Project Crashing Using Critical Path Method

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Abbreviations and Acronyms

DC: Direct cost
IC: Indirect cost
TC: Total cost
FL: Float or slack
ES: Early start
LS: Late start
EF: Early finish
LF: Late finish
Tn: Normal time
Cn: Normal cost
Tc: Crashed time
Cc: Crashed cost
CPM: Critical path method
CP: Critical path
NCP: Non critical path
PERT: Program evaluation and review technique

What Is CPM?

Critical path analysis (CPA) is an important aid to planning, scheduling, and coordinating activities of large-scale projects. CPA is the synthesis of PERT (multiple time estimate) and CPM (single time estimate). CPM is used to describe the project activities. The critical path is generally the longest full path on the project without any float or slack time (Heldman, 2011). A graphical representation called network diagram is used to describe CPM. A network diagram consists of both noncritical path and critical path. The critical path is shown in the network by either a red line, double line, or thick line. The network diagram may be represented by activity on arrow (AOA) or activity on node (AON) types as indicated in notations. In network diagram activities, they may be classified as initial activities, concurrent activities, preceding activities, succeeding activities, and end activities which form the network.

- Initial activities are those that can start at the outset of the project.
- Concurrent activities are those that can be performed simultaneously or happen together.
- Succeeding activities are those that depend upon others.
- Preceding activities are those that succeeding activities depend upon.
- End activities are those that are last in the project.

We can establish the network diagram for CPM through node numbering using Fulkerson's Numbering Rule (Heldman, 2011) as explained below:

1. Each activity (e.g., i–j) of the project network is numbered as such that i
2. Step 1: Identify the source node from the activities for the project network and number them sequentially from 1 onward.
3. Step 2: For each numbered node, delete the outgoing activity and instead identify the new sources of that activity if any.
4. Step 3: Number the newly discovered sources sequentially.
5. Step 4: Continue until one of the following thing happens:
    - All the nodes are numbered, indicating a consistent network.
    - The absence of sources in the unnumbered nodes indicates an inconsistency (i.e., continue until the last event is obtained).

How Can Crashing Be Approached?
When the crashing approach is used, any additional costs associated with crashing the project are reviewed against the possible benefits of completing the project within a shorter span of time. In addition to that, other items that are considered when one is using the crashing approach include adding more resources to the project, allowing additional overtime, and paying extra to receive delivery of critical components more quickly, among others. Crashing only works if the additional resources are going to allow you to complete the project sooner.

Normal Cost-Time
The normal cost-time project's analysis gives the number of paths with different activity combinations in a project network to help finish the project successfully. The paths may be NCP or CP for a single, *similar output through each path*. After choosing CP, the project normal cost-time is calibrated and plotted accordingly.

Numerical Example With Calculation: Crashing the Project By Critical Path Method
The following is a model of a network diagram consisting of six different network paths: (1-2-5-6-7-8), (1-2-3-5-6-7-8), (1-2-5-6-8), (1-2-3-5-6-8), (1-2-4-5-6-7-8), and (1-2-4-5-6-8). All of these paths show the project finishing successfully with their respective durations. The activity 4–5 is a "dummy activity." Take overheads as Rs. 100 per day for both normal and crashed time-calculation purposes. The cost-time data for all the activities is given in the table below.

Table 1: Project's activity data

Sr. No.	Activity	Normal Time Days (Tn)	Normal Cost Rs. (Cn)	Maximum Crashed Time Limit in Days	Crashed Time in Days (Tc)	Crashed Cost in Rs. (Cc)
1	1-2	12	900	4	10	1200
2	2-3	12	90	6	11	111
3	2-4	33	1260	10	30	1740
4	2-5	36	2160	14	32	2430
5	3-5	20	750	8	18	900
6	4-5	0(dummy)	0(dummy)	0(dummy)	0(dummy)	0(dummy)
7	5-6	24	960	8	21	1230
8	6-7	16	1200	6	15	1410
9	6-8	52	2340	20	49	2700
10	7-8	40	3000	18	37	3600

Note 1:

1. From network diagram, the critical path has calibrated as shown below.
2. The critical path with zero float or slack time has chosen to finish the project activity.

