Scheduling Project Management Using Crashing CPM Network to get Project completed on Time

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Abstract

Most of the companies suffer from difficulties and challenges due to complexity of project and because of dependency on the traditional tool to plan, schedule and control the project development. The needs for continuous control of time, cost and performance of project also can be completed on time with good quality and within the allocated budget.

To reduce a projects completion time, a technique called "Crashing" is performed which involves bringing in additional resources for activities along the critical path of the network.

The research created model to determine the order in which activities should be crashed as well as using CPM techniques helps good project management in achieving the objective with minimum of time and least cost and also in predicting the probable project duration and associates cost meeting the desired project and by using a Linear Programming Model we provide a more easy and appropriate way of crashing a problem.

This paper objective mainly provides a framework for reducing total project time at the least cost by crashing the project network. Then the model is solved with Linear Programming Method.

Introduction

Project management is the discipline that relates all those words that you thought of that apply to project. This discipline cultivates the expertise to plan, monitor, track and manage the people, the time, the budget, and the quality of the work on project.

Project scheduling is a part of project management which relates to the use of schedules such as Grantt Charts, CPM/PERT to plan and subsequently report progress within the project environment. Project scheduling looks at which tasks need to be performed for a project and assigns deadlines for their completion. The project scheduler sets these deadlines by calculating how long each task should take to perform. It requires a comprehensive understanding of which actions needs to get done and when.

The Objective:

Why is the project needed?

Broadly the objective must meet the three fundamental criteria:

- The project must be completed on time.
- The project must be accomplished within the budgeted cost.
- The project must meet the prescribed quality requirement.

Keywords

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Project Management, Activities, Critical Path Method (CPM), Slack Time, Crashing.

The Methodology of the Research

Study the CPM strategic planning process for planning and development of "Columbia Pkoana Precast Block Production Plant" in order to get the optimal time at minimum total cost to complete implementation of project. This research enables the project management to study and analyze the value of project activity during all phases of project, so as to reach the maximum benefits and minimum cost palnning.

Time and Schedule Management

Project Scheduling:

The target of project scheduling is to construct a time table where each individual activity receive a start time and a corresponding finish time within the predefined precedence relations and the various predefined activity constraints.

The scheduling process is based on the traditional critical path based forward (to create an earliest start time schedule) and or backward (to create a latest start schedule).Scheduling calculations aiming to construct a project schedule with a minimal project lead time.Project scheduling is often the most visible step in the sequence of steps of project management. The two most common techniques of basic project scheduling are the Critical Path Method (CPM) and Program Evaluation and review technique (PERT).

Network Techniques

Network techniques are used for managing time, they are so called because they are based on the network diagrams to achieve the following:

- Schedule activities namely define the start and end time of each activity and consequently the duration of the entire project.
- Analyze the allowable floats slacks for non critical activities (that do not increase the duration of the project), which means identifying those activities that if delayed would prolong the duration of the project and are therefore known as critical.

There are three types of starting data:

a. The activities (task name or identification code).
b. Their duration.
c. The links of precedence between activities.

There are therefore various network techniques:

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These are CPM (critical path method), PERT (program evaluation and review technique), GERT (graphical evaluation and review technique), VERT (venture evaluation and review technique), but here we will be discussing only two techniques.

Critical Path Method

The critical path method sometimes referred to as Critical Path Analysis(CPA) was developed in 1950's by DuPont Corporation and Remington Rand Corporation. It was specifically developed to manage Power Plant Maintenance Projects. They wanted to develop a management toll that would help in scheduling of chemical plant shut downs for maintenance and then restarting once maintenance was complete.

Note: used when the duration of all the activities is considered fixed and likewise the links of precedence, which are of the finish-to-start type (namely the beginning of a certain activity is linked to the end of a previous one).

Program Evaluation and Review Technique (PERT)

PERT was originally developed in 1958 and 1959 to meet the needs of the "age of massive engineering" where the techniques of Taylor and Grantt were inapplicable.

Note: PERT namely a CPM having all durations expressed in a probabilistic manner.

PERT and CPM Critical Path Procedure

Develop a list of activities that make up the project.

