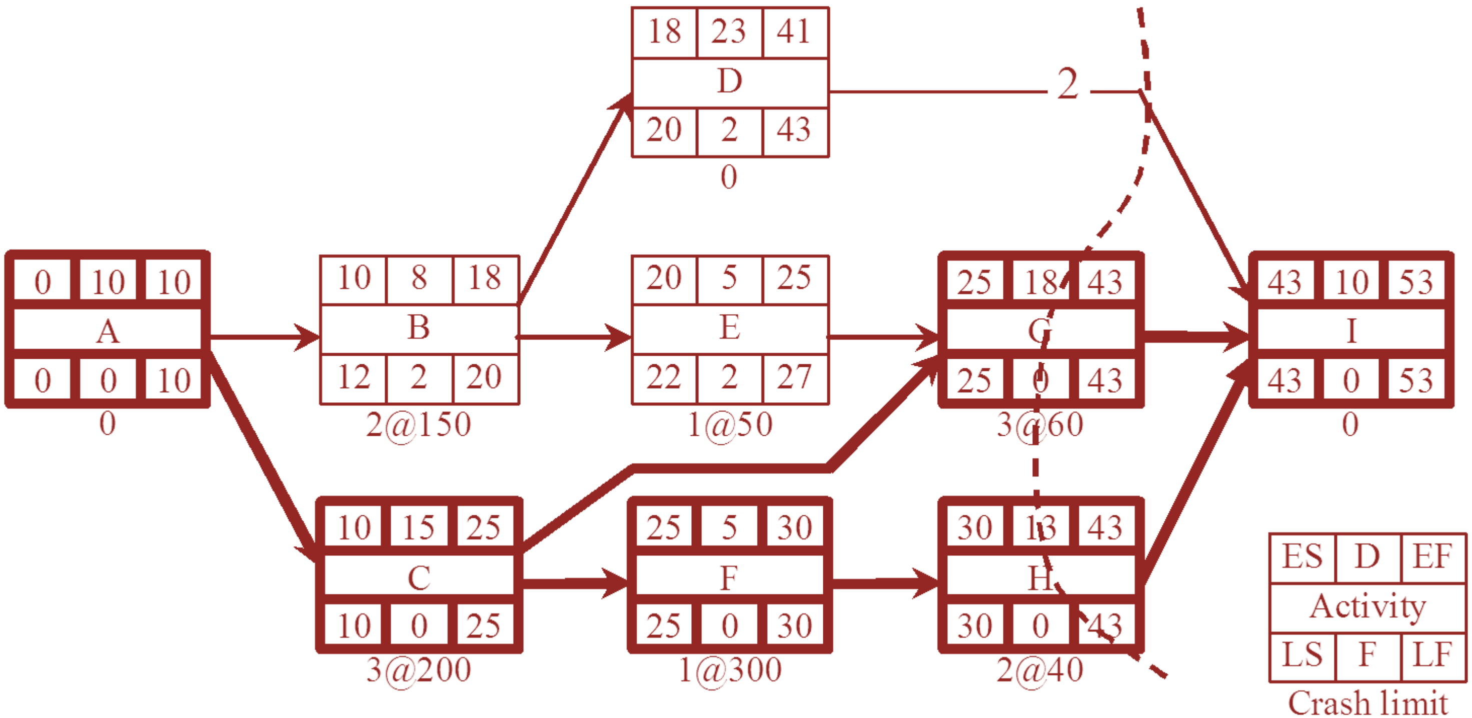
Cycle #	Activity to Shorten	Can Be Shortened	Nil	Days Shortened	Cost per Week	Cost for Cycle	Total Cost	Project Duration
0	–	–	–	–	–	–	36,500	59
1	G	5	2	2	60	120	36,620	57
2	I	2	2	2	70	140	36,760	55