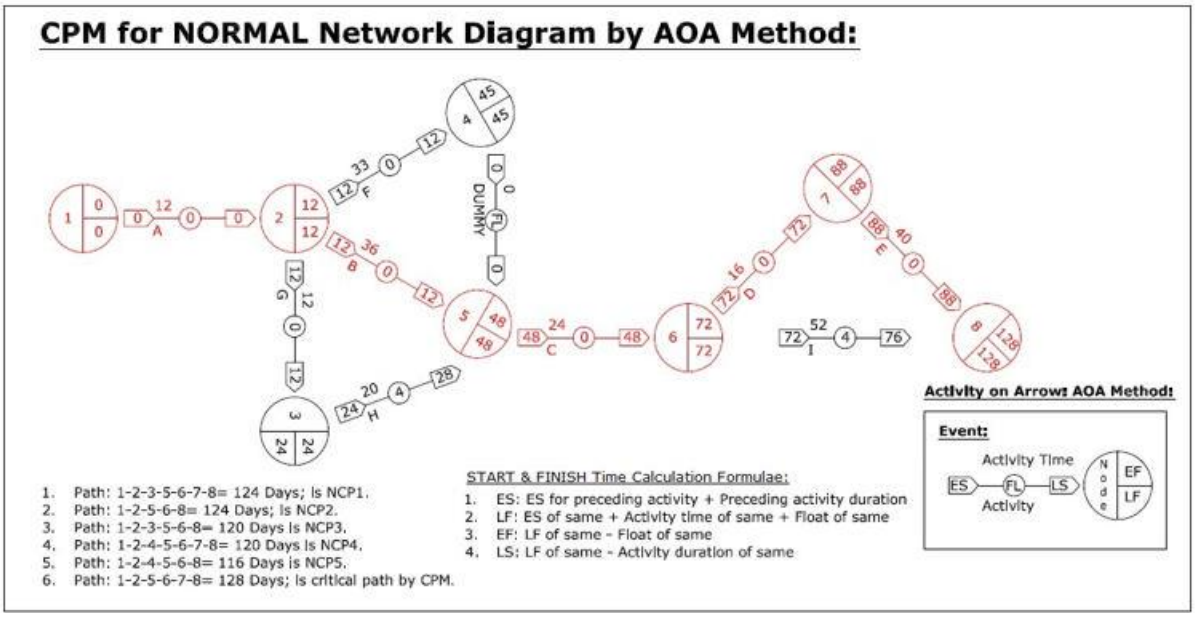

Figure 1: Normal critical path network diagram

To find the direct, indirect, and total cost, we must consider only “CP” as shown in Figure 1. As CP: 1-2-5-6-7-8=128 days is the longest duration path with zero float, this is the ideal path to finish the project activities usefully.

Table 2: Project’s cost calculation for CP (Jhamb, 2002; Heldman, 2011)

Sr. No.	Activity	Duration Days (T)	Normal Direct Cost RS. (DC)	Normal Indirect Cost Rs. (IC=Oxt)	Overhead Rs. (O)	Normal Total Cost Rs. (TC=DC+IC)
1	1-2	12	900	1,200	100	2,100
2	2-5	36	2,160	3,600	100	5,760
3	5-6	24	960	2,400	100	3,360
4	6-7	16	1,200	1,600	100	2,800
5	7-8	40	3,000	4,000	100	7,000
	Total:	**128**	**8,220**	**12,800**		**21,020**

Now, find the **cost slope** for crashed cost calculation purposes from the given data.

Procedure 1: Cost-slope calculation (Heldman, 2011; Jhamb, 2002)

Table 3-1: Cost-slope calculation

Sr. No.	Activity	Normal Time (Tn of CP) Days	Normal Cost (Cn of CP) Rs.	Maximum Crashed Time Limit Days	Crashed Time (Tc) Days	Crashed Cost (Cc) Rs.
1	1-2	12	900	2	10	1,200
2	2-3	-	-	3	11	111
3	2-4	-	-	5	30	1,740
4	2-5	36	2,160	7	32	2,430
5	3-5	-	-	4	18	900
6	4-5	0	0	0	0	0
7	5-6	24	960	4	21	1230
8	6-7	16	1,200	3	15	1,410
9	6-8	-	-	10	49	2,700
10	7-8	40	3,000	9	37	3,600
	Total:	**128**	**8220**		**115**	

Table 3-2: Cost-slope calculation

Sr. No.	Activity	Normal Time (Tn of NCP1) Days	Normal Cost (Cn of NCP1) Rs.	Normal Time (Tn of NCP2) Days	Normal Cost (Cn of NCP2) Rs.	Normal Time (Tn of NCP3) Days	Normal Cost (Cn of NCP3) Rs.
1	1-2	12	900	12	900	12	900
2	2-3	12	90	-	-	12	90
3	2-4	-	-	-	-	-	-
4	2-5	-	-	36	2,160	-	-
5	3-5	20	750	-	-	20	750
6	4-5	-	-	-	-	-	-
7	5-6	24	960	24	960	24	960
8	6-7	16	1,200	-	-	-	-
9	6-8	-	-	52	2,340	52	2,340
10	7-8	40	3,000	-	-	-	-
	Total:	**124**	**6,900**	**124**	**6,360**	**120**	**5,040**

Table 3-3: Cost-slope calculation

Sr. No.		Activity	Normal Time (Tn of NCP4) Days	Normal Cost (Cn of NCP4) Rs.	Normal Time (Tn of NCP5) Days	Normal Cost (Cn of NCP5) Rs.	ΔT (Tn-Tc) Days	ΔC (Cc-Cn) Rs.	Cost Slope ΔC/ΔT Rs./days
1		1-2	12	900	12	900	2	300	150
2		2-3	-	-	-	-	1	21	21
3		2-4	33	1,260	33	1,260	3	480	160
4		2-5	-	-	-	-	4	270	67.5
5		3-5	-	-	-	-	2	150	75
6		4-5	0	0	0	0	0	0	0
7		5-6	24	960	24	960	3	270	90
8		6-7	16	1,200	-	-	1	210	210
9		6-8	-	-	52	2,340	3	360	120
10		7-8	40	3000	-	-	3	600	200
		Total:	**125**	**7,320**	**121**	**5,460**			
		Total:	**125**	**7,320**	**121**	**5,460**			

