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Study on Shrink-Critical Path And Cost Analysis Using Crashing Techniques

Mathematics

KEYWORDS : CPM; PERT; floats; network planning; total float theorem; optimization algorithm; Crashing, Critical Path, Cost slope value, Time-cost Trade off

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ABSTRACT

The aim of this paper is to set out the essential and common aspects that should be included in Network planning and crashing techniques. Furthermore, the paper seeks how to find the optimum time and cost using Shrink Critical Path Method. The total cost of project which is aggregate of the activities costs will also depends upon the project duration. The aim is always to strike a balance between the cost and time and to obtain an optimum cost schedule. An optimum cost schedule implies lowest possible cost and the associated time for the project management. In order to find the optimum duration based on the SCPM and crashing techniques. As per the concept of algorithm, the optimum cost schedule exists in the Shrink Critical Path duration.

1. Introduction

Through developing quickly more than ten years, modern project management not only becomes a new knowledge, but also has a profession. According to the 'project Management Body of Knowledge', project management has been separated into nine domains. There into "Project time management and "Project Cost Management" are two core domains [1]. Time-cost trade off problem [2-8] represents crossover of the two core domains, and it is applied very widely in practice.

There are mainly two aspects about time-cost trade off problem: firstly, which activities durations need to be decreased; secondly, how many quantities of these activities durations need to be decreased. Age long study has proved that using CPM network planning technology especially theory of float [8-16] to analyze time-cost trade off problem could solve above two aspects problems more intutionistic. At present there are five conceptions of float, which named total float, free float, safety float, node float and interference float respectively in intention, but now common algorithms are difficult to solve the problem and have biggish computation, especially when fare large-scale project one very important reason is that the whole project need to be considered object when using these algorithms. Generally, speaking people are mainly interested to minimization of algorithm, by improving and designing algorithm to try to decrease difficult of solving problem. Although the approach is feasible, it is hard to avoid biggish difficulty computations.

Now we could try to consider from other angle. The decision to reduce the project duration must be based an analysis of trade off problem between time and cost. In our paper we want to represent the time management by crashing. Time management with optimum cost plays an important role in any project. We obtain optimum cost and time and also the minimum duration of the project by using crashing techniques and shrink critical path method (SCPM) [17-18], because the emphasis of shrink critical path will be focused on scheduled time and associated costs. This SCPM is performed by directly minimum critical slope value to shorten project duration. This SCPM give better crashing with effective time management.

In this paper, according to the idea that finding the shrink critical path is equivalent to the optimum time & cost to solve the problems, through studying inherent rule of CPM network planning, properties of activity of total float, free float ant safety float, shrink critical path, cost slope. Use these conceptions to find the optimum cost and time. Use this algorithm could obtain the effect that optimizing in whole and the workload of resolving problem could be reduced greatly and also it don't affect the main result.

Conception and Theorem:

Total Float

The total float activity (i,j) which marked as TF_{ij} is defined as :

$$TF_{ij} = LT_j - ET_i - T_{ij}$$

The total float denotes the time an activity can be delayed without causing a delay in the project.

Safety Float

The safety float of (i,j) which marked as SF_{ij} is computed as :

$$SF_{ij} = LT_j - LT_i - T_{ij}$$

The safety float of an activity represents the number of periods by which the duration of the activity may be prolong furthest when all its predecessor activities complete at the latest completion time without increasing the completion time of the project.

Free Float

The free float of activity (i,j) which marked as FF_{ij},

$$FF_{ij} = ET_j - ET_i - T_{ij}$$

The free float defines the allowable delay in the activity finish time without affecting the earliest start time of its immediate successor activities.

Crashing:

Crashing is compression technique applied in project scheduling to shorten the project or activity duration by exploring alternatives to apply maximum schedule compression at least additional cost. The objective of crashing a network is to determine the optimum project schedule. Crashing may lost be required to expedite the execution of a project, irrespective of the increase in cost. The total cost of the project, which is aggregate of the activities costs will also depends upon the project duration, can be cut down to some extent. The aim is always to strike balance between the cost and time and to obtain optimum project schedule. An optimum minimum cost project schedule implies lowest possible cost and the associated time for the project management.

