SIMPLIFIED CPM/LOB METHODOLOGY FOR CONSTRUCTION SCHEDULING MANAGEMENT

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ABSTRACT

The CPM (Critical Path Method)/LOB (Line of Balance) technique for planning and scheduling repetitive projects has been used since the 1994. The objective of this study is to propose faster and simple approach that can be used in the development of a computerized CPM/LOB scheduling system that overcomes the problems associated with existing systems. This study mainly examines the simplified CPM/LOB methodology, especially in construction scheduling planning and control, so as to achieve effective project schedule analysis without the complex procedure. The effectiveness of the proposed simplified CPM/LOB methodology will be investigated and validated by a case study. Finally, the suggestion and limitation are proposed and discussed for further related applications.

Keywords: Critical Path Method; Line of Balance; LOB; Construction Management; Scheduling Management.

1. INTRODUCTION

The repeatability project resources continuously and repeatedly take advantage of the characteristics of the use of labor, materials, equipment and configuration must consider continuity. Ignored the former information will resulting in misallocation of resources, disruption of construction continuity or time delays. Critical Path Method (CPM) is the widely used and accepted planning and scheduling method for traditional (non-repetitive) projects; However, CPM does not suit the planning and scheduling needs of repetitive projects (Mohammad 2012). Line-of-balance (LOB) is a variation of linear scheduling methods that allows the balancing of operations such that each activity is continuously performed. The major benefit of the LOB methodology is that it provides production rate and duration information in the form of an easily interpreted graphics format (David, Onur, Kangsuk 2002). Thus this task for combining the two techniques or sometimes combining

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their merits under different names has been a heavily researched theme for decades. This reinforces the notion that CPM and LOB are complementary (Carr and Meyer 1974).

CPM/LOB method controls repetitive project scheduling effectively, but increases the difficult of applied to the complex scheduling. This research examined through improved scheduling calculations of CPM/LOB to simplify existing scheduling method, straightforward design of the discharge procedure and enhance its applicability through CPM/LOB to provide CPM scheduling repetitive reference information for the use of project resources.

2. LITERATURE REVIEW

CPM/LOB is a methodology, made by Suhail and Neal（1994）, which combined the activity relationship logic and floating of the CPM Method, could improve the scheduling logic of the Line of Balance Method and use a linear row of partogram to control continuously resources. Ammar (2012) integrated CPM and LOB model which has been developed to schedule repetitive projects in an easy non-graphical way considering both logic dependency and resource continuity constraints. Overlapping activities of a single typical unit are used to model duration and logical relationships of repetitive activities. Hegazy and Wassef (2001) used macro program for Microsoft Excel 1997 written EasyPlan, CPM/LOB e-scheduling model and performs a cost-optimized scheduling operation. Lin (2009) attempted to simplify the CPM/LOB method by his viewpoint in order to speed up computations.

In short, some scholars invented new CPM/LOB theories no matter aimed for improved CPM or LOB method, other scholar designed the related scheduling system mostly emphasis on cost optimization; but this research only focus on the area which they did not study in CPM/LOB technique.

3. SIMPLIFIED CPM/LOB METHODOLOG

Basically CPM/LOB method must calculate in accordance with the schedule of the absolute location; it entirely cannot use the location of LOB formula. This research simplifies the way of the original LOB method location scheduling that through with relationships between productivity of the predecessor and successor activity to calculate start time and finish time, reduces the linear schedule diagram schedule complexity, so can solve the problem of original LOB method which the location calculation formula cannot provide multiple predecessor activities and the location calculation problem of CPM/LOB.

LOB technique is the base of simplified CPM/LOB method in this research. LOB method is a suitably used technique which has the characteristic of the two-dimensional geometry to display activity information and visual scheduling technique to conduct project schedule method for the repeatability project. Basic diagrams and every variables of LOB method show in the diagram (a) of figure 1, the simplified LOB method shows the diagram (b) of figure 1. In the diagram (a), ST on behalf of the activity start time, FT on behalf of the activity finish time, Lag on behalf of the delay

Time, C on behalf of the number of working group, D on behalf of the activity time of a single unit, N on behalf of the total number of units each activity, R on behalf of the activity productivity, of which R=D/C. In the diagram (b), each slash is a repeating activity which has duration, working crew number and ratio; it is an easy way to show the former information of activity about LOB method in the diagram (b).