Table 3-4: Cost-slope sequence

Sr. No.	Activity	ΔT (Tn-Tc) Days	Cost Slope ΔC/ΔT Rs./Days	Sequence for CP	Sequence for all
1	1-2	2	150	3	6
2	2-3	1	21	N.A.	1
3	2-4	3	160	N.A.	7
4	2-5	4	67.5	1	2
5	3-5	2	75	N.A.	3
6	4-5	0	0	N.A.	N.A.
7	5-6	3	90	2	4
8	6-7	1	210	5	9
9	6-8	3	120	N.A.	5
10	7-8	3	200	4	8

Sequence for all activities: 2–3, 2–5, 3–5, 5–6, 6–8, 1–2, 2–4, 7–8, 6–7

Sequence for CP activities: 2–5, 5–6, 1–2, 7–8, 6–7

Procedure 2: Project crashing technique

Step 1: Arranging the values for CP, NCP1, NCP2, NCP3, NCP4, NCP5

Sr. No.	CP	Tn of CP (Days)	ΔT (Days)	NCP1	Tn of NCP1 (Days)	ΔT (Days)	NCP2	Tn of NCP2 (Days)	ΔT (Days)
1	1-2	12	2	1-2	12	2	1-2	12	2
2	-	-	-	2-3	12	1	-	-	-
3	-	-	-	-	-	-	-	-	-
4	2-5	36	4	-	-	-	2-5	36	4
5	-	-	-	3-5	20	2	-	-	-
6	-	-	-	-	-	-	-	-	-
7	5-6	24	3	5-6	24	3	5-6	24	3
8	6-7	16	1	6-7	16	1	-	-	-
9	-	-	-	-	-	-	6-8	52	3
10	7-8	40	3	7-8	40	3	-	-	-
	Total:	128			124			124	

Sr. No.	NCP3	Tn of NCP3 (Days)	ΔT (Days)	NCP4	Tn of NCP4 (Days)	ΔT (Days)	NCP5	Tn of NCP5 (Days)	ΔT (Days)
1	1-2	12	2	1-2	12	2	1-2	12	2
2	2-3	12	1	-	-	-	-	-	-
3	-	-	-	2-4	33	3	2-4	33	3
4	-	-	-	-	-	-	-	-	-
5	3-5	20	2	-	-	-	-	-	-
6	-	-	-	4-5	0	0	4-5	0	0
7	5-6	24	3	5-6	24	3	5-6	24	3
8	-	-	-	6-7	16	1	-	-	-
9	6-8	52	3	-	-	-	6-8	52	3
10	-	-	-	7-8	40	3	-	-	-
	Total:	120			125			121	

Step 2: Crashing = Tn – T, excluding initially for an activity containing float as show in pink

Sr. No.	CP	Tn of CP (Days)	∆T (Days)	NCP1	Tn of NCP1 (Days)	∆T (Days)	NCP2	Tn of NCP2 (Days)	∆T (Days)
1	1-2	10	2	1-2	10	2	1-2	10	2
2	-	-	-	2-3	11	1	-	-	-
3	-	-	-	-	-	-	-	-	-
4	2-5	32	4	-	-	-	2-5	32	4
5	-	-	-	3-5	19	2	-	-	-
6	-	-	-	-	-	-	-	-	-
7	5-6	21	3	5-6	21	3	5-6	21	3
8	6-7	15	1	6-7	15	1	-	-	-
9	-	-	-	-	-	-	6-8	50	3
10	7-8	37	3	7-8	37	3	-	-	-
	Total:	**115**			**113**			**113**	

*Check CP activity total in Step 2 with given crashed activity duration (i.e., 115 days).

Sr. No.	NCP3	Tn of NCP3 (Days)	∆T (Days)	NCP4	Tn of NCP4 (Days)	∆T (Days)	NCP5	Tn of NCP5 (Days)	∆T (Days)
1	1-2	10	2	1-2	10	2	1-2	10	2
2	2-3	11	1	-	-	-	-	-	-
3	-	-	-	2-4	30	3	2-4	30	3
4	-	-	-	-	-	-	-	-	-
5	3-5	19	2	-	-	-	-	-	-
6	-	-	-	4-5	0	0	4-5	0	0
7	5-6	21	3	5-6	21	3	5-6	21	3
8	-	-	-	6-7	15	1	-	-	-
9	6-8	50	3	-	-	-	6-8	50	3
10	-	-	-	7-8	37	3	-	-	-
	Total:	**111**			**113**			**111**	

Step 3: Crashing = Tn – T, initially excluding any activity containing float as shown in pink

