Project Crashing to Solve Time-Cost Trade-Off

Anagha Katti[#1], Milind Darade[*2]
[#]P.G. Student, Civil-Construction & Management, SPPU Dr. D.Y.Patil SOET Charoli,Pune
* Prof, Civil-Construction & Management, SPPU Dr. D.Y.Patil SOET Charoli,Pune
Maharashtra India

Abstract

In the construction industry, project time & project cost are given upmost priority. But since there are innumerable uncertainties involved in construction, delays in project completion are fairly common which lead to an increase in project's total cost. Thus project time crashing plays an important role in project management determining which activities duration to crash to complete the project in the stipulated time. But crashing the duration will mean adding more resources which will lead to an increased additional cost of the project. Thus, the paper deals with determining how to crash the project duration so as to complete the project at the earliest with minimum added cost obtaining a Time-Cost Tradeoff for the project. This paper provides a framework for reducing total project time at the least added total cost by crashing the duration of an actual residential building construction project. The project is scheduled in Microsoft Project and crashed using the Solver add-in of Microsoft Excel.

I. INTRODUCTION

Crashing the activities of a project relates to the cost-evaluation of reducing the duration of those activities which are in the critical path. After this evaluation, the activities that correspond to the lowest cost for crashing should be worked on. This means that the addition of more financial resources, manpower (extra hours, for example), materials or equipments, will cause an increase in the project's budget.

Construction of a real time structure involves thousands of activities including not only civil but also mechanical electrical & various other aspects. . The project considered for this paper is that of a Residential Building in Kolte Patil I Ven Township "Life Republic" Jhambe Marunji Hinjewadi Pune. For academic purposes, the scope of this paper limits to the planning & crashing of only RCC works of the tower A of Residential sector R3. The project is scheduled in MS Project and since manual crashing of the project of this scale will prove tedious and unnecessarily time consuming, the paper uses an add-in of MS Excel called Excel Solver.

The second section of this paper presents the problem statement formulated comprising of the complexities involved in crashing of the construction project.

The third section presents the analysis of the crashing problem with a view to determine the least possible time for a project's completion; and to program the project's crashing that would implicate the least additional cost. Some trade-off discussions concerning the crash costs, and project's duration are also carried out.

II. PROBLEM STATEMENT & METHODOLOGY OF WORK

A. *Problem Definition:*

Project Time-Cost Trade-Off problem can be defined as follows: a project is represented by activities i associated with its time T_i and cost C_i.

To manually calculate the earliest/latest times (ES/EF/LS/LF) for each activity *i* can be quite time consuming and tedious using the forward-backward passes. Thus for this paper, these times are calculated in MS.Excel using specific formulae.

To encapsulate, Project Time Cost Trade-off Problem can be formally stated as follows: given a network with a lot of activities by their sequences, durations, costs, a general status is determined by each activity according to at least one of the following objectives: minimize the project duration and minimize budget. [5]

B. *Problem Statement:*

Kolte-Patil Developers Ltd is a leading Pune-based real estate company. The company has developed and constructed 42 projects including 30 residential complexes, 8 commercial complexes, and 4 information technology parks across Pune and Bengaluru. The Township of Life Republic is an ongoing project by Kolte Patil Developers which commenced in 2010. The total cost of the whole project is estimated to be 11,000 crores.

The scope of work for the whole project is large and complex since the vast 400 acre of township area is planned to be developed into several sectors containing Infrastructural Projects, Residential Projects, Commercial, Retail, Entertainment & Recreational, Educational, Sports, Health Sectors, Urban Farm, Management & Maintenance Projects. A residential tower "A" in the residential sector "R3" of the township has been chosen for the analysis of Time-Cost Tradeoff.

Considering the fact that the construction of this residential tower is subject to a large number of exogenous factors, mostly economical & beyond the scope of the top management, it was decided to focus this research on only the RCC works of the residential tower A in sector R3.

Table 1 summarizes the data related to the RCC works of the tower A.

Table 1: Project Data

ID	Activity Name	Normal Duration	Normal Cost
1	**RCC**		
2	**Substructure:**		
3	***Footings***		
4	PCC below footings	55 days	4,60,156
5	Reinforcement Fixing	56 days	8,20,954
6	Shuttering	52 days	2,63,487
7	Concreting	49 days	7,95,369
8	Deshuttering	49 days	2,63,487
9	***Column & lift pardi upto Plinth beam***		
10	**1st Step**		
11	Reinforcement Fixing	42 days	8,20,954
12	Shuttering	45 days	2,63,487
13	Concreting	43 days	7,95,369
14	Deshuttering	43 days	2,63,487
15	**2nd Step**		
16	Reinforcement Fixing	35 days	8,20,954
17	Shuttering	35 days	2,63,487
18	Concreting	35 days	7,95,369
19	Deshuttering	35 days	2,63,487
20	**Plinth Beams**		
21	PCC below Plinth beams	12 days	89,284
22	Reinforcement Fixing	17 days	8,20,954
23	Shuttering	16 days	2,63,487
24	Concreting	16 days	7,95,369
25	Deshuttering	17 days	2,63,487
26	PCC for plinth	25 days	4,05,212
27	***Construction of Parking Floor Slab (Conventional Shuttering)***		
28	**West side half portion**		
29	Column / Retaining wall	24 days	21,43,292
30	Reinforcement Fixing	20 days	8,20,954
31	Shuttering	20 days	5,26,969
32	Concreting	20 days	7,95,369
33	Slab	44 days	21,43,292
34	Shuttering	42 days	5,26,969
35	Reinforcement placing	40 days	8,20,954
36	Concreting	1 day	7,95,369
37	**East side half portion**		
38	**Column / Retaining wall**		
39	Reinforcement Fixing	45 days	8,20,954
40	Shuttering	45 days	5,26,969
ID	**Activity Name**	**Normal Duration**	**Normal Cost**
41	Concreting	48 days	7,95,369
42	**Slab**		
43	Shuttering	29 days	5,26,969
44	Reinforcement placing	27 days	8,20,954
45	Concreting	1 day	7,95,369
46	**Superstructure**		
47	***Aluform RCC Slab Cycle***		
48	**1st Floor**		
49	Part 1	30 days	287,90,559
50	Part 2	25 days	287,90,559
51	**2nd Floor**		
52	Part 1	20 days	287,90,559
53	Part 2	20 days	287,90,559
54	**3rd Floor**		
55	Part 1	15 days	287,90,559
56	Part 2	15 days	287,90,559
57	**4th Floor**		
58	Part 1	10 days	287,90,559
59	Part 2	10 days	287,90,559
60	**5th Floor**		
61	Part 1	10 days	287,90,559
62	Part 2	10 days	287,90,559
63	**6th Floor**		
64	Part 1	10 days	287,90,559

65	Part 2	10 days	287,90,559
66	**7th Floor**		
67	Part 1	10 days	287,90,559
68	Part 2	10 days	287,90,559
69	**8th Floor**		
70	Part 1	10 days	287,90,559
71	Part 2	10 days	287,90,559
72	**9th Floor**		
73	Part 1	10 days	287,90,559
74	Part 2	10 days	287,90,559
75	**10th Floor**		
76	Part 1	10 days	287,90,559
77	Part 2	10 days	287,90,559
78	**11th Floor**		
79	Part 1	10 days	287,90,559
80	Part 2	10 days	287,90,559
81	**12th Floor**		
82	Part 1	10 days	287,98,952