Cost Slope:

Shortening the duration on an activity will normally increase its direct cost. A duration which implies minimum direct cost is called the normal duration and the minimum possible time to complete an activity is called crush duration, but at a maximum cost. It is possible that some intermediate point may represent the ideal or optimal trade-off between time and cost for this activity. The slope of the line connecting the normal point and the crash point is called the cost slope of the activity. The slope of this line can be calculated mathematically by knowing the coordinates of the normal and crash points:

Cost Slope = (Crash cost-Normal cost) / (Normal duration-Crash duration)

2. Algorithms of calculating time parameter in CPM network planning

2.1 Algorithm of Calculating Time Parameter of Node

In any activity-on-arc representation network, suppose that P(j) and S (j) denote the set of immediate predecessor and immediate successor activities of node (j) respectively, ET_j and LT_j denote the earliest and latest realization time of node (j) respectively, and T_{ij} denotes the duration of activity(i, j) .ET_j is defined as the maximum of the earliest completion times of the activities which terminate at node (j) , while LT_j is defined as the minimum of the latest allowable start times of the activities which start at node (j) . From these, one algorithm of calculating and correcting time parameter of node inactivity-on-arc representation network could be designed as follows:

Step 1 Algorithm of calculating time parameter of node.

(1) For j = 2,3,……,n , do

$$ET_1=0$$

$$ET_j=\max_{(i)\in p(j)}\left\{ET_i+T_{ij}\right\} \quad (1)$$

(2) Then for j =n−1,n−2,…..,1, do

$$LT_n=ET_n$$

$$LT_j=\min_{(k)\in s(j)}\left\{LT_k-T_{jk}\right\} \quad (2)$$

Step 2 Algorithm of correcting time parameter of node.

(1) For j = 2,3,…,n , if node (j) is in-dummy node whose immediate predecessor activities are all dummy, do

$$LT_j=\min_{(i)\in p(j)}\left\{LT_i\right\}, j=2,3,...,n \quad (3)$$

(2) Then for j =n−1,n−2,…,1 , if node (j) is out-dummy node whose immediate successor activities are all dummy, do

$$ET_j=\max_{(k)\in s(j)}\left\{ET_k\right\}, j=n-1,n-2,...,1 \quad (4)$$

2.2 Algorithm of Calculating Time Parameter of Activity

In activity-on-arc representation network, for any one activity (i, j) , it suppose that ES_{ij} , EF_{ij} , LS_{ij} and LF_{ij} denote the earliest start time, the earliest completion time, the latest start time and the latest completion time of the activity respectively. Then these time parameters could be computed as follows:

$$\begin{aligned} ES_{ij}&=ET_i\\ EF_{ij}&=ES_{ij}+T_{ij}=ET_i+T_{ij}\\ LF_{ij}&=LT_j\\ LS_{ij}&=LF_{ij}-T_{ij}=LT_j-T_{ij}\end{aligned} \quad (5)$$

Here, we will find the shrink-critical path by using float especially total float. Therefore, we study relation between float and path length firstly, and deduce total float theorem as follows:

Lemma 1

Free floats of activities on the longest path $\lambda_{1\to i}^{\nabla}$ from start node (1) to any node (i) are all zero, and length L($\lambda_{1\to i}^{\nabla}$) of the path is equal to the earliest time ET_i of the node (i), and also equal to the earliest finish time EF_{ij} of immediate successor activity (i,j) of the node (i), viz.

$$L(\lambda_{1\to i}^{\nabla}) = ET_i = EF_{ij} \tag{6}$$

Proof:

In activity-on-arc representation network, according to conception and algorithm of time parameter of activity, the earliest start time of any activity is equal to the maximal earliest finish time of immediate predecessor of the activity, viz.

$$ES_{ij} = max\ \{EF_{k_1 i},\ EF_{k_2 i},\ \ldots..,\ EF_{k_n i}\} \tag{7}$$

Suppose that

$$ES_{ij} = EF_{ki} \tag{8}$$

It means that for all immediate predecessor activities (i,j), there are at least one activity (k,i) whose the earliest finish time being equal to the earliest start time of activity (i,j)