Sr. No.	CP	Tn of CP (Days)	ΔT (Days)	NCP1	Tn of NCP1 (Days)	ΔT (Days)	NCP2	Tn of NCP2 (Days)	ΔT (Days)
1	1-2	8	2	1-2	8	2	1-2	8	2
2	-	-	-	2-3	10	1	-	-	-
3	-	-	-	-	-	-	-	-	-
4	2-5	28	4	-	-	-	2-5	28	4
5	-	-	-	3-5	17	2	-	-	-
6	-	-	-	-	-	-	-	-	-
7	5-6	18	3	5-6	18	3	5-6	18	3
8	6-7	14	1	6-7	14	1	-	-	-
9	-	-	-	-	-	-	6-8	47	3
10	7-8	34	3	7-8	34	3	-	-	-
	Total:	**102**			**101**			**101**	

Sr. No.	NCP3	Tn of NCP3 (Days)	ΔT (Days)	NCP4	Tn of NCP4 (Days)	ΔT (Days)	NCP5	Tn of NCP5 (Days)	ΔT (Days)
1	1-2	8	2	1-2	8	2	1-2	8	2
2	2-3	10	1	-	-	-	-	-	-
3	-	-	-	2-4	27	3	2-4	27	3
4	-	-	-	-	-	-	-	-	-
5	3-5	17	2	-	-	-	-	-	-
6	-	-	-	4-5	0	0	4-5	0	0
7	5-6	18	3	5-6	18	3	5-6	18	3
8	-	-	-	6-7	14	1	-	-	-
9	6-8	47	3	-	-	-	6-8	47	3
10	-	-	-	7-8	34	3	-	-	-
	Total:	**100**			**101**			**100**	

Step 4: Crashing = Tn – T, initially excluding any activity containing float as shown in pink

Sr. No.	CP	Tn of CP (Days)	ΔT (Days)	NCP1	Tn of NCP1 (Days)	ΔT (Days)	NCP2	Tn of NCP2 (Days)	ΔT (Days)
1	1-2	6	2	1-2	6	2	1-2	6	2
2	-	-	-	2-3	9	1	-	-	-
3	-	-	-	-	-	-	-	-	-
4	2-5	24	4	-	-	-	2-5	24	4
5	-	-	-	3-5	15	2	-	-	-
6	-	-	-	-	-	-	-	-	-
7	5-6	15	3	5-6	15	3	5-6	15	3
8	6-7	13	1	6-7	13	1	-	-	-
9	-	-	-	-	-	-	6-8	44	3
10	7-8	31	3	7-8	31	3	-	-	-
	Total:	89			89			89	

Sr. No.	NCP3	Tn of NCP3 (Days)	ΔT (Days)	NCP4	Tn of NCP4 (Days)	ΔT (Days)	NCP5	Tn of NCP5 (Days)	ΔT (Days)
1	1-2	6	2	1-2	6	2	1-2	6	2
2	2-3	9	1	-	-	-	-	-	-
3	-	-	-	2-4	24	3	2-4	24	3
4	-	-	-	-	-	-	-	-	-
5	3-5	15	2	-	-	-	-	-	-
6	-	-	-	4-5	0	0	4-5	0	0
7	5-6	15	3	5-6	15	3	5-6	15	3
8	-	-	-	6-7	13	1	-	-	-
9	6-8	44	3	-	-	-	6-8	44	3
10	-	-	-	7-8	31	3	-	-	-
	Total:	89			89			89	

Stop crashing, as all paths became "critical path" (i.e., all path durations match with CP durations).

Note 2:

1. We should stop project crashing at Step 3, as Tn of CP reached maximum crashed limit.
2. We should stop project crashing at Step 3, as all paths could become CP.
3. Even if we are not reaching the given crashed limit of: 2, 7, 4, 3, 9 for respective activities, we should stop crashing as all paths could become "critical path."
4. The crashed duration of the project is 89 days.
5. The pink highlighting in the above tables shows activities containing float.
6. Float activity can be crashed at the end to approximate the NCP duration with the CP duration.