ID	Activity Name	Normal Duration	Normal Cost
83	Part 2	10 days	287,98,952
84	**13th Floor**		
85	Part 1	10 days	287,98,952
86	Part 2	10 days	287,98,952
87	**14th Floor**		
88	Part 1	10 days	287,98,952
89	Part 2	10 days	287,98,952
90	**15th Floor**		
91	Part 1	10 days	287,98,952
92	Part 2	10 days	287,98,9
			52
93	**16th Floor**		
94	Part 1	10 days	287,98,952
95	Part 2	10 days	287,98,952
96	**17th Floor**		
97	Part 1	10 days	287,98,952
98	Part 2	10 days	287,98,952
99	**18th Floor**		

ID	Activity Name	Normal Duration	Normal Cost
100	Part 1	10 days	287,98,952
101	Part 2	10 days	287,98,952
102	**19th Floor**		
103	Part 1	10 days	287,98,952
104	Part 2	10 days	287,98,952
105	**20th Floor**		
106	Part 1	10 days	287,98,952
107	Part 2	10 days	287,98,952
108	**21st Floor**		
109	Part 1	10 days	287,98,952
110	Part 2	10 days	287,98,952
111	**22nd Floor**		
112	Part 1	10 days	287,98,952
113	Part 2	10 days	287,98,952
114	Terrace Parapet	15 days	30,12,097
115	**OHT & LMR**		
116	Bottom slab	15 days	279,19,526
117	Top Slab	15 days	279,19,526

The challenge is of bringing the project on schedule and even finishing early.

Adding up these times gives a grand total of 1631 days, which is far too much time for the construction of a residential building. Fortunately, some of the activities can be done in parallel, which substantially reduces the project completion time. Given all the information in Table 1, Answers have to be developed to the following questions.

1. What is the total time required to complete the project if no delays occur?
2. When can the individual activities start and finish (at the earliest) if no delays occur?
3. When do the individual activities need to start and finish (at the latest) to meet this project completion time?
4. Which are the critical bottleneck activities where any delays must be avoided to prevent delaying project completion?
5. If extra money is spent to expedite the project, what is the least expensive way of attempting to crash the project duration?
6. Assuming Funds of Rs 30 crores will be received in the form of the final instalments if the project is completed 3 weeks earlier to the estimated project completion, what is the least expensive way of attempting to meet the target completion time?

C. Methodology:

The Methodology adopted to crash the project to answer the Problem Statement consequently solving the Time-Cost Trade-off is depicted in the following points.

i) Using MS Project to plan & schedule the project.

A myriad of details are considered in planning how to coordinate all the RCC activities, in developing a realistic schedule. Of the many Project Management softwares, Microsoft Project is the most commonly used software to deal with all the data needed to develop schedule information.

- The various activities are linked by the software in terms of their predecessors and successors.
- Once completed, the total time required to complete the project is displayed thus answering Question 1 in the preceding section.

ii) Using MS Excel to schedule the project with CPM

- Each activity is scheduled by calculating its earliest & latest times (ES/EF/LS/LF) in MS Excel with the help of specific formulae thus answering Questions 2 & 3.
- The slack for an activity is the difference between its latest finish time and its earliest finish time. Thus knowing the earliest & latest times of each activity, their corresponding slack is calculated. Those activities with 0 slack will be classified as Critical activities, thus answering Question 4.

iii) Using Excel Solver to crash the project and solve the Time-Cost Trade-Offs

The problem of finding the least expensive way of crashing activities and the consequent Time-Cost Trade-off can be rephrased in a form more familiar to MS Excel Sheet and solved using MS Excel Solver Add-in. This section provides the answers to questions 5 & 6.

III. PROJECT CRASHING

A. Using MS Excel:

The calculations for scheduling (ES, LS, slack, etc.) are set up in MS Excel. They require use of the "min" and "max" functions and (to identify the critical path) the "if" function.

The following columns are imported to MS Excel from MS Project:

- Activity ID
- Activity Description
- Normal Duration
- Normal Cost
- The Immediate Predecessors
- The Immediate Successors

The following columns are then set up along with the above:

- ES, EF, LS, LF (For Each Activity)
- Crash Duration
- Crash Cost
- Maximum Crash Duration
- Crash cost/day
- Days to crash
- Realised time
- Slack
- Critical (1 for Yes & 0 otherwise).

If there are two (or more) activities with no successors, it helps (for the setup) to add a "Finish" activity (all activities with no successors are predecessors of "Finish", duration is 0) but this is not required. Similarly, if there are two or more activities with no predecessors, it helps to add a "Start" activity (all activities without predecessors are successors of "Start", duration is 0).

❖ Filling in the columns:

1. First five columns are just the imported information on the activities
2. Forward pass for "Early" times (ES; EF):

In the column for ES the entry is always "=max(the EF entries for the immediate predecessors { separated by commas})" . The immediate predecessors are the nodes listed in the "Predecessors" column. In the EF column all entries are "= cell with ES + cell with Realised Time".

For the "Finish" node (if there is one) ES is "=max(all EF entries)"

3. Backward pass for "Late" times (LS; LF):
   In the LS column, the entry is "= cell containing LF - cell containing Realised Time"
   In the LF column, the entry is "= min(the LS entries for all the immediate successors { separated by commas})"
   The immediate successors of an activity are all the activities that have the activity in their "predecessors" list) [If you don't have a "Finish" node you need to remember that for an activity that has no successors, the LF entry is "=max(all EF entries)"
4. Slack is "=cell for LF - cell for EF" (or = cell for LS - cell for ES)
5. Critical is "=IF(slack=0,"1","0")" . This will put "1" in the cell if "slack = 0" is true and "0" if it is not. Finish time is "= EF of the "Finish" node" if there is a Finish node, or "= max(all EF entries)". Use the mouse to select the range of all EF entries. [11]
6. Finish-to-Start (F-S) is the most commonly used Task relationship and is by default used by MS Project to link the predecessors and successors unless specified otherwise. Complications may arise if there are different Task Relationships involved such as Start-to-Start (S-S), Start-to-Finish (S-F) & Finish-to-Finish (F-F). For this project there are a number of activities linked with S-S relationship. Thus the calculations of ES,LS & LF differ as follows:

i. In the column for ES the entry is now "=max(the ES entries for the immediate predecessors { separated by commas})". If the predecessor has a lag value (example see Table 2. Activity 5 has a predecessor relationship of 4SS+2days), it is added to the formula and if the predecessor has a lead value, it is subtracted from the formula.