Suppose that any path between start node (1) and node (i) of activity (i,j) is marked as $\lambda_{1\to i} = (1) \to (a) \to (b) \to (c) \to \ldots..(e) \to (f) \to (g) \to (i),$ for duration of any activity (u,v) could be computed as $T_{uv} = EF_{uv} - ES_{uv},$ length $L(\lambda_{1\to i})$ of the path $\lambda_{1\to i}$ could be computed as follows:

$$\begin{aligned} L(\lambda_{1\to i}) &= T_{1a} + T_{ab} + T_{bc} + \ldots.. + T_{ef} + T_{fg} + +T_{gi} \\ &= (EF_{1a} - ES_{1a}) + (EF_{ab} - ES_{ab}) + \ldots\ldots + (EF_{fg} - ES_{fg}) + (EF_{gi} - ES_{gi}) \quad (9) \\ &= (EF_{1a} - ES_{ab}) + (EF_{ab} - ES_{bc}) + \ldots. + (EF_{gi} - ES_{ij}) + (EF_{ij} - ES_{1a}) \end{aligned}$$

According to formula (7),

$$EF_{1a} - ES_{ab} \le 0,\ EF_{ab} - ES_{bc} \le 0, \ldots.,\ EF_{fg} - ES_{gi} \le 0,\ EF_{gi} - ES_{ij} \le 0.$$

Then according to formula (8),

$$L(\lambda_{1\to i}) \le EFij - ES_{1a}$$

In activity-on-arc representation network, $ES_{1a} = 0$, therefore

$$L(\lambda_{1\to i}) \le EF_{ij} \tag{10}$$

According to formulae (9) and (10), one path whose length being equal to EF_{ij} could be found out, viz.

$$EF_{1a} - ES_{ab} = 0,\ EF_{ab} - ES_{bc} = 0, \ldots.,\ EF_{fg} - ES_{gi} = 0,\ EF_{gi} - ES_{ij} = 0.$$

According to conception of free float, free floats of activities on the path are all zero. And then deduced by formula (8), this path is the longest path between start node (1) and node (i), therefore the length which marked as $L(\lambda_{1\to i}^{\nabla})$ is equal to EF_{ij}.

Lemma 2:

Safety float of activities on the longest path $\lambda_{1\to n}^{\nabla}$ from start node (1) to any node (i) are all zero, and length $L(\lambda_{1\to n}^{\nabla})$ of the path is equal to value of length $L(\lambda^{\nabla})$ minus the latest finish time of immediate predecessor activity (i,j) of node(j), viz.

$$\begin{aligned} L(\lambda_{1\to n}^{\nabla}) &= L(\lambda^{\nabla}) - LT_j \\ &= L(\lambda^{\nabla}) - LF_{ij} \end{aligned} \tag{11}$$

Proof:

The proof is similar with proof of Lemma 1, and the details will not be deduced.

On the basis of above Lemmas, theorem which represent relations between total float and the path's length are deduced as in the following theorem:

Total Theorem:

The total float of any activity (i,j) is equal to the margin of $L(\lambda^{\nabla})$ of the critical path minus length of the least duration path marked as $L(\lambda_{ij}^{m\nabla})$ which passes the activity (i,j) viz.

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$$TF_{ij} = L(\lambda^{\nabla}) - L(\lambda_{ij}^{m\nabla}) \quad (12)$$

Proof:

According to Lemma 1 and 2, length $L(\lambda_{ij}^{m\nabla})$ of the least duration path which pass the activity (i,j) is equal to

$$L(\lambda_{ij}^{m\nabla}) = L(\lambda_{1\to i}^{m\nabla}) + T_{ij} + L(\lambda_{j\to n}^{m\nabla})$$

$$= ES_{ij} + T_{ij} + \{L(\lambda^{\nabla}) - LF_{ij}\}$$

$$= EF_{ij} + L(\lambda^{\nabla}) - LF_{ij}$$

$$= L(\lambda^{\nabla}) - (LF_{ij} - EF_{ij})$$

According to conception of total float, then

$$L(\lambda_{ij}^{m\nabla}) = L(\lambda^{\nabla}) - TF_{ij}$$

$$TF_{ij} = L(\lambda^{\nabla}) - L(\lambda_{ij}^{m\nabla})$$

Theorem is correct.