1. Determine the immediate predecessors for each activity in the project.
2. Estimate the completion time for each activity.
3. Draw a project network depicting the activities and immediate predecessors listed in step 1 and 2.
4. Use the project network and the activity time estimates to determine the earliest start and earliest finish time for each activity by making a forward pass through the network. The earliest finish time for the last activity in the project identifies the total time required to complete the project.
5. Use the project completion time identified in step 4 as the latest finish time for the last activity and make a backward pass through the network to identify the latest start and finish time for each activity.

Scheduling Individual Activities (CPM Computations)

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The actual duration of each activity turns out to be the same as its estimated duration.

➢ **Critical Path** = Total activities on this path is greater than any other path through the network (delay in any task on the critical path leads to delay in the project.

➢ **Forward Pass (Earliest Occurrence Times):**

The earliest start time of an activity is equal to the largest of the earliest finish times of its immediate predecessors.
ES = Earliest Start time for a particular activity.
EF = Earliest Finish time for a particular activity.
Where EF = ES + (estimated) duration of the activity
(For each activity that starts the project its earliest start time is ES = 0).

➢ **Backward Pass (Latest Occurrence Times):**

The latest start time for an activity is the latest possible time that it can start without delaying the completion of the project.
LS = Latest Start times for a particular activity.
LF = Latest Finish time for a particular activity.
Where LS = LF – (estimated) duration of the activity.
(Latest Finish Time of an activity is equal to the smallest of the latest start times of its immediate successors).

➢ **Determination of Slack**

Slack is the amount of time an activity can be delayed without delaying the project completion time, assuming no other delays are taking place in the project.
Slack = LF – EF
Since LF – EF = LS – ES either difference actually can be used to calculate slack.

Scheduling of "Columbia Pkoana Precast Block Production Plant for Crashing Time"

Investigate the scheduling for Columbia Pkoana Precast Block Production Plant in order to suggest improvements that could reduce the time by crashing the time. The schedule analysis project activities consist of (14) different activities including different works. As shown in table (i).
The process is simulated to reveal its critical path, which identifies the activities that determine the overall completion time required by the process. Then the model is solved with a linear programming model.

Requirements for Projects

- Well defined activities.
- Some activities may be started and Finished frequently.
- Some activities may require Completion of other activities.
- If an activity is started it must be Completed without interruption.

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Table 1 Activity List of Columbia Pkoana Precast Block Production plant

S.No	Activity	Activity Description	Predecess	Activity Duration (minutes)
1	A	Raw material testing and sampling	None	25
2	B	Loading aggregate by loader to four bean	A	20
3	C	Loading cement through cement screw conveyorfrom cement silo	B	12
4	D	Conveying Batched aggregate as per mix design through aggregate conveyor belt from four bean to pan	B	15
5	E	Loading flyash through flyash screw conveyor from flyash silo to pan mixer	B	14
6	F	Mixing of batched aggregate, cement, flyash and water in pan mixer	C,D,E	5
7	G	Conveyor in grean mix through mud Belt conveyor from Pan mixer to SPM -20	F	4
8	H	Stamping final product as per mould through SPM - 20 machine	G	8
9	I	Loading pallet with final product in to the rack through hydraulic off bearer	H	5
10	J	Shifting rack into curing klin chamber	I	10
11	K	Demoulding or depallesing	J	20
12	L	Storage and production	K,M	30
13	M	Moulds and pallets cleaning and repair	K	15
14	N	Testing Visual / Laboratory	L	20

Network Representation of a Project

Project and activities are represented by a network.

Network is a graph showing each activity to be performed its predecessor and successor.

Activities are represented by an arrow generally needs some resources for its performance (use letters)

Node Activities start or end at points called node represented by circle.

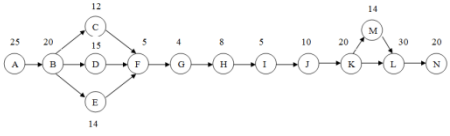

Fig (i) Network Analysis Diagram with Duration of each activity

Establishment of Critical Path

The path and paths lengths through Pkoana's Project network

A-B-C-F-G-H-I-J-K-L-N = 25+20+12+5+4+8+5+10+20+30+20 = 159

A-B-C-F-G-H-I-J-K-M-L-N = 25+20+12+5+4+8+5+10+20+15+30+20 = 174

A-B-D-F-G-H-I-J-K-L-N = 25+20+15+5+4+8+5+10+20+30+20 = 162

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A-B-D-F-G-H-I-J-K-M-L-N = 25+20+15+5+4+8+5+10+20+15+30+20 = 177

A-B-E-F-G-H-I-J-K-L-N = 25+20+14+5+4+8+5+10+20+30+20 = 161

A-B-E-F-G-H-I-J-K-M-L-N = 25+20+14+5+4+8+5+10+20+15+30+20 = 177.