ID	Activity Name	Predec es-sors	Success o-rs	ES	EF	LS	LF
4	PCC below footings	-	5SS+2d	0	55	0	55
5	Reinforc ---ement Fixing	4SS+2 d	6SS+5d	2	58	2	58
6	Shutteri ng	5SS+5 d	7SS+3d	7	59	7	59

Table 2: Snippet of the main Schedule (Start-to-Start)

ii. In the LS column, the entry is now "= min(the LS entries for all the immediate successors { separated by commas})". If the successor has a lead value (example see Table 2. Activity 5 has a successor relationship of 6SS+5days), it is subtracted from the formula and if the successor has a lag value, it is added to the formula.

iii. In the LF column, the entry is now "= cell containing LS + cell containing Realised Time"

❖ Activity Crash Time & Cost:

According to the site engineers, the regular working time of workers is 8 hours a day for 7 days a week from 9:00am to 6:00pm with 1 hr lunch. According to the project managers, the only way activities can be accelerated is through using overtime. Since the maximum overtime allowed is 6 hours on top of the regular 8-hour working day, (from 8:00am to 12:00am, 14hrs a day) activities may be crashed on average at a ratio of 4:7 (i.e. Regular 8/ Overtime 14). The results are the maximum crash durations used. Site managers also believed that when activities need to be crashed, the cost increase is mostly due to the double rate for overtime. As consequence, they had no problem in accepting the assumption of linear relationship between cost escalation and time crashed.

Table 3 has thus been created containing the project's best estimates of activity duration & costs and their subsequent crash duration and crash costs. The Table also shows the previously calculated values of activities ES/EF/LS LF times and available Slack. The critical activities have been highlighted in red showing zero slack.

Maximum crash time for each activity has been calculated by the following formula:

Maximum crash duration = Normal Duration – Crash Duration

Cost slope indicating the cost of crashing per day is calculated as:

Crash cost/day = (Crash cost – Normal cost)/ Maximum crash duration

Crash cost/day of some activities (36 & 45) is zero since they have no scope of being crashed. Hence, they are edited to a large number such as 10000000,00,000, to steer the software away from these values.

The Realized time column has been included which is nothing but the number of days available after crashing which is calculated by:

Realized time = Normal duration – Days to crash

Initially, the days to crash are set to 0 which gives the value of realized time = normal duration. The ES/EF/LS/LF times are formulated using this realized time so that these times are revised every time an activity is crashed. Doing so, the Maximum Duration without crashing is obtained which is equal to 451 days. Total Cost of project is calculated using the "SUMPRODUCT" function in Excel. The entry is "=SUMPRODUCT('days to be crashed' range,'maximum crash duration' range)". Using this formula gives the Total Cost of Rs 134,39,21,406.

This will be the Base Table to be used while using MS Excel Solver add-in.

B. Using MS Excel Solver:

To calculate the crashing of activities leading to the Time Cost Trade-off has been undertaken in MS Excel using the Excel add-in Solver. This add-in greatly aids in solving the complex crashing problem within minutes provided the input data is correctly inserted.

Once the solver is open, in the solver parameter dialogue box, (see Figure 1) the data required is carefully input.

1. In the 'Set Target Cell' box, the objective cell is input. The objective cell in this case is the Total Crash Cost. Our objective is to keep the Total Crash Cost as minimum as possible, hence select 'MIN'
2. In the 'By Changing Cells' box, the cells which will be varied throughout the course of the crashing process is entered. In this case, it is the column containing days to be crashed.
3. In the 'Subject to the Constraints' box, the constraints are entered. (see Figure 2)

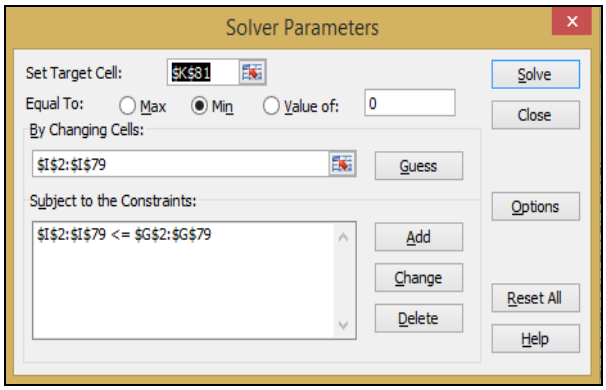

Fig 1: Solver Parameter dialouge box

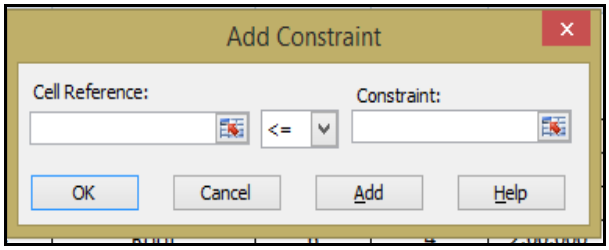

Fig 2: Solver Constraint dialouge box

i. Days to be crashed <= Maximum crash time

Under the cell reference, the entire range of days to be crashed is input & under constraint the entire range of maximum crash time is input.

ii. LF of project = Deadline

Under the cell reference, the latest finish time is input & under constraint the deadline is input. The deadline in this case is:

= Maximum Duration without crashing – 3 weeks

= 451 – 21 days = 430

The days to be crashed are set to zero and all the data in entered in solver.

4. Next step importantly, the solver is closed. The input values in days to be crashed are edited to maximum crash duration. This automatically gives us the result shown in Table 4 depicting the latest finish time if all the activities are fully crashed which is 288 days
costing Rs 94,92,45,225**.**

5. The days to crash are again edited to maximum crash durations and Solver is opened again and given the command to Solve. The result is shown in Table 5 which depicts that the project can be completed in the deadline of 430 days by spending a total crash cost of Rs7,15,05,085

Table 3: Base table used in MS.Excel for furthur calculations

ID	Activity Name	Normal Duration	Crash Duration	Normal Cost	Crash Cost	Max Crash Duration	Crash Cost/Day	Days to be crashed	Realised time	ES	EF	LS	LF	Slack	Critical
4	PCC below footings	55	31	4,60,156	8,05,273	24	14,641	0	55	0	55	0	55	0	1
5	Reinforcement Fixing	56	32	8,20,954	14,36,669	24	25,655	0	56	2	58	2	58	0	1
6	Shuttering	52	30	2,63,487	4,61,102	22	8,867	0	52	7	59	7	59	0	1
7	Concreting	49	28	7,95,369	13,91,896	21	28,406	0	49	10	59	10	59	0	1
8	Deshuttering	49	28	2,63,487	4,61,102	21	9,410	0	49	11	60	11	60	0	1
11	Reinforcement Fixing	42	24	8,20,954	14,36,669	18	34,206	0	42	22	64	22	64	0	1
12	Shuttering	45	26	2,63,487	4,61,102	19	10,247	0	45	24	69	24	69	0	1
13	Concreting	43	25	7,95,369	13,91,896	18	32,370	0	43	26	69	26	69	0	1
14	Deshuttering	43	25	2,63,487	4,61,102	18	10,723	0	43	28	71	28	71	0	1
16	Reinforcement Fixing	35	20	8,20,954	14,36,669	15	41,048	0	35	33	68	33	68	0	1
17	Shuttering	35	20	2,63,487	4,61,102	15	13,174	0	35	37	72	37	72	0	1
18	Concreting	35	20	7,95,369	13,91,896	15	39,768	0	35	39	74	39	74	0	1
19	Deshuttering	35	20	2,63,487	4,61,102	15	13,174	0	35	40	75	40	75	0	1
21	PCC below Plinth beams	12	7	89,284	1,56,247	5	13,021	0	12	59	71	59	71	0	1
22	Reinforcement Fixing	17	10	8,20,954	14,36,669	7	84,510	0	17	60	77	60	77	0	1
23	Shuttering	16	9	2,63,487	4,61,102	7	28,819	0	16	63	79	63	79	0	1
24	Concreting	16	9	7,95,369	13,91,896	7	86,994	0	16	65	81	65	81	0	1
25	Deshuttering	17	10	2,63,487	4,61,102	7	27,124	0	17	67	84	67	84	0	1
26	PCC for plinth	25	14	4,05,212	7,09,121	11	28,365	0	25	84	109	84	109	0	1
30	Reinforcement Fixing	20	11	8,20,954	14,36,669	9	71,833	0	20	108	128	108	128	0	1
31	Shuttering	20	11	5,26,969	9,22,195	9	46,110	0	20	110	130	110	130	0	1
32	Concreting	20	11	7,95,369	13,91,896	9	69,595	0	20	112	132	112	132	0	1
34	Shuttering	42	24	5,26,969	9,22,195	18	21,957	0	42	122	164	122	164	0	1
35	Reinforcement placing	40	23	8,20,954	14,36,669	17	35,917	0	40	125	165	125	165	0	1