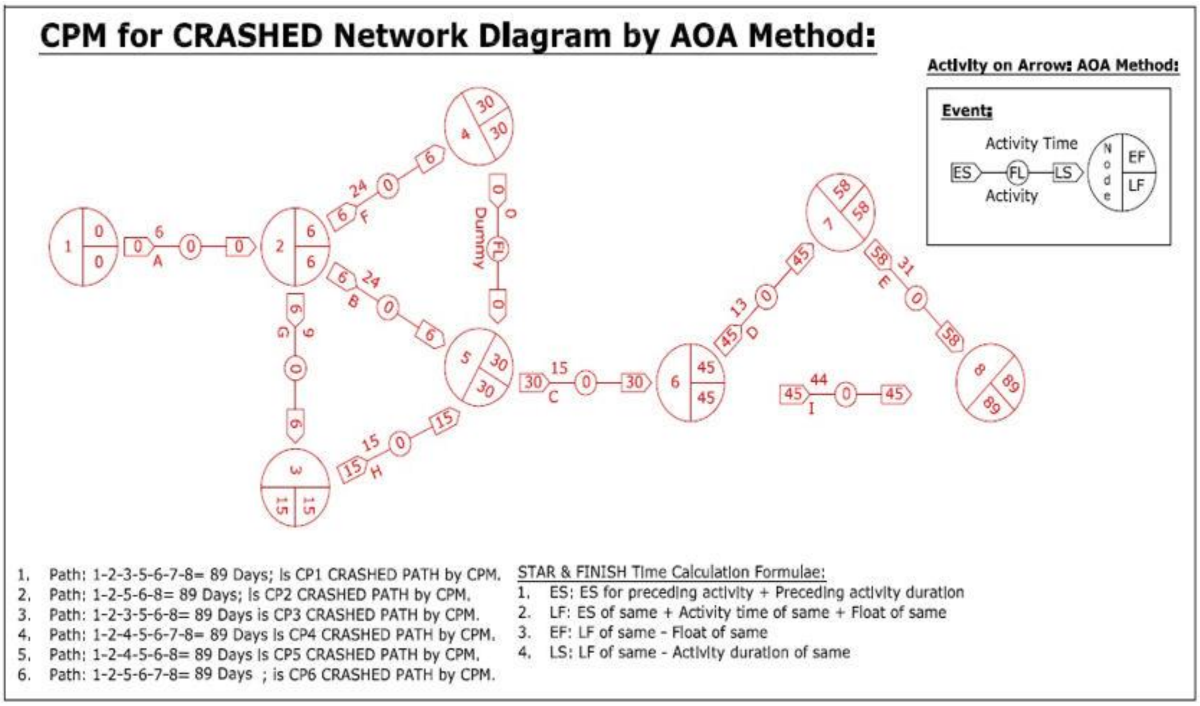

Figure 2: Crashed critical path network diagram

As shown in Figure 2, all paths become "CP" within the same duration of 89 days.

Procedure 3-1: Crashed direct cost calculation using cost-slope sequence for all activities, as shown in Table 3–4

- Direct normal direct cost of project: Rs. 8,220
- Project normal time: 128 days
- Project crashed time: 89 days
- Cost-slope activity sequence for crashed cost calculation, sequence for all: 2–3, 2–5, 3–5, 5–6, 6–8, 1–2, 7–8, 6–7

Step 1: Crashing the activity (2–3) by one day because it has the lowest cost slope
Crashed project duration: 128 – 1 = **127 days**
Crashed project cost: 8,220 + (1 x 21) = **Rs. 8,241**

Step 2: Crashing the activity (2–5) by four days because it has the next-lowest cost slope
Crashed project duration: 127 – 4 = **123 days**
Crashed project cost: 8,241 + (1 x 67.5) = R**s. 8,288**

Step 3: Crashing the activity (3–5) by two days because it has the next-lowest cost slope
Crashed project duration: 123 – 2 = **121 days**
Crashed project cost: 8,511 + (2 x 75) = **Rs. 8,661**

Step 4: Crashing the activity (5–6) by three days because it has the next-lowest cost slope
Crashed project duration: 121 – 3 = **118 days**
Crashed project cost: 8,661 + (3 x 90) = **Rs. 8,931**

Step 5: Crashing the activity (6–8) by three days because it has the next-lowest cost slope
Crashed project duration: 118 – 3 = **115 days**
Crashed project cost: 8,931 + (3 x 120) = **Rs. 9,291**

Step 6: Crashing the activity (1–2) by two days because it has the next-lowest cost slope
Crashed project duration: 115 – 2 = **113 days**
Crashed project cost: 9,291 + (2 x 150) = **Rs. 9,591**

Step 7: Crashing the activity (2–4) by three days because it has the next-lowest cost slope
Crashed project duration: 113 – 2 = **110 days**
Crashed project cost: 9,591 + (3 x 160) = **Rs. 10,071**

Step 8: Crashing the activity (7–8) by three days because it has the next-lowest cost slope
Crashed project duration: 110 – 3 = **107 days**
Crashed project cost: 10,071 + (3 x 200) = **Rs. 10,671**

Step 9: Crashing the activity (6–7) by one day because it has the next-lowest cost slope
Crashed project duration: 107 – 1 = **106 days**
Crashed project cost: 10,671 + (1 x 210) = **Rs. 10,881**

Step 10: Crashing the activity (2–3) by one day because it has the next-lowest cost slope
Crashed project duration: 106 – 1 = **105 days**
Crashed project cost: 10,881 + (1 x 21) = **Rs. 10,902**

Step 11: Crashing the activity (2–5) by four days because it has the next-lowest cost slope
Crashed project duration: 105 – 4 = **101 days**
Crashed project cost: 10,902 + (4 x 67.5) = **Rs. 11,172**

Step 12: Crashing the activity (3–5) by two days because it has the next-lowest cost slope
Crashed project duration: 101 – 2 = **99 days**
Crashed project cost: 11,172 + (2 x 75) = **Rs. 11,322**