Table (ii) Output of the Whole Project

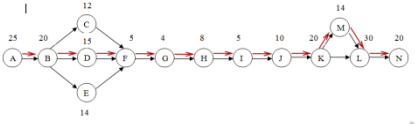

Fig.(ii) Network Diagram Showing Critical Path

Time - Cost Trade Offs

Now our next step is to investigate how much extra would it cost to reduce the project duration.

Crashing the project refers to reduce crashing a number of activities to reduce the duration of project below its normal value.

Crashing an activity refers to taking some special measures to reduce the duration of project below its normal value. These special measures might include using overtime, hiring additional temporary help, using special time saving materials, obtaining special equipment and so forth.

CPM Method of Time Cost Trade Offs is concerned with how much (if any) to crash each of the activities to anticipated duration of the project down to a desired value.

The data necessary for determining how much to crash a particular activity is given by the time cost trade graph for the activity.

Cost Scheduling Computations:

Let

NT = Normal Time = completion time of an activity with allocation of resources.

NC = Normal Cost = cost associated with normal time.

CT = Crash Time = shortest completion time of an activity with extra resources.

CC = Crash Cost = cost associated with crash time.

Cost Slope = Change in Cost / Change in Time.

= (Normal Cost – Crash Cost) / (Crash Time – Normal Time)

The time cost computations are as shown in Table. With two exceptions:

- Cost Slope (Change in Cost / Change in Time) is computed for all the activities on Critical Path. (crashing of non critical activities will result in reducing slack ,there is no savings in project duration).
- There is no cost reduction for activities F, G, H, I, and L even though all these are on the critical path.

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Table (iii) Time Cost Trade off Data for Activities of Columbia Pkoana's Project

Activity	Immediate Predecessor	Normal Time (min.)	Crash Time (min.)	Normal Cost (Rs.)	Crash Cost(Rs.)	Maximum Reduction in Time (min.)	Crash Cost per minute saved (Rs./min.)
A	None	25	20	255	315	5	12.00
B	A	20	13	65	118	7	7.55
C	B	12	10	40	46	2	3.00
D	B	15	12	25	34	3	3.00
E	B	14	12	15	22	2	3.50
F	C,D,E	5	5	20	20	N/A	N/A
G	F	4	4	22	22	N/A	N/A
H	G	8	8	58	58	N/A	N/A
I	H	5	5	32	32	N/A	N/A
J	I	10	7	52	69	3	5.67
K	J	20	16	18	25	4	1.75
L	K,M	30	30	30	30	N/A	N/A
M	K	15	12	15	18	3	1.00
N	L	20	15	180	225	5	9.00

The table below lists all the paths through the project network and current length of each of these paths.

Table (iv) Initial table for starting marginal cost analysis for Columbia Pkoana Plant

Activity to Crash	Crash Cost	Length of Path					
		ABCFGHIJKLN	ABCFGHIJKMLN	ABDFGHIJKLN	ABDFGHIJKMLN	ABEFGHIJKLN	ABEFGHIJKMLN
		159	174	162	177	161	176

Procedure for the Marginal Cost Analysis:

i. Take economic decision concerning which activity should be accelerated to reduce the project duration.

ii. Crash that activity one time unit.

iii. Weigh this against the maximum time reduction allowed for that activity.

iv. Caution: make sure that critical path does not change.

v. Go back to step ii. And repeat till minimum cost schedule is obtained.