Description of the Algorithm

According to above theories, the algorithm of finding optimum cost using shrink-critical path method could be designed as follows:

Step 1:

Compute time parameters of each node and activity by using the formulae (1)-(5).

Step 2:

Compute total float of each activity by the definition, and find out non-critical activity with positive maximal total float which could be marked as (i,j).

Step 3:

Find out the least duration path $\lambda_{1\to i}^{m\nabla}$ between start node (1) and node (i).

(1) Compute free floats of immediate predecessor activities of node (i), and find out activity with zero free float which could be marked as (h,i);

(2) Compute free floats of immediate predecessor activities of node (h), and find out activity with zero free float which could be marked as (g,h);

………

This process won't stop until to start node (1), and find out the minimized longest path $\lambda_{1\to i}^{m\nabla}$ between start node (1) and node (i) which composed by these activities.

Step 4:

Find out the least duration path $\lambda_{j\to n}^{m\nabla}$ between node (j) and terminal node (n).

(1) Compute safety floats of immediate successor activities of node (j), and find out activity with zero safety float which could be marked as (j,k);

(2) Compute safety floats of immediate successor activities of node (k), and find out activity with zero safety float which could marked as (k,l);

……..

This process won't stop until to terminal node (n), and find out the minimized longest path $\lambda_{j\to n}^{m\nabla}$ between node (j) and terminal node (n) which composed by these activities.

The path $\lambda_{ij}^{m\nabla} = \lambda_{1\to i}^{m\nabla} \to \textbf{(i,j)} \to \lambda_{j\to n}^{m\nabla}$ is the shrink-critical path $\lambda^{m\nabla}$, and its

Length is $L\ (\lambda_{ij}^{m\nabla}) = L(\ \lambda^{\nabla}\ ) - TF_{ij}$

Step 5:

Find out the cost slope using the formula:

Cost Slope = (Crash cost-Normal cost) / (Normal duration-Crash duration)

Step 6:

Rank the activities in critical path activities which have least cost slope.

Step 7:

Reduce the activity time of the selected activity progressively until crashed time reached.

Step 8:

Proceed above steps until there is at least one critical path on which none of the activities can be further crashed.

Step 9:

Calculate the Total cost of the project by using the formula:

Total Cost = Normal Cost + Crash Cost + Indirect Cost.

The Total Cost which has minimum that is called the Optimum Cost which corresponding time is known s minimum time of the project.

Analysis on Correctness of Algorithm:

According to the total theorem the path which found out by step 3 & 4 is the lest duration critical path $\lambda_{ij}^{m\nabla}$ which passes the activity (i,j). The path $\lambda_{ij}^{m\nabla}$ is the shrink critical path $\lambda^{m\nabla}$.

Then according to the algorithm, the optimum cost which found out by step 9.

Finally, we obtain the optimum cost exists in the Shrink Critical Path.

Application of Shrink-Critical Path and Cost Analysis in Network Planning:

Description of Algorithm

For time-cost trade off problem, if we want to decrease total duration to optimum duration, we

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only need to decrease the length of paths using Shrink Critical Path method in network planning.
Example for correctness of algorithm

Activity	Normal Time	Crash Time	COST SLOPE
1→2	2	1	50
1→3	2	1	58
1→4	3	2	60
2→4	3	2	44
2→5	7	5	63
3→4	2	2	56
3→6	4	4	66
4→5	4	4	68
4→6	5	4	42
4→7	6	6	70
5→7	3	3	74
5→8	6	4	57
6→7	4	3	40
6→9	2	2	68
7→8	2	2	70
7→9	2	1	43
7→10	4	4	72
8→10	3	3	58
8→11	2	2	80
9→10	5	4	46
9→11	2	2	85
10→11	4	3	54

The Indirect cost is Rs. 80/day. Determine the optimum cost and optimum schedule.

The CPM network planning of one project is described in Figure1. We have to find the shrink critical path for the following activities, and also prove that the project has optimum cost exists in the shrink critical path.