Step 13: Crashing the activity (5–6) by three days because it has the next-lowest cost slope
Crashed project duration: 99 – 3 = **96 days**
Crashed project cost: 11,322 + (3 x 90) = **Rs. 11,592**

Step 14: Crashing the activity (6–8) by three days because it has the next-lowest cost slope
Crashed project duration: 96 – 3 = **93 days**
Crashed project cost: 11,592 + (3 x 120) = **Rs. 11,952**

Step 15: Crashing the activity (1–2) by two days because it has the next-lowest cost slope
Crashed project duration: 93 – 2 = **91 days**
Crashed project cost: 11,952 + (2 x 150) = **Rs. 12,252**

Step 16: Crashing the activity (2–4) by three days because it has the next-lowest cost slope
Crashed project duration: 91 – 3 = **88 days**
Crashed project cost: 12,252 + (3 x 160) = **Rs. 12,732**

Step 17: Crashing the activity (7–8) by three days because it has the next-lowest cost slope
Crashed project duration: 88 – 3 = **85 days**
Crashed project cost: 12,732 + (3 x 200) = **Rs. 13,332**

Step 18: Crashing the activity (6–7) by one day because it has the next-lowest cost slope
Crashed project duration: 85 – 1 = **84 days**
Crashed project cost: 13,332 + (1 x 210) = **Rs. 13,542**

Note 3:

1. Project crashed duration by Procedure 3–1 has come at 84 days, which does not match with the crashed project duration of 89 days; hence, this procedure fails.
2. Now, you must proceed to the crashed calculation to revise Procedure 3-1 for the CP cost-slope sequence.

Revised Procedure 3-1: Crashed direct cost calculation using cost-slope sequence for CP activities, as shown in Table 3-4:

- Direct normal direct cost of project: Rs. 8,220
- Project normal time: 128 days
- Project crashed time: 89 days
- Cost-slope activity sequence for crashed cost calculation; sequence for CP: 2–5, 5–6, 1–2, 7–8, 6–7

Step 1: Crashing the activity (2–5) by four days because it has the lowest cost slope
Crashed project duration: 128 – 4 = **124 days**
Crashed project cost: 8,220 + (4 x 67.5) = **Rs. 8,490**

Step 2: Crashing the activity (5–6) by three days because it has the lowest cost slope
Crashed project duration: 124 – 3 = **121 days**
Crashed project cost: 8,490 + (3 x 90) = **Rs. 8,760**

Step 3: Crashing the activity (1–2) by two days because it has the lowest cost slope
Crashed project duration: 121 – 2 = **119 days**
Crashed project cost: 8,760 + (2 x 150) = **Rs. 9,060**

Step 4: Crashing the activity (7–8) by three days because it has the lowest cost slope
Crashed project duration: 119 – 3 = **116 days**
Crashed project cost: 9,060 + (3 x 250) = **Rs. 9,660**

Step 5: Crashing the activity (6–7) by one day because it has the lowest cost slope
Crashed project duration: 116 – 1 = **115 days**
Crashed project cost: 9,660 + (1 x 210) = **Rs. 9,870**

Step 6: Crashing the activity (2–5) by four days because it has the lowest cost slope
Crashed project duration: 115 – 4 = **111 days**
Crashed project cost: 9,870 + (4 x 67.5) = **Rs. 10,140**

Step 7: Crashing the activity (5–6) by three days because it has the lowest cost slope
Crashed project duration: 111 – 3 = **108 days**
Crashed project cost: 10,140 + (3 x 90) = **Rs. 10,410**

Step 8: Crashing the activity (1–2) by two days because it has the lowest cost slope
Crashed project duration: 108 – 2 = **106 days**
Crashed project cost: 10,410 + (2 x 150) = **Rs. 10,710**

Step 9: Crashing the activity (7–8) by three days because it has the lowest cost slope
Crashed project duration: 106 – 3 = 1**03 days**
Crashed project cost: 10,710 + (3 x 200) = **Rs. 11,310**

Step 10: Crashing the activity (6–7) by one day because it has the lowest cost slope
Crashed project duration: 103 – 1 = 1**02 days**
Crashed project cost: 11,310 + (1 x 210) = **Rs. 11,520**

Step 11: Crashing the activity (2–5) by four days because it has the lowest cost slope
Crashed project duration: 102 – 4 = **98 days**
Crashed project cost: 11,520 + (4 x 67.5) = **Rs. 11,790**

Step 12: Crashing the activity (5–6) by three days because it has the lowest cost slope
Crashed project duration: 98 – 3 = **95 days**
Crashed project cost: 11,790 + (3 x 90) = **Rs. 12,060**

Step 13: Crashing the activity (1–2) by two days because it has the lowest cost slope
Crashed project duration: 95 – 2 = **93 days**
Crashed project cost: 12,060 + (2 x 150) = **Rs. 12,360**

Step 14: Crashing the activity (7–8) by three days because it has the lowest cost slope
Crashed project duration: 93 – 3 = **90 days**
Crashed project cost: 12,360 + (3 x 200) = **Rs. 12,960**

Step 15: Crashing the activity (6–7) by one day because it has the lowest cost slope
Crashed project duration: 90 – 1 = **89 days**
Crashed project cost: 12,960 + (1 x 210) = **Rs. 13,170**

Note 4: Crashed project duration by revised Procedure 3-1: 89 days matching with crashed project duration of 89 days. Hence, this revised Procedure 3-1 is correct.