Table (v) Final Table for starting marginal cost analysis for Columbia Pkoana Project

Activity to Crash	Crash Cost	Length of Path (min.)					
		ABCFGHIJKLN	ABCFGHIJKMLN	ABDFGHIJKLN	ABDFGHIJKMLN	ABEFGHIJKLN	ABEFGHIJKMLN
		159	174	162	177	161	176
M	1.00 Rs.	159	173	162	176	161	175
M	1.00 Rs.	159	172	162	175	161	174
M	1.00 Rs.	159	171	162	174	161	173
K	1.75 Rs.	158	170	161	173	160	172
K	1.75 Rs.	157	169	160	172	159	171
K	1.75 Rs.	156	168	159	171	158	170
K	1.75 Rs.	155	167	158	170	157	169
D	3.00 Rs.	155	167	157	169	157	169

Using Linear Programming to make Crashing Decisions:

The problem of finding the least expensive way of crashing activities can be rephrased in form more familiar to linear programming as follows:
Restatement of the problem:
Let Z be the total cost of activities. The problem then is to minimize Z, subject to the constraint the project duration

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must be less than or equal to the time desired by the project manager.
The natural decision variables are
X_i = reduction in the duration of activity j due to crashing this activity.
For j = A, B, C, E, F, G, H, I, J, K, L, M, N.
By using the last column of table (iii) the objective function to be minimized then is
$Z = 12X_A + 7.55\ X_B + 3.00X_C + 3.00X_D + +3.50X_E + 5.67X_J + 1.75X_K + 1.00X_M + 9.00X_N$
Each of the nine decision variables on the right hand side needs to be restricted to non negative variables that do not exceed the maximum given in the next to last column of table (iii).

To impose the constraint that the project duration must be less than or equal to the desired value (169 minutes).

Let,
Y_{finish} = Project duration i.e the time at which the FINISH node in the project is reached the constraints then is,
$Y_{finish} \leq 169$.
Y_i = start time of activity (for j = (B, C,…….., ,N) given the values of $X_{B,}$ X_C ..... X_N. No such variables are needed for activity A since being the starting activity is automatically assigned a value 0 (zero). Similarly the end activity is also assigned zero value. The start time to each activity is (including Finish) is directly related to the start time and duration of each of its immediate predecessors as summarized below. Furthermore by using the normal times from table …the duration of each activity is given by the following formula.
For each activity (B, C,……N) and each of its immediate predecessor
Start time of this activity ≥ (start time + duration) of its immediate predecessors.
Furthermore by using normal time from table…the duration of each activity is given by
Duration of activity j = its normal time $- X_i$.
To illustrate this

Consider the following relation for the following activities:
By including relationships for all activities as constraints we obtain the complete linear programming model given below:
Minimize
$Z = 12X_A + 7.55\ X_B + 3.00X_C + 3.00X_D + +3.50X_E + 5.67X_J + 1.75X_K + 1.00X_M + 9.00X_N$
Subjected to the following constraints
Maximum Reduction Constraints
Using the next to last column of table (iii).
$X_A \leq 5,\ X_B \leq 7,\ X_C \leq 2,\ X_D \leq 3,\ X_E \leq 2,\ X_J \leq 3,\ X_K \leq 4,\ X_M \leq 3,\ X_N \leq 5.$
Non Negative Constraints
$X_A \geq 0,\ X_B \geq 0,\ X_C \geq 0,\ X_D \geq 0,\ X_E \geq 0,\ X_J \geq 0,\ X_K \geq 0,\ X_M \geq 0,\ X_N \geq 0$
Start Time Constraints
As described above the objective function, except for activity A (which starts the project), there is one such constraint for each activity with a single immediate predecessor (activities B, C, D, E, G, H, I, J, K, M) with two immediate predecessors (activity L) and three activity

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constraints for each activity with three immediate predecessors.

One immediate Predecessor

$Y_B \geq (0 + 25 - X_A)$
$Y_C \geq (Y_B + 20 - X_B)$
$Y_D \geq (Y_B + 20 - X_B)$
$Y_E \geq (Y_B + 20 - X_B)$
$Y_G \geq (Y_F + 5 - X_F)$
$Y_H \geq (Y_G + 4 - X_G)$
$Y_I \geq (Y_H + 8 - X_H)$
$Y_J \geq (Y_I + 5 - X_I)$
$Y_K \geq (Y_J + 10 - X_J)$
$Y_M \geq (Y_K + 20 - X_K)$
$Y_N \geq (Y_L + 30 - X_L)$