Step 1:

Compute time parameters of each node and activity by using the formulae (1)-(5). This showed in figure 1.

Step 2:

Compute total float of each activity by the definition, and total floats of non-critical activity (8, 11) is positive maximal ones.

Step 3:

Find out the least duration path $\lambda_{1\to 8}^{m\nabla}$ is that

$$\lambda_{1\to 8}^{m\nabla} = (1) \to (4) \to (7) \to (8).$$

Step 4:

Find out the least duration path $\lambda_{8\to 11}^{m\nabla}$ is that

$$\lambda_{8\to 11}^{m\nabla} = (8) \to (10) \to (11).$$

Therefore, the shrink critical path $\lambda^{m\nabla}$ is

$$\lambda^{m\nabla} = \lambda^{m\nabla}_{1\to 8} + \lambda^{m\nabla}_{8\to 11}$$

$$= (1) \to (4) \to (7) \to (8) \to (10) \to (11).$$

And its length is $L(\lambda^{m\nabla}) = L(\lambda^{\nabla}) - TF_{(8,11)}$.

$$= 25 - 7 = 18.$$

Step 5:

Find out the cost slope using the formula which is showed in table 1.

Step 6:

Rank the activity on critical path activity which has least cost slope, which also showed in table 1.

Step 7:

Reduce the activity time of the selected activity progressively until crashed time reached, which is showed in table 2.

Step 8:

Proceed above steps until there is at least one critical path on which none of the activities can be further crashed.

Step 9:

Calculate the total cost of the project by using the formula, which also showed in table 2. Therefore, the total cost which is minimum cost is Rs. 1759, that is called the optimum cost which corresponding the time is 18 days and it is known as minimum duration of the project. Hence the optimum cost exist only shrink critical path.