Procedure 4: Crashed total cost of project according to revised Procedure 3-1

Table 4: Total cost and optimal time-cost of project for crashed time

Sr. No.	Duration Days (t)	Crashed Direct Cost Rs. (DC)	Crashed Indirect Cost Rs. (IC=Oxt)	Overheads Rs. (O)	Crashed Total Cost Rs. (TC=DC+IC)
1	89	13,170	8,900	100	22,070
2	90	12,960	9,000	100	21,960
3	93	12,360	9,300	100	21,660
4	95	12,060	9,500	100	21,560
5	98	11,790	9,800	100	21,590
6	102	11,520	10,200	100	21,720
7	103	11,310	10,300	100	21,610
8	106	10,710	10,600	100	21,310
9	108	10,410	10,800	100	21,210
10	111	10,140	11,100	100	21,240
11	115	9,870	11,500	100	21,370
12	116	9,660	11,600	100	21,260
13	119	9,060	11,900	100	20,960
14	121	8,760	12,100	100	20,860
15	124	8,490	12,400	100	20,890
16	128	8,220	12,800	100	21,020

Blue-shaded row showing optimal cost-time.

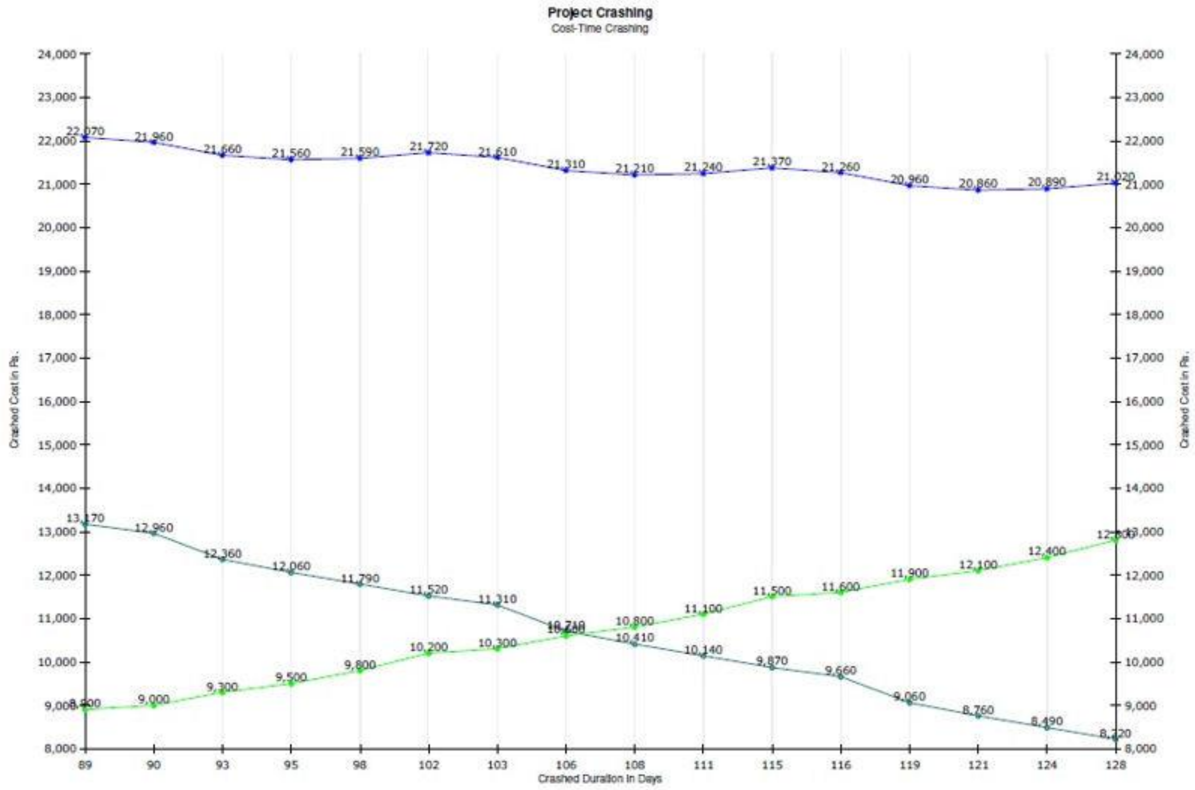

Figure 3: Project crashed graph w.r.t. Table 4 (Heldman, 2011)

Table 5: Crashed total cost of project for crashed critical path

Sr. No.	CP Activity	Crashed CP Duration Days (t)	Crashed Direct Cost Rs. (DC)	Crashed Indirect Cost Rs. (IC=100xt)	Crashed Total Cost Rs. (TC=DC+IC)
1	1-2	6	1,800	600	2,400
2	2-5	24	2,970	2,400	5,370
3	5-6	15	1,770	1,500	3,270
4	6-7	13	1,830	1,300	3,130
5	7-8	31	4,800	3,100	7,900
	Total:	**89**	**13,170**	**8,900**	**22,070**

Crashed direct cost is calculated by iteration with given data in Table 1 which is matched with Step 15 of revised Procedure 3-1.