Two immediate Predecessors

$Y_L \geq (Y_K + 20 - X_K)$
$Y_L \geq (Y_M + 15 - X_M)$

Three immediate Predecessors

$Y_F \geq (Y_E + 14 - X_E)$
$Y_F \geq (Y_D + 15 - X_D)$
$Y_F \geq (Y_C + 12 - X_C)$

Project Duration Constraint

$Y_{Finish} \geq 169$

Table (vi) shows how this problem can be formulated as a linear programming model on a spread sheet. The decision to be made are shown in the changing cells, Start time (I6:I19), Time Reduction (J6:J19), and Project Finish Time (I22). As the equations in the bottom half of the figure indicates, column G and H are calculated in a straight forward way. The equation entered into the target cell Total Cost (I24) adds all the normal cost plus the extra cost due to crashing to obtain the total cost.

The constraints involving Start Time (I6:I19) all are start time constraints that specify that an activity can not start until each of its immediate predecessor has finished.

Table (vi) The table displays the application of the CPM method of time cost tradeoffs to Columbia Pkoana's Precast Block Production

A	B	C	D	E	F	G	H	I	J	K
1	Columbia Pkoana's Precast Block Production Plant									
2										
3										
4	Activity	Time (minute)		Cost (Rs.)		Maximum Time Reduction (min.)	Crash Cost per minute saved (Rs./min.)	Start Time (min.)	Time Reduction (min.)	Finish Time (min.)
5		Normal	Crash	Normal	Crash					
6	A	25	20	255	315	5	12	0	0	25
7	B	20	13	65	118	7	7.5714286	25	0	45
8	C	12	10	40	46	2	3	45	0	57
9	D	15	12	25	34	3	3	45	1	59
10	E	14	12	15	22	2	3.5	45	0	59
11	F	5	5	20	20	0	N/A	59	0	64
12	G	4	4	22	22	0	N/A	64	0	68
13	H	8	8	58	58	0	N/A	68	0	76
14	I	5	5	32	32	0	N/A	76	0	81
15	J	10	7	52	69	3	5.6666667	81	0	91
16	K	20	16	18	25	4	1.75	91	4	107
17	L	30	30	30	30	0	N/A	107	0	137
18	M	15	12	15	18	3	1	137	3	149
19	N	20	15	180	225	5	9	149	0	169
										Max.Time
						Project Finish Time (min.)		169		169
							Total Cost	840		

Range Name	Cells
AFinish	K6
AStart	I6
BFinish	K7
BStart	I7
CFinish	K8
CrashCost	F6:F19
CrashCostPerM	H6:H19
CrashTime	D6:D19
CStart	I8
DFinish	K9
DStart	I9
EFinish	K10
EStart	I10
FFinish	K11
FinishTime	K6:K19
FStart	I11
GFinish	K12
GStart	I12
HFinish	K13
HStart	I13

Range Name	Cells
IFinish	K14
IStart	I14
JFinish	K15
JStart	I15
KFinish	K16
KStart	I16
LFnish	K17
LStart	I17
Max. Time	K22
Max. Time Reduction	G6:G19
MFinish	K18
MStart	I18
NFinish	K19
Normal Cost	E6:E19
Normal Time	C6:C19
NStart	I19
ProjectFinishTime	I22
StartTime	I6:I19
TimeReduction	J6:J19
TotalCost	I24

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Result

Because crashing a non critical activity does not affect the overall project time to completion, only critical activities that can be crashed are considered. The activities to be crashed are chosen in order of increasing expenses. Thus the activity with the smallest crash cost in table (vi) (Activity M) is chosen to be crashed first. The next activity to be crashed is Activity K. Then next activity to be crashed is Activity D, but it is crashed by one time unit only because further crashing will result in change in critical path so after that crashing is stopped.

By using the linear programming model presented in this paper we will be able to determine how much (if any) to crash each activity in order to minimize the total cost of meeting any specified deadline for the project.

Conclusion

The data needed for crashing project Cost programming techniques are the time and cost for each activity when it is done in the normal way and then when it is partially crashed. We can investigate the effect on total cost of changing the estimated duration of the project to various alternative values.

In the project management literature, quantitative models were developed for project crashing to determine the appropriate activities for crashing at minimal cost. In this paper, we suggest that the project quality may be affected by project crashing and develop tradeoffs among time, cost and quality.

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