36	Concreting	1	1	7,95,369	13,91,896	0	10000000,00,000	0	1	165	166	165	166	0	1
ID	**Activity Name**	**Normal Duration**	**Crash Duration**	**Normal Cost**	**Crash Cost**	**Max Crash Duration**	**Crash Cost/Day**	**Days to be crashed**	**Realised time**	**ES**	**EF**	**LS**	**LF**	**Slack**	**Critical**
39	Reinforcement Fixing	45	26	8,20,954	14,36,669	19	31,926	0	45	122	167	126	171	4	0
40	Shuttering	45	26	5,26,969	9,22,195	19	20,493	0	45	123	168	127	172	4	0
41	Concreting	48	27	7,95,369	13,91,896	21	28,998	0	48	124	172	128	176	4	0
43	Shuttering	29	17	5,26,969	9,22,195	12	31,800	0	29	137	166	141	170	4	0
44	Reinforcement placing	27	15	8,20,954	14,36,669	12	53,210	0	27	139	166	143	170	4	0
45	Concreting	1	1	7,95,369	13,91,896	0	10000000,00,000	0	1	166	167	170	171	4	0
49	Part 1	30	17	287,90,559	503,83,479	13	16,79,449	0	30	166	196	166	196	0	1
50	Part 2	25	14	287,90,559	503,83,479	11	20,15,339	0	25	167	192	171	196	4	0
52	Part 1	20	11	287,90,559	503,83,479	9	25,19,174	0	20	196	216	196	216	0	1
53	Part 2	20	11	287,90,559	503,83,479	9	25,19,174	0	20	192	212	196	216	4	0
55	Part 1	15	9	287,90,559	503,83,479	6	33,58,899	0	15	216	231	216	231	0	1
56	Part 2	15	9	287,90,559	503,83,479	6	33,58,899	0	15	212	227	216	231	4	0
58	Part 1	10	6	287,90,559	503,83,479	4	50,38,348	0	10	231	241	231	241	0	1
59	Part 2	10	6	287,90,559	503,83,479	4	50,38,348	0	10	227	237	231	241	4	0
61	Part 1	10	6	287,90,559	503,83,479	4	50,38,348	0	10	241	251	241	251	0	1
62	Part 2	10	6	287,90,559	503,83,479	4	50,38,348	0	10	237	247	241	251	4	0
64	Part 1	10	6	287,90,559	503,83,479	4	50,38,348	0	10	251	261	251	261	0	1
65	Part 2	10	6	287,90,559	503,83,479	4	50,38,348	0	10	247	257	251	261	4	0
67	Part 1	10	6	287,90,559	503,83,479	4	50,38,348	0	10	261	271	261	271	0	1
68	Part 2	10	6	287,90,559	503,83,479	4	50,38,348	0	10	257	267	261	271	4	0
70	Part 1	10	6	287,90,559	503,83,479	4	50,38,348	0	10	271	281	271	281	0	1
71	Part 2	10	6	287,90,559	503,83,479	4	50,38,348	0	10	267	277	271	281	4	0
73	Part 1	10	6	287,90,559	503,83,479	4	50,38,348	0	10	281	291	281	291	0	1
74	Part 2	10	6	287,90,559	503,83,479	4	50,38,348	0	10	277	287	281	291	4	0
76	Part 1	10	6	287,90,559	503,83,479	4	50,38,348	0	10	291	301	291	301	0	1

77	Part 2	10	6	287,90,559	503,83,479	4	50,38,348	0	10	287	297	291	301	4	0
79	Part 1	10	6	287,90,559	503,83,479	4	50,38,348	0	10	301	311	301	311	0	1
ID	**Activity Name**	**Normal Duration**	**Crash Duration**	**Normal Cost**	**Crash Cost**	**Max Crash Duration**	**Crash Cost/Day**	**Days to be crashed**	**Realised time**	**ES**	**EF**	**LS**	**LF**	**Slack**	**Critical**
80	Part 2	10	6	287,90,559	503,83,479	4	50,38,348	0	10	297	307	301	311	4	0
82	Part 1	10	6	287,98,952	503,98,166	4	50,39,817	0	10	311	321	311	321	0	1
83	Part 2	10	6	287,98,952	503,98,166	4	50,39,817	0	10	307	317	311	321	4	0
85	Part 1	10	6	287,98,952	503,98,166	4	50,39,817	0	10	321	331	321	331	0	1
86	Part 2	10	6	287,98,952	503,98,166	4	50,39,817	0	10	317	327	321	331	4	0
88	Part 1	10	6	287,98,952	503,98,166	4	50,39,817	0	10	331	341	331	341	0	1
89	Part 2	10	6	287,98,952	503,98,166	4	50,39,817	0	10	327	337	331	341	4	0
91	Part 1	10	6	287,98,952	503,98,166	4	50,39,817	0	10	341	351	341	351	0	1
92	Part 2	10	6	287,98,952	503,98,166	4	50,39,817	0	10	337	347	341	351	4	0
94	Part 1	10	6	287,98,952	503,98,166	4	50,39,817	0	10	351	361	351	361	0	1
95	Part 2	10	6	287,98,952	503,98,166	4	50,39,817	0	10	347	357	351	361	4	0
97	Part 1	10	6	287,98,952	503,98,166	4	50,39,817	0	10	361	371	361	371	0	1
98	Part 2	10	6	287,98,952	503,98,166	4	50,39,817	0	10	357	367	361	371	4	0
100	Part 1	10	6	287,98,952	503,98,166	4	50,39,817	0	10	371	381	371	381	0	1
101	Part 2	10	6	287,98,952	503,98,166	4	50,39,817	0	10	367	377	371	381	4	0
103	Part 1	10	6	287,98,952	503,98,166	4	50,39,817	0	10	381	391	381	391	0	1
104	Part 2	10	6	287,98,952	503,98,166	4	50,39,817	0	10	377	387	381	391	4	0
106	Part 1	10	6	287,98,952	503,98,166	4	50,39,817	0	10	391	401	391	401	0	1
107	Part 2	10	6	287,98,952	503,98,166	4	50,39,817	0	10	387	397	391	401	4	0
109	Part 1	10	6	287,98,952	503,98,166	4	50,39,817	0	10	401	411	401	411	0	1
110	Part 2	10	6	287,98,952	503,98,166	4	50,39,817	0	10	397	407	401	411	4	0
112	Part 1	10	6	287,98,952	503,98,166	4	50,39,817	0	10	411	421	411	421	0	1
113	Part 2	10	6	287,98,952	503,98,166	4	50,39,817	0	10	407	417	411	421	4	0
114	Terrace Parapet	15	9	30,12,097	52,71,170	6	3,51,411	0	15	421	436	421	436	0	1

116	Bottom slab	15	9	279,19,526	488,59,170	6	32,57,278	0	15	421	436	421	436	0	1
117	Top Slab	15	9	279,19,526	488,59,170	6	32,57,278	0	15	436	451	436	451	0	1

Maximim Duration without crashing = 451 days
Total Cost (including indirect costs) = Rs 134,39,21,406

Table 4: Maximum Crash Durations are the input values for Days to be crashed in MS Excel, automatically giving the Total Crash Duration due to formulae linkages.