Table 6: Crashed duration and cost for all crashed paths
(click image for larger view)

Sr.No.	Activity	Crashed CP0 Duration days (x3)	Crashed CP1 Duration days (x3)	Crashed CP2 Duration days (x3)	Crashed CP3 Duration days (x3)	Crashed CP4 Duration days (x3)	Crashed CP5 Duration days (x3)	Normal Cost Rs.	Iterative Slope 'm'	Crashed Cost for each activity D.C. (y3) Rs.	Indirect Cost I.C.=100*(x3) Rs.	Total Cost T.C.=D.C.+I.C. Rs.
1	1-2	6	6	6	6	6	6	900	-150	1800	600	2400
2	2-3		9		9			90	-21	153	900	1053
3	2-4					24	24	1260	-160	2700	2400	5100
4	2-5	24		24				2160	-67.5	2970	2400	5370
5	3-5		15		15			750	-75	1125	1500	2625
6	4-5	0(Dummy)	0(Dummy)	0(Dummy)	0(Dummy)	0	0	0(Dummy)	0(Dummy)	0(Dummy)	0	0
7	5-6	15	15	15	15	15	15	960	-90	1770	1500	3270
8	6-7	13	13		13	13		1200	-210	1830	1300	3130
9	6-8			44			44	2340	-120	3300	4400	7700
10	7-8	31	31		31	31		3000	-200	4800	3100	7900
	Total:	89	89	89	89	89	89					
	Direct Cost:	13,170	11,478	9,840	11,478	12,900	9,570					
	Indirect Cost:	8,900	8,900	8,900	8,900	8,900	8,900					
	Total Cost:	22,070	20,378	18,740	20,378	21,800	18,470					

Observations

1. Optimal time-cost point occurs on the total cost line at or near the intersection of direct cost and indirect cost line in the same graph.
2. Direct cost in project crashing graph suddenly increases while reading from higher to lower time.
3. Indirect cost in project crashing graph gradually decreases while reading from higher to lower time.
4. Total cost line gives inverted dome shape by providing optimal time-cost point on it.
5. Direct cost, indirect cost, and total cost speak about expenditure only during the execution of projects.
6. While calculating crashed cost, “crashed direct cost” is calibrated.
7. Total cost value for CP has been considered, as the path CP was the only critical path before crashing.

Conclusion

1. If total cost after crashing shows minimum value at that crashed specific-time duration as compared to normal duration at the end of project crashing, then project crashing will be beneficial.
2. If the crashed activities in project crashing fulfill the project completion goal (even if the condition explained in “1” is not occurring), the crashing will also be beneficial.
3. Project optimal time-cost: The effect on direct cost for this example.
   - For project crashing up to the 89th day, direct cost is more than on its 128th day.
   - If re-crashing is done up to the optimal duration (e.g., up to the 108th day), its direct cost will show the same value of 10,410 for the same Tn of CP.
4. The benefit of “total cost line” and “optimal cost-time point” on it: In normal cost time, “total cost line” will serve the purpose of fund required (FR) as shown in S-curve.
5. The most important purpose of project crashing is that the project crashing ensures the use of any critical path (from more than one critical path combination) to finish the project in a shorter time frame but with a potentially higher cost than that of normal time.
6. On a particular project crashing step, the entire path becomes “critical path” (i.e., with zero float); you should stop the crashing of the project at that instant.
7. Stop crashing when any of the below conditions is reached:
   - During the crashing activity, the crashing of any individual activity of any path reached up to its maximum-allowable crashing duration.
   - The entire path becomes the “critical path” (i.e., the entire path will have the same duration as that of the “crashed critical path duration”).
8. Even if the crashed activity duration has given (for example, total given crashed activity duration of 115 days), the values of Delta T and the cost slope will be suitable in proportion for crashing the activities up to all the “critical path” appearing. Which, in this above case, is up to the 89th day. It can be checked in the Procedure 1, Table 3-1 calculation in the project crashing table.
9. While calculating project duration from the path in the network diagram, the float or slack time is not considered in the summation of duration of path activity.

10. The project also must be crashed (shortening the project duration) or fast tracked (parallel activities) for negative project float value (e.g., if the negative value comes for latest time—earliest time).
11. CP and NCP are the sequence of the combination of activities to complete the whole project task through the respective path duration successfully.

References

1. Heldman, K. (2011). *PMP Study Guide.* (6th ed.). Hoboken, NJ: Wiley Publishing.
2. Jhamb, L. C. (2002). *Industrial Management.* Pune, India: Everest Publications.