Example 3



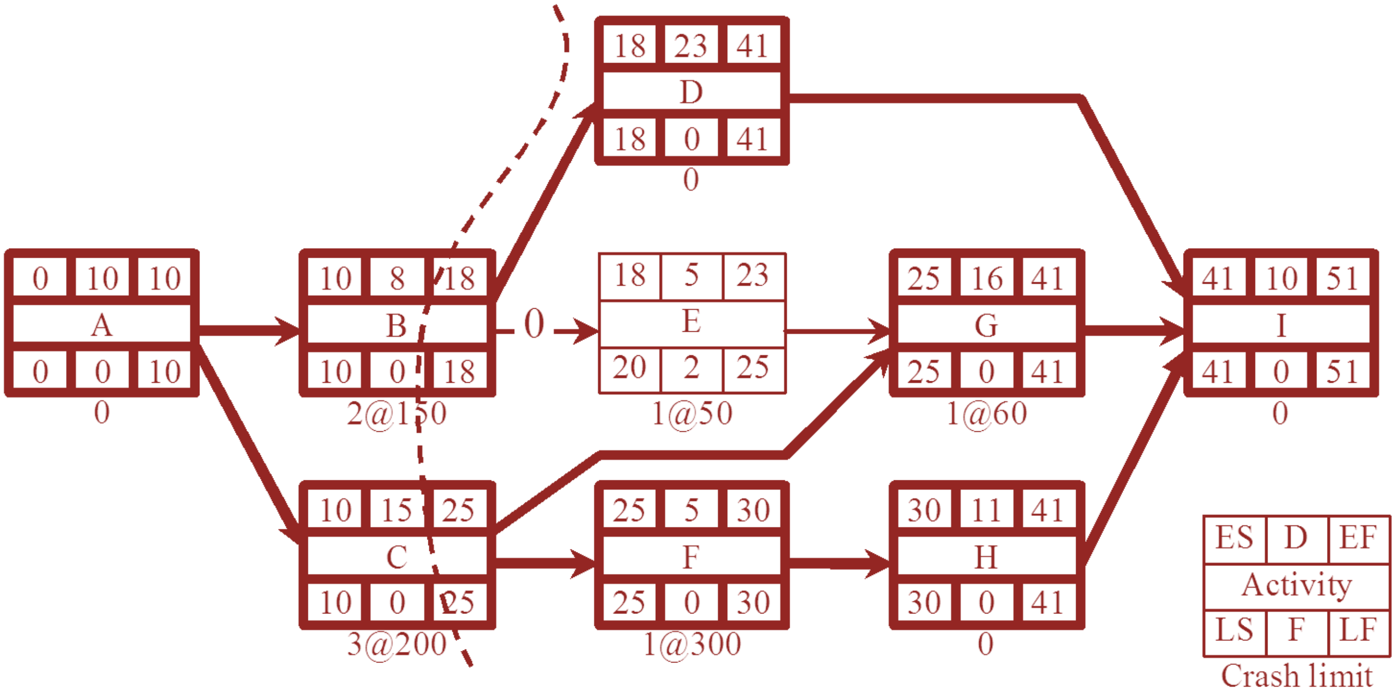
Cycle #	Activity to Shorten	Can Be Shortened	Nil	Days Shortened	Cost per Week	Cost for Cycle	Total Cost	Project Duration
0	–	–	–	–	–	–	36,500	59
1	G	5	2	2	60	120	36,620	57
2	I	2	–	2	70	140	36,760	55
3	A	2	–	2	100	200	36,960	53