ID	Activity Name	Normal Duration	Crash Duration	Normal Cost	Crash Cost	Max Crash Duration	Crash Cost/Day	Days to be crashed	Realised time	ES	EF	LS	LF	Slack	Critical
4	PCC below footings	55	31	4,60,156	8,05,273	24	14,641	**24**	31	0	31	0	31	0	1
5	Reinforcement Fixing	56	32	8,20,954	14,36,669	24	25,655	**24**	32	2	34	2	34	0	1
6	Shuttering	52	30	2,63,487	4,61,102	22	8,867	**22**	30	7	37	7	37	0	1
7	Concreting	49	28	7,95,369	13,91,896	21	28,406	**21**	28	10	38	10	38	0	1
8	Deshuttering	49	28	2,63,487	4,61,102	21	9,410	**21**	28	11	39	11	39	0	1
11	Reinforcement Fixing	42	24	8,20,954	14,36,669	18	34,206	**18**	24	22	46	22	46	0	1
12	Shuttering	45	26	2,63,487	4,61,102	19	10,247	**19**	26	24	50	24	50	0	1
13	Concreting	43	25	7,95,369	13,91,896	18	32,370	**18**	25	26	51	26	51	0	1
14	Deshuttering	43	25	2,63,487	4,61,102	18	10,723	**18**	25	28	53	28	53	0	1
16	Reinforcement Fixing	35	20	8,20,954	14,36,669	15	41,048	**15**	20	33	53	33	53	0	1
17	Shuttering	35	20	2,63,487	4,61,102	15	13,174	**15**	20	37	57	37	57	0	1
18	Concreting	35	20	7,95,369	13,91,896	15	39,768	**15**	20	39	59	39	59	0	1
19	Deshuttering	35	20	2,63,487	4,61,102	15	13,174	**15**	20	40	60	40	60	0	1
21	PCC below Plinth beams	12	7	89,284	1,56,247	5	13,021	**5**	7	44	51	44	51	0	1
22	Reinforcement Fixing	17	10	8,20,954	14,36,669	7	84,510	**7**	10	45	55	45	55	0	1
23	Shuttering	16	9	2,63,487	4,61,102	7	28,819	**7**	9	48	57	48	57	0	1
24	Concreting	16	9	7,95,369	13,91,896	7	86,994	**7**	9	50	59	50	59	0	1
25	Deshuttering	17	10	2,63,487	4,61,102	7	27,124	**7**	10	52	62	52	62	0	1
26	PCC for plinth	25	14	4,05,212	7,09,121	11	28,365	**11**	14	62	76	62	76	0	1
30	Reinforcement Fixing	20	11	8,20,954	14,36,669	9	71,833	**9**	11	75	86	75	86	0	1

31	Shuttering	20	11	5,26,969	9,22,195	9	46,110	**9**	11	77	88	80	91	3	0
32	Concreting	20	11	7,95,369	13,91,896	9	69,595	**9**	11	79	90	82	93	3	0
34	Shuttering	42	24	5,26,969	9,22,195	18	21,957	**18**	24	89	113	92	116	3	0
35	Reinforcement placing	40	23	8,20,954	14,36,669	17	35,917	**17**	23	92	115	95	118	3	0
36	Concreting	1	1	7,95,369	13,91,896	0	10000000,00,000	**0**	1	115	116	118	119	3	0
39	Reinforcement Fixing	45	26	8,20,954	14,36,669	19	31,926	**19**	26	89	115	89	115	0	1

ID	Activity Name	Normal Duration	Crash Duration	Normal Cost	Crash Cost	Max Crash Duration	Crash Cost/Day	Days to be crashed	Realised time	ES	EF	LS	LF	Slack	Critical
40	Shuttering	45	26	5,26,969	9,22,195	19	20,493	**19**	26	90	116	90	116	0	1
41	Concreting	48	27	7,95,369	13,91,896	21	28,998	**21**	27	91	118	91	118	0	1
43	Shuttering	29	17	5,26,969	9,22,195	12	31,800	**12**	17	104	121	104	121	0	1
44	Reinforcement placing	27	15	8,20,954	14,36,669	12	53,210	**12**	15	106	121	106	121	0	1
45	Concreting	1	1	7,95,369	13,91,896	0	10000000,00,000	**0**	1	121	122	121	122	0	1
49	Part 1	30	17	287,90,559	503,83,479	13	16,79,449	**13**	17	116	133	119	136	3	0
50	Part 2	25	14	287,90,559	503,83,479	11	20,15,339	**11**	14	122	136	122	136	0	1
52	Part 1	20	11	287,90,559	503,83,479	9	25,19,174	**9**	11	133	144	136	147	3	0
53	Part 2	20	11	287,90,559	503,83,479	9	25,19,174	**9**	11	136	147	136	147	0	1
55	Part 1	15	9	287,90,559	503,83,479	6	33,58,899	**6**	9	144	153	147	156	3	0
56	Part 2	15	9	287,90,559	503,83,479	6	33,58,899	**6**	9	147	156	147	156	0	1
58	Part 1	10	6	287,90,559	503,83,479	4	50,38,348	**4**	6	153	159	156	162	3	0
59	Part 2	10	6	287,90,559	503,83,479	4	50,38,348	**4**	6	156	162	156	162	0	1
61	Part 1	10	6	287,90,559	503,83,479	4	50,38,348	**4**	6	159	165	162	168	3	0
62	Part 2	10	6	287,90,559	503,83,479	4	50,38,348	**4**	6	162	168	162	168	0	1
64	Part 1	10	6	287,90,559	503,83,479	4	50,38,348	**4**	6	165	171	168	174	3	0
65	Part 2	10	6	287,90,559	503,83,479	4	50,38,348	**4**	6	168	174	168	174	0	1
67	Part 1	10	6	287,90,559	503,83,479	4	50,38,348	**4**	6	171	177	174	180	3	0
68	Part 2	10	6	287,90,559	503,83,479	4	50,38,348	**4**	6	174	180	174	180	0	1
70	Part 1	10	6	287,90,559	503,83,479	4	50,38,348	**4**	6	177	183	180	186	3	0