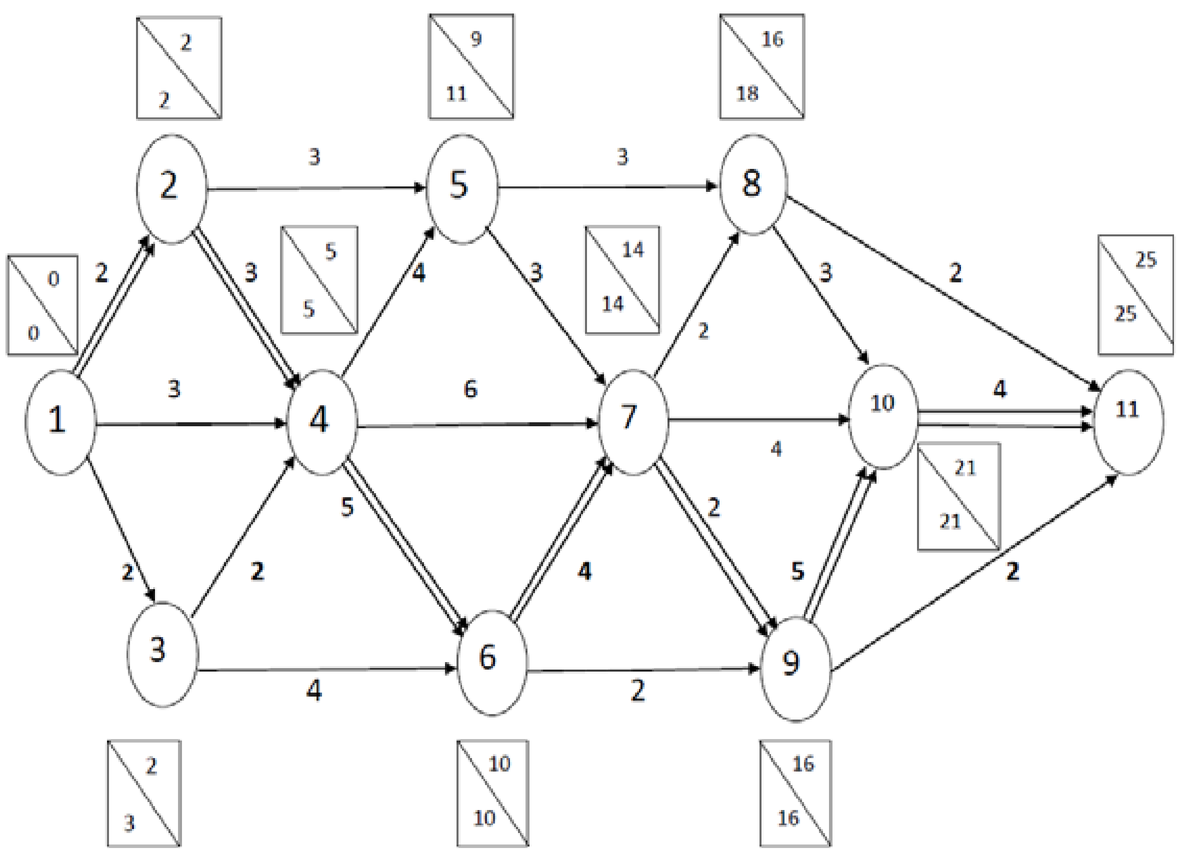

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Table 1: to find Total float, Safety float, free float and Cost slope.

Activity	Time	EARLIEST		LATEST		TOTAL FLOAT	SAFETY FLOAT	FREE FLOAT	COST SLOPE
		START	FINISH	START	FINISH				
1→2	2	0	2	0	2	0	0	0	50
1→3	2	0	2	1	3	1	0	0	58
1→4	3	0	3	2	5	2	0	0	60
2→4	3	2	5	2	5	0	0	0	44
2→5	3	2	5	8	11	2	0	0	63
3→4	2	2	4	3	5	1	0	0	56
3→6	4	2	6	6	10	4	0	0	66
4→5	4	5	9	7	11	2	0	0	68
4→6	5	5	10	5	10	0	0	0	42
4→7	6	5	11	8	14	3	0	0	70
5→7	3	9	12	11	14	2	0	0	74
5→8	3	9	12	15	18	3	0	0	57
6→7	4	10	14	10	14	0	0	0	40
6→9	2	10	12	14	16	4	0	0	68
7→8	2	14	16	16	18	2	0	0	70
7→9	2	14	16	14	16	0	0	0	43
7→10	4	14	18	17	21	3	0	0	72
8→10	3	16	19	18	21	2	0	0	58
8→11	2	16	18	23	25	7	0	0	80
9→10	5	16	21	16	21	0	0	0	46
9→11	2	16	18	23	25	7	0	0	85
10→11	4	21	25	21	25	0	0	0	54

Table 2: To find Optimum cost using Crashing Technique.

Duration	Crashing activity	Crashing cost	Indirect cost	Total cost
25	-	-	2000	2000
24	6→7	40	40+1920	1960
23	4→6	40+42	82+23*80	1922
22	9→10	82+43	125+22*80	1885
21	10→11	125+44	169+21*80	1849
20	7→9	169+46	215+20*80	1815
19	1→2	215+50	265+19*80	1785
18	**2→4**	**265+54**	**319+18*80**	**1759**
17	2→4, 1→4,1→3	319+54+58+60	481+17*80	1841

Conclusion:

An According to the idea that simplify object of planning is equivalent to simplify any algorithms to find optimum cost using shrink critical path method.

The SCPM approach is one of a variety of tools we can use to project back under control and reinforce the use of project management in organizations. Using method of SCPM, to crash the project management networks in order to reduce time cost. Firstly, the properties of floats are analyzed, and then the relations between time and cost are also analyzed. Next we can find the length of the project, and then the algorithm is designed to find optimum cost and time, when solving the time-cost trade-off problem. The algorithm is simply applied, and realizes the effect of simplifying object of problem and all correlative algorithms, which could decrease computation of solving time-cost trade off problem. The remembering fact of this SCPM is (i) Parallel critical Path does not exists in the basic crashing techniques, (ii) Indirect cost/ Overhead cost values is not less than the Cost slope values. The above result shows that the optimization of time and cost, SCPM can be incorporated as a standard procedure for every project. The SCPM cost analysis results reflect. The application of algorithm provides new idea to study network planning. This method provides new idea and theory to study network planning. Seeing from point of development, the theorem and algorithm in this paper have important significance.

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