Example 3



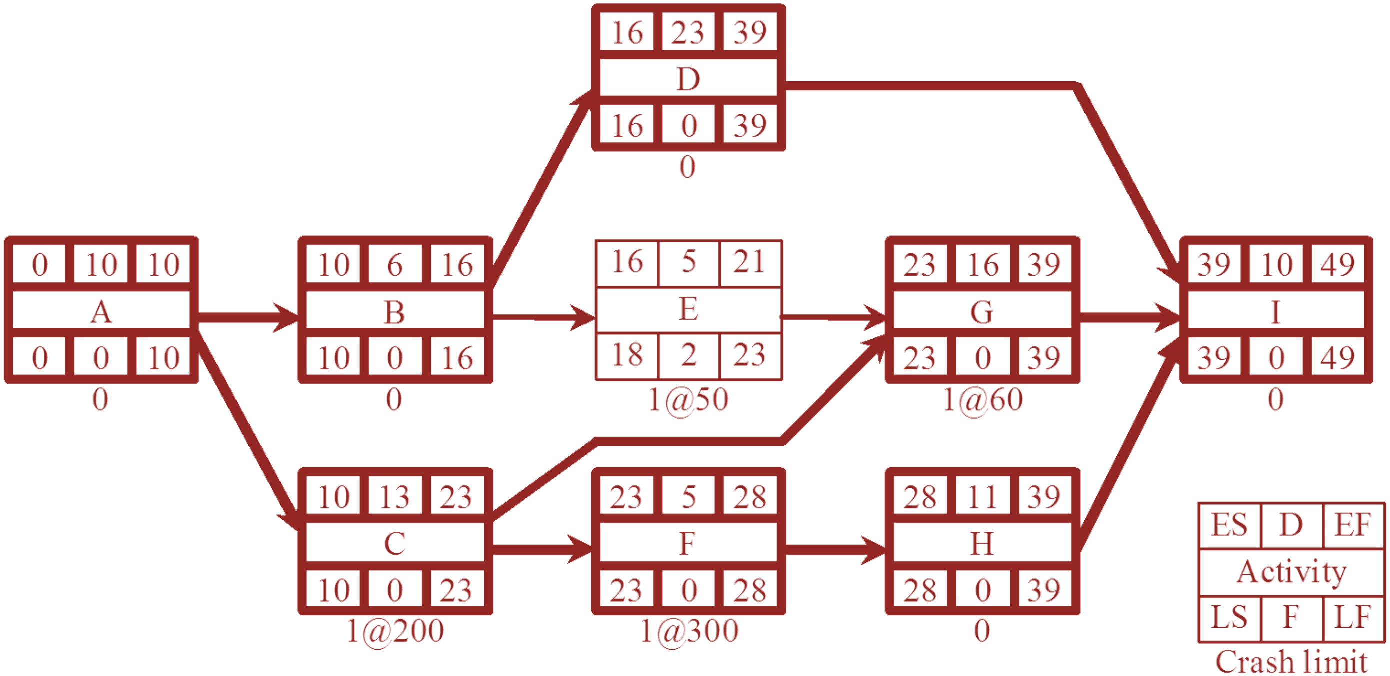
Cycle #	Activity to Shorten	Can Be Shortened	Nil	Days Shortened	Cost per Week	Cost for Cycle	Total Cost	Project Duration
0	–	–	–	–	–	–	36,500	59
1	G	5	2	2	60	120	36,620	57
2	I	2	–	2	70	140	36,760	55
3	A	2	–	2	100	200	36,960	53
4	H, G	2	2	2	60+40	200	37,160	51

Example 3



Cycle #	Activity to Shorten	Can Be Shortened	Nil	Days Shortened	Cost per Week	Cost for Cycle	Total Cost	Project Duration
0	–	–	–	–	–	–	36,500	59
1	G	5	2	2	60	120	36,620	57
2	I	2	–	2	70	140	36,760	55
3	A	2	–	2	100	200	36,960	53
4	G, H	2	2	2	60+40	200	37,160	51
5	B, C	2	–	2	150+200	700	37,860	49