71	Part 2	10	6	287,90,559	503,83,479	4	50,38,348	**4**	6	180	186	180	186	0	1
73	Part 1	10	6	287,90,559	503,83,479	4	50,38,348	**4**	6	183	189	186	192	3	0
74	Part 2	10	6	287,90,559	503,83,479	4	50,38,348	**4**	6	186	192	186	192	0	1
76	Part 1	10	6	287,90,559	503,83,479	4	50,38,348	**4**	6	189	195	192	198	3	0
77	Part 2	10	6	287,90,559	503,83,479	4	50,38,348	**4**	6	192	198	192	198	0	1
79	Part 1	10	6	287,90,559	503,83,479	4	50,38,348	**4**	6	195	201	198	204	3	0
80	Part 2	10	6	287,90,559	503,83,479	4	50,38,348	**4**	6	198	204	198	204	0	1

ID	**Activity Name**	**Normal Duration**	**Crash Duration**	**Normal Cost**	**Crash Cost**	**Max Crash Duration**	**Crash Cost/Day**	**Days to be crashed**	**Realised time**	**ES**	**EF**	**LS**	**LF**	**Slack**	**Critical**
82	Part 1	10	6	287,98,952	503,98,166	4	50,39,817	**4**	6	201	207	204	210	3	0
83	Part 2	10	6	287,98,952	503,98,166	4	50,39,817	**4**	6	204	210	204	210	0	1
85	Part 1	10	6	287,98,952	503,98,166	4	50,39,817	**4**	6	207	213	210	216	3	0
86	Part 2	10	6	287,98,952	503,98,166	4	50,39,817	**4**	6	210	216	210	216	0	1
88	Part 1	10	6	287,98,952	503,98,166	4	50,39,817	**4**	6	213	219	216	222	3	0
89	Part 2	10	6	287,98,952	503,98,166	4	50,39,817	**4**	6	216	222	216	222	0	1
91	Part 1	10	6	287,98,952	503,98,166	4	50,39,817	**4**	6	219	225	222	228	3	0
92	Part 2	10	6	287,98,952	503,98,166	4	50,39,817	**4**	6	222	228	222	228	0	1
94	Part 1	10	6	287,98,952	503,98,166	4	50,39,817	**4**	6	225	231	228	234	3	0
95	Part 2	10	6	287,98,952	503,98,166	4	50,39,817	**4**	6	228	234	228	234	0	1
97	Part 1	10	6	287,98,952	503,98,166	4	50,39,817	**4**	6	231	237	234	240	3	0
98	Part 2	10	6	287,98,952	503,98,166	4	50,39,817	**4**	6	234	240	234	240	0	1
100	Part 1	10	6	287,98,952	503,98,166	4	50,39,817	**4**	6	237	243	240	246	3	0
101	Part 2	10	6	287,98,952	503,98,166	4	50,39,817	**4**	6	240	246	240	246	0	1
103	Part 1	10	6	287,98,952	503,98,166	4	50,39,817	**4**	6	243	249	246	252	3	0
104	Part 2	10	6	287,98,952	503,98,166	4	50,39,817	**4**	6	246	252	246	252	0	1
106	Part 1	10	6	287,98,952	503,98,166	4	50,39,817	**4**	6	249	255	252	258	3	0
107	Part 2	10	6	287,98,952	503,98,166	4	50,39,817	**4**	6	252	258	252	258	0	1
109	Part 1	10	6	287,98,952	503,98,166	4	50,39,817	**4**	6	255	261	258	264	3	0

110	Part 2	10	6	287,98,952	503,98,166	4	50,39,817	**4**	6	258	264	258	264	0	1
112	Part 1	10	6	287,98,952	503,98,166	4	50,39,817	**4**	6	261	267	264	270	3	0
113	Part 2	10	6	287,98,952	503,98,166	4	50,39,817	**4**	6	264	270	264	270	0	1
114	Terrace Parapet	15	9	30,12,097	52,71,170	6	3,51,411	**6**	9	270	279	270	279	0	1
116	Bottom slab	15	9	279,19,526	488,59,170	6	32,57,278	**6**	9	270	279	270	279	0	1
117	Top Slab	15	9	279,19,526	488,59,170	6	32,57,278	**6**	9	279	288	279	288	0	1

Total Crash Duration = 288 days
Total Cost of Crashing = Rs 94,92,45,225

Table 5: Crashing in Solver showing maximum number of days to crash to meet the deadline of 430 days with minimum total crash cost.

ID	Activity Name	Normal Duration	Crash Duration	Normal Cost	Crash Cost	Max Crash Duration	Crash Cost/Day	Days to be crashed	Realised time	ES	EF	LS	LF	Slack	Critical
4	PCC below footings	55	31	4,60,156	8,05,273	24	14,641	**24**	31	0	31	2	34	2	0
5	Reinforcement Fixing	56	32	8,20,954	14,36,669	24	25,655	**24**	32	2	34	4	36	2	0
6	Shuttering	52	30	2,63,487	4,61,102	22	8,867	**22**	30	7	37	9	39	2	0
7	Concreting	49	28	7,95,369	13,91,896	21	28,406	**21**	28	10	38	12	40	2	0
8	Deshuttering	49	28	2,63,487	4,61,102	21	9,410	**21**	28	11	39	13	41	2	0
11	Reinforcement Fixing	42	24	8,20,954	14,36,669	18	34,206	**18**	24	22	46	24	48	2	0
12	Shuttering	45	26	2,63,487	4,61,102	19	10,247	**19**	26	24	50	26	52	2	0
13	Concreting	43	25	7,95,369	13,91,896	18	32,370	**18**	25	26	51	28	53	2	0
14	Deshuttering	43	25	2,63,487	4,61,102	18	10,723	**18**	25	28	53	30	55	2	0
16	Reinforcement Fixing	35	20	8,20,954	14,36,669	15	41,048	**15**	20	33	53	35	55	2	0
17	Shuttering	35	20	2,63,487	4,61,102	15	13,174	**15**	20	37	57	39	59	2	0
18	Concreting	35	20	7,95,369	13,91,896	15	39,768	**15**	20	39	59	41	61	2	0
19	Deshuttering	35	20	2,63,487	4,61,102	15	13,174	**10**	25	40	65	42	67	2	0
21	PCC below Plinth beams	12	7	89,284	1,56,247	5	13,021	**5**	7	49	56	51	58	2	0
22	Reinforcement Fixing	17	10	8,20,954	14,36,669	7	84,510	**7**	10	50	60	52	63	2	0
23	Shuttering	16	9	2,63,487	4,61,102	7	28,819	**7**	9	53	62	55	65	2	0

24	Concreting	16	9	7,95,369	13,91,896	7	86,994	**7**	9	55	64	57	67	2	0
25	Deshuttering	17	10	2,63,487	4,61,102	7	27,124	**0**	17	57	74	59	76	2	0
26	PCC for plinth	25	14	4,05,212	7,09,121	11	28,365	**1**	24	74	98	76	100	2	0
30	Reinforcement Fixing	20	11	8,20,954	14,36,669	9	71,833	**9**	11	97	108	99	110	2	0
31	Shuttering	20	11	5,26,969	9,22,195	9	46,110	**9**	11	99	110	133	145	34	0
32	Concreting	20	11	7,95,369	13,91,896	9	69,595	**9**	11	101	112	135	147	34	0
34	Shuttering	42	24	5,26,969	9,22,195	18	21,957	**18**	24	111	135	145	169	34	0
35	Reinforcement placing	40	23	8,20,954	14,36,669	17	35,917	**17**	23	114	137	148	171	34	0
36	Concreting	1	1	7,95,369	13,91,896	0	10000000,00,000	**0**	1	137	138	171	172	34	0
39	Reinforcement Fixing	45	26	8,20,954	14,36,669	19	31,926	**19**	26	111	137	113	139	2	0

ID	**Activity Name**	**Normal Duration**	**Crash Duration**	**Normal Cost**	**Crash Cost**	**Max Crash Duration**	**Crash Cost/Day**	**Days to be crashed**	**Realised time**	**ES**	**EF**	**LS**	**LF**	**Slack**	**Critical**
40	Shuttering	45	26	5,26,969	9,22,195	19	20,493	**19**	26	112	138	114	140	2	0
41	Concreting	48	27	7,95,369	13,91,896	21	28,998	**21**	27	113	140	115	142	2	0
43	Shuttering	29	17	5,26,969	9,22,195	12	31,800	**12**	17	126	143	128	145	2	0
44	Reinforcement placing	27	15	8,20,954	14,36,669	12	53,210	**2**	25	128	152	130	155	2	0
45	Concreting	1	1	7,95,369	13,91,896	0	10000000,00,000	**0**	1	152	153	155	156	2	0
49	Part 1	30	17	287,90,559	503,83,479	13	16,79,449	**12**	18	138	156	172	191	34	0
50	Part 2	25	14	287,90,559	503,83,479	11	20,15,339	**0**	25	153	178	156	181	2	0
52	Part 1	20	11	287,90,559	503,83,479	9	25,19,174	**7**	13	156	170	191	204	34	0
53	Part 2	20	11	287,90,559	503,83,479	9	25,19,174	**0**	20	178	198	181	201	2	0
55	Part 1	15	9	287,90,559	503,83,479	6	33,58,899	**3**	12	170	181	204	216	34	0
56	Part 2	15	9	287,90,559	503,83,479	6	33,58,899	**0**	15	198	213	201	216	2	0
58	Part 1	10	6	287,90,559	503,83,479	4	50,38,348	**0**	10	181	191	216	226	34	0
59	Part 2	10	6	287,90,559	503,83,479	4	50,38,348	**0**	10	213	223	216	226	2	0
61	Part 1	10	6	287,90,559	503,83,479	4	50,38,348	**0**	10	191	201	226	236	34	0
62	Part 2	10	6	287,90,559	503,83,479	4	50,38,348	**0**	10	223	233	226	236	2	0
64	Part 1	10	6	287,90,559	503,83,479	4	50,38,348	**0**	10	201	211	236	246	34	0

65	Part 2	10	6	287,90,559	503,83,479	4	50,38,348	**0**	10	233	243	236	246	2	0
67	Part 1	10	6	287,90,559	503,83,479	4	50,38,348	**0**	10	211	221	246	256	34	0
68	Part 2	10	6	287,90,559	503,83,479	4	50,38,348	**0**	10	243	253	246	256	2	0
70	Part 1	10	6	287,90,559	503,83,479	4	50,38,348	**0**	10	221	231	256	266	34	0
71	Part 2	10	6	287,90,559	503,83,479	4	50,38,348	**0**	10	253	263	256	266	2	0
73	Part 1	10	6	287,90,559	503,83,479	4	50,38,348	**0**	10	231	241	266	276	34	0
74	Part 2	10	6	287,90,559	503,83,479	4	50,38,348	**0**	10	263	273	266	276	2	0
76	Part 1	10	6	287,90,559	503,83,479	4	50,38,348	**0**	10	241	251	276	286	34	0
77	Part 2	10	6	287,90,559	503,83,479	4	50,38,348	**0**	10	273	283	276	286	2	0
79	Part 1	10	6	287,90,559	503,83,479	4	50,38,348	**0**	10	251	261	286	296	34	0
80	Part 2	10	6	287,90,559	503,83,479	4	50,38,348	**0**	10	283	293	286	296	2	0

ID	**Activity Name**	**Normal Duration**	**Crash Duration**	**Normal Cost**	**Crash Cost**	**Max Crash Duration**	**Crash Cost/Day**	**Days to be crashed**	**Realised time**	**ES**	**EF**	**LS**	**LF**	**Slack**	**Critical**
82	Part 1	10	6	287,98,952	503,98,166	4	50,39,817	**0**	10	261	271	296	306	34	0
83	Part 2	10	6	287,98,952	503,98,166	4	50,39,817	**0**	10	293	303	296	306	2	0
85	Part 1	10	6	287,98,952	503,98,166	4	50,39,817	**0**	10	271	281	306	316	34	0
86	Part 2	10	6	287,98,952	503,98,166	4	50,39,817	**0**	10	303	313	306	316	2	0
88	Part 1	10	6	287,98,952	503,98,166	4	50,39,817	**0**	10	281	291	316	326	34	0
89	Part 2	10	6	287,98,952	503,98,166	4	50,39,817	**0**	10	313	323	316	326	2	0
91	Part 1	10	6	287,98,952	503,98,166	4	50,39,817	**0**	10	291	301	326	336	34	0
92	Part 2	10	6	287,98,952	503,98,166	4	50,39,817	**0**	10	323	333	326	336	2	0
94	Part 1	10	6	287,98,952	503,98,166	4	50,39,817	**0**	10	301	311	336	346	34	0
95	Part 2	10	6	287,98,952	503,98,166	4	50,39,817	**0**	10	333	343	336	346	2	0
97	Part 1	10	6	287,98,952	503,98,166	4	50,39,817	**0**	10	311	321	346	356	34	0
98	Part 2	10	6	287,98,952	503,98,166	4	50,39,817	**0**	10	343	353	346	356	2	0
100	Part 1	10	6	287,98,952	503,98,166	4	50,39,817	**0**	10	321	331	356	366	34	0
101	Part 2	10	6	287,98,952	503,98,166	4	50,39,817	**0**	10	353	363	356	366	2	0
103	Part 1	10	6	287,98,952	503,98,166	4	50,39,817	**0**	10	331	341	366	376	34	0

104	Part 2	10	6	287,98,952	503,98,166	4	50,39,817	**0**	10	363	373	366	376	2	0
106	Part 1	10	6	287,98,952	503,98,166	4	50,39,817	**0**	10	341	351	376	386	34	0
107	Part 2	10	6	287,98,952	503,98,166	4	50,39,817	**0**	10	373	383	376	386	2	0
109	Part 1	10	6	287,98,952	503,98,166	4	50,39,817	**0**	10	351	361	386	396	34	0
110	Part 2	10	6	287,98,952	503,98,166	4	50,39,817	**0**	10	383	393	386	396	2	0
112	Part 1	10	6	287,98,952	503,98,166	4	50,39,817	**0**	10	361	371	396	406	34	0
113	Part 2	10	6	287,98,952	503,98,166	4	50,39,817	**0**	10	393	403	396	406	2	0
114	Terrace Parapet	15	9	30,12,097	52,71,170	6	3,51,411	**6**	9	403	413	406	415	2	0
116	Bottom slab	15	9	279,19,526	488,59,170	6	32,57,278	**3**	12	403	415	403	415	0	1
117	Top Slab	15	9	279,19,526	488,59,170	6	32,57,278	**0**	15	415	430	415	430	0	1

Total Crash Duration = 430 days
Total Cost of Crashing = Rs 7,14,21,085

IV. TIME-COST TRADE-OFF

As the project duration is crashed, the increase in direct cost is also associated with a decrease in indirect cost. Along with the salaries of the Senior Engineer, Junior Engineer & Supervisor, indirect cost also includes maintenance, security and various other administrative costs. As per the Quantity Surveyor & Cost Estimator in KPDL, the indirect cost for this project can be assumed as 4000 Rs/day.