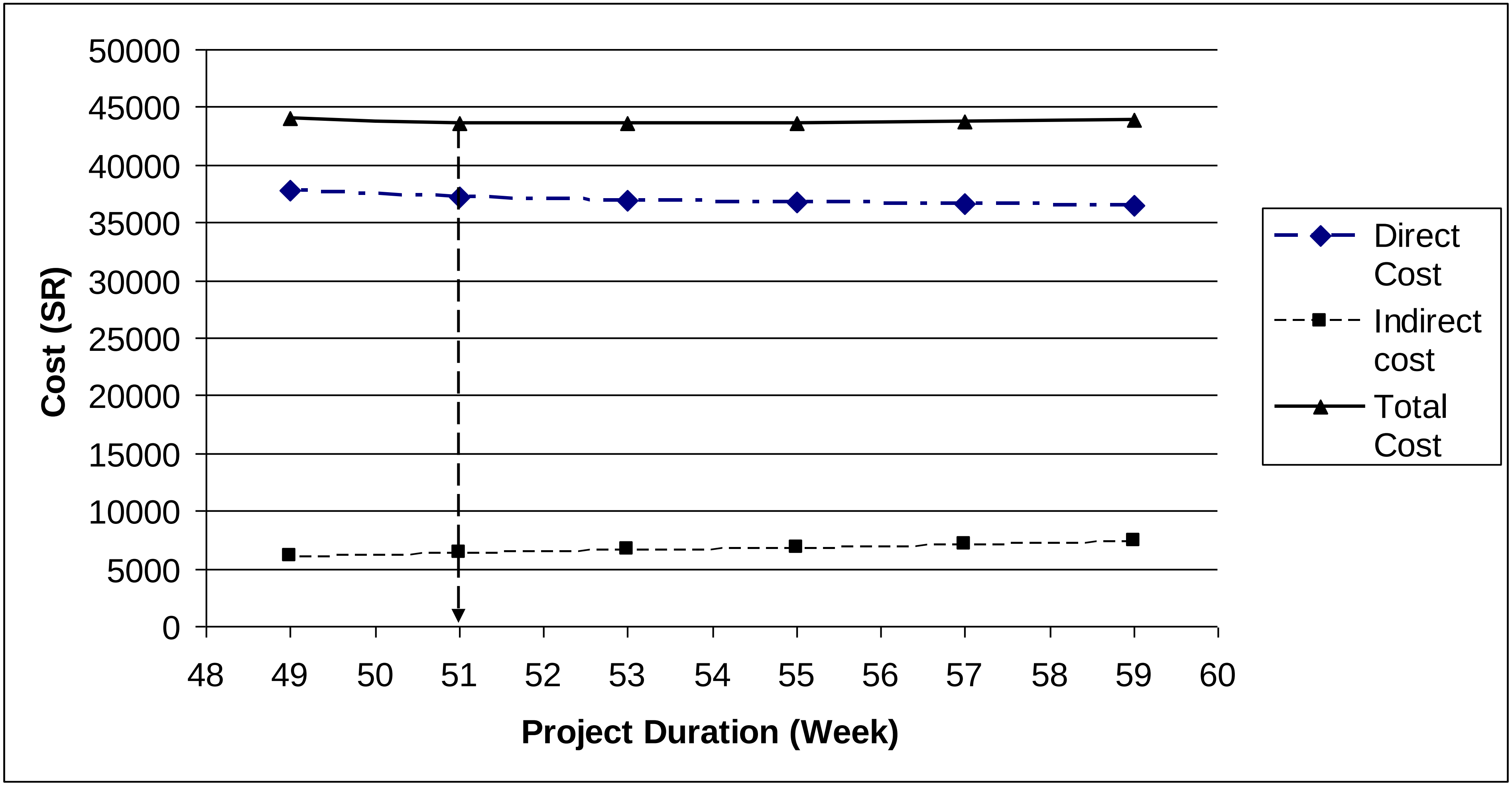
Example 3



Cycle #	Project Duration	Direct Cost	Indirect Cost	Total Cost
0	59	36500	7375	43875
1	57	36620	7125	43745
2	55	36760	6875	43635
3	53	36960	6625	43585
4	51	37160	6375	43535
5	49	37860	6125	43985

Example 3

Project Optimal Duration



CASE WORK

Data on small maintenance project is given as below:

Activity	Depends on	Normal		Crash	
		Time	Cost	Time	Cost
A	–	6 days	$700	4 days	$800
B	–	4 days	400	4 days	400
C	–	5 days	650	4 days	700
D	A	8 days	625	5 days	700
E	B	10 days	200	7 days	350
F	B	7 days	500	5 days	700
G	C	3 days	600	3 days	600
H	D, E	6 days	300	5 days	400
I	F, G	7 days	350	4 days	425

On completion, the project will give a return of $110/day. Using time-cost trade-off method, how much would you like to compress the project for maximizing the return? Show all calculations.