- Trade-Off Calculations:

A. Normal Duration & Cost without crashing:

1. Maximum Duration without Crashing = 451 days
2. Total Cost of Project = Rs 134,39,21,406

B. Maximum Crashed Duration & Cost:

1. Maximum Duration without Crashing = 451 days
2. Maximum Crash Duration = 288 days
3. Total Cost of Crashing = Rs 94,92,45,225

- Total number of days crashed = 451-288 = 163
- Total Indirect Cost = 163 * 4000 = Rs 6,52,000
- Total Added Cost of Project = Rs 94,85,93,225

C. Crashed Duration & Cost with Deadline:

1. Deadline = 430 Days
2. Maximum Duration without Crashing = 451 days
3. Maximum Crash Duration = 430 days
4. Total Cost of Crashing = Rs 7,15,05,085

- Total number of days crashed = 451-430 = 21
- Total Indirect Cost = 21 * 4000 = Rs 84,000
- Total Added Cost of Project = Rs 7,14,21,085

The Trade-off Results have been tabulated and displayed in Table 7.

V. CONCLUSION

The questions raised in the problem statement are answered below.

1. As shown in Table 3, the total time required to complete the project if no delays occur is 451 days.

2. The individual activities start and finish (at the latest & earliest) to meet this project completion time have been also depicted in Table 3.

3. The critical bottleneck activities where any delays must be avoided to prevent delaying project completion are the activities of the critical path with zero slack highlighted in pink in Table 3.

   Recall that the company will be receive Rs 30 crores bonus for finishing 3 weeks earlier than the estimated duration. This payment needs to cover some *overhead costs* in addition to the costs of the activities listed in the Table 1, as well as provide a reasonable profit to the company. The project has to be kept as close to both budget and schedule as possible.

4. As found previously in Table 3 if all the activities are performed in the normal way, the anticipated duration of the project would be 451 days (if delays can be avoided).

5. If all the activities were to be fully crashed instead, then a similar calculation would find that this duration would be reduced to only 288 days as depicted in Table 4. But look at the prohibitive cost (Rs 94,92,45,225) of doing this. It is way more than the bonus that will be received thus incurring heavy losses. Fully crashing all activities clearly is not a viable option.

6. The total cost of crashing activities to get down to Deadline of 430 days is costing a total of Rs 7,14,21,085 as depicted in Table 5. Since by spending an additional Rs 7,14,21,085 will result in recieving the bonus of Rs 30 crores for finishing within the deadline, the solution is thus feasible.

7. Crashing of any project must be undertaken only when the benefits received from crashing are more than the actual cost of crashing.

8. The Problem of Time-Cost Trade-Off is unique to every project and cannot be applied as a general rule. Project managers need to carefully understand the Time-Cost Trade-Off of the project before deciding on whether or not to crash it.

ACKNOWLEDGMENT

I am greatly indebted to my guide Prof. Milind Darade, Faculty of Civil Engineering Department, Dr D Y Patil School of Engineering & Technology, for his valuable guidance.

I express a deep sense of gratitude to Kolte Patil Developers Pvt Ltd for providing the opportunity to intern at Life Republic I Ven Townships Pvt Ltd, where without the encouraging support of its staff, the project undertaken would not have been accomplished at all

I would like to thank our Head of Department Dr. Sanjay Kulkarni, Pricipal Dr. Ashok Kasnale and all the faculty of Civil Engineering Department & Library staff for their support and cooperation.

Lastly but most importantly, I immeasurably thank my family & friends for being a constant source of encouragement and support.

Sr no	Scenario	Maximum Duration without Crashing	Maximum Crash Duration	Total Cost of Crashing	Total number of days crashed	Total Indirect Cost	Deadline	Total Added Cost of Project	Total cost of Project
1	Normal Duration & Cost without crashing	451	-	-	-	-	-		134,39,21,406
1	Maximum Crashed Duration	451	288	9492,45,225	163	6,52,000	-	9485,93,225	22925,14,631
3	Crashed Duration & Cost with Deadline	451	430	715,05,085	21	84,000	430	714,21,085	14153,42,491

Table 7: Trade-off Results

REFERENCES

[1] J. Magalhães-Mendes, "Multiobjective optimization: Time-cost application in construction" department of Civil Engineering, School of Engineering, Polytechnic of Porto, Portugal, The Congress on Numerical Methods in Engineering (CMN 2015), July, 2015)

[2] Bhushan V Tatar, Rahul S Patil, "optimization tools for time cost trade off applicable in construction project management" Department of Civil Engineering, Padmashree Dr. D.Y. Patil Institute of Engineering & Technology, Pune, (M.S), (India) International Journal of Science, Technology & Management,Volume No 04, Special Issue No. 01, March 2015

[3] Nhat-Duc Hoang, "A Novel Improved Differential Evolution for Construction Project Crashing Optimization" Institute of Research and Development, Faculty of Civil Engineering, Duy Tan University, Quang Trung, DaNang, Vietnam, October 2014

[4] Ming Li and Guangdong Wu, "Robust Optimization for Time-Cost Trade off Problem in Construction Projects", School of Tourism and Urban Management, Jiangxi University of Finance & Economics, Nanchang, China, August 2014

[5] Wenfa Hu and Xinhua He, "An Innovative Time-Cost-Quality Tradeoff Modeling of Building Construction Project Based on Resource Allocation", ScientificWorld Journal 2014.

[6] Omar M. Elmabrouk "A Linear Programming Technique for the Optimization of the Activities in Maintenance Projects" Department of Industrial and Manufacturing System Engineering Garyounis University, Benghazi-Libya, International Journal of Engineering & Technology IJET-IJENS Vol: 11 No: 0111 Feb 2011

[7] Mohammad Nazmul Islam, Md. Baktiar Rana, Shuddasattwa Rafique,Tasnima Aziza . "Crashing Project Time with Least Cost: A Linear Programming Approach". Journal of Business Research, Vol. 6, 2004

[8] Do Ba Khang And Yin Mon Myint "Time, cost and quality trade-off in project management: a case study" School of Management, Asian Institute of Technology, P.O. Box 2754, Bangkok 10501, Thailand International Journal of Project Management Vol. 17, No. 4, pp. 249±256, 1999

[9] Raida Abuizam , Purdue University Calumet , Lin Zhao , "Project management using Excel spreadsheets: The case of Jules Event Planning Company" Purdue University Calumet , Journal of Business Cases and Applications

[10] "Introduction to Operations Management" Hillier & Lieberman 8th-edition,chapter 22.

[11] http://sites.saintmarys.edu/~cpeltier/Math251F13.pdf

[12] Omar M. Elmabrouk, "Scheduling Project Crashing Time using Linear Programming Technique" Department of Industrial and Manufacturing System Engineering Benghazi University, Benghazi Libya. Proceedings of the 2012 International Conference on Industrial Engineering and Operations Management Istanbul, Turkey, July 3 – 6, 2012