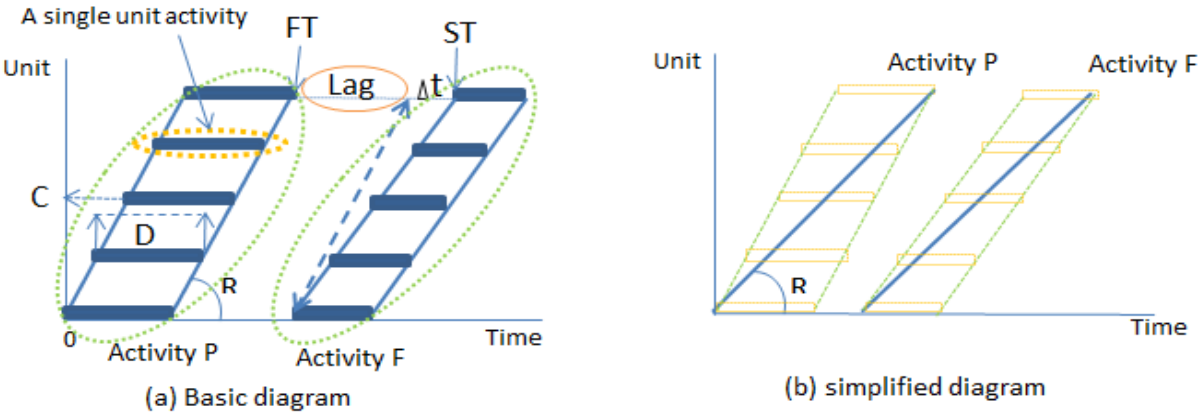

Figure 1: LOB diagrams.

For easily shown how two ratios of activities cause affected situations in simplified CPM/LOB method, the simplified LOB diagram is choice to show three kinds of relationship of the predecessor and successor activity in figure 2 in this research. This research only considers the start-to-finish relationship (FS) of activity, and shows the relationship between the predecessor and successor activity as shown in figure 2. There are three subfigures in this figure; each one has two activities, one is predecessor activity and another is successor activity, and shows two different ratios of activities or two kinds of productivity.

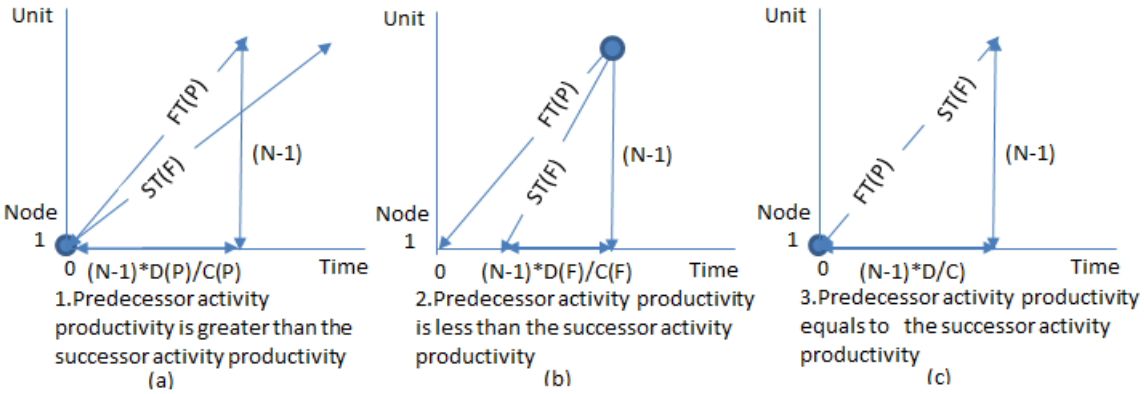

Figure 2: CPM/LOB scheduling sequence formula (FS).

In accordance with precedence diagram schedule method of the CPM between the two before-and-after relationship activities, the formula is that successor activity (ES) equals that predecessor activity (EF) plus Lag, the formula as follow:

$$ES = EF + Lag \tag{1}$$

The start time of the first unit and the last unit of repetitive activity P or F are putted into the former formula (1), get formulas as follow:

$$STL（F）= FTL（P）+ Lag \quad (2)$$

$$ST1（F）= FT1（P）+ Lag \quad (3)$$

The activity time of the first unit and the last unit of the repetitive activity of P or F are putted into the formula (2) and (3), get formulas as follow:

$$ST_L（F）=ST_1（F）+（N-1）* D（F）/C（F） \quad (4)$$

$$FT_L（P）=FT_1（P）+（N-1）* D（P）/C（P） \quad (5)$$

If the first unit and the last unit time of the predecessor and successor of activity be simultaneously be putted into former (4) and (5), then formulas will be changed as follow:

$$ST_1（F）=FT_L（P）-（N-1）* D（F）/ C（F）+ Lag \quad (6)$$

$$ST_1（F）=FT_L（P）-（N-1）* D（P）/ C（P）+ Lag \quad (7)$$

If moreover increased the productivity and delay time of the predecessor activity (P) and the successor activity (F) into former formulas (6) and (7), both formulas are modified as follows:

1. Predecessor activity productivity is greater than the successor activity productivity:

   $ST_1 (F) = FT_L (P) - (N-1) * D(P) / C(P) + Lag.$

2. Predecessor activity productivity is less than the successor activity productivity:

   $ST_1 (F) = FT_L (P) - (N-1) * D(F)/ C(F) + Lag.$

3. Predecessor activity productivity equal to the successor activity productivity:

   $ST_1 (F) = FT_L (P) - (N-1) * D / C + Lag.$

There are of two kinds of elements based on the foregoing formula for calculation as follow: the first category contains the total number of units, activity, activity date, logic of activities, activity delays, the project period and the maximum number of working group which is the content of the calculating elements; the second category contains the number of the working group, productivity, activity float and the basic unit of time after scheduling which is the content of the calculating elements.

Scheduling can be calculated based on the derivation of the formula to get the activity start time and last finish time of activity. After recognized the contents of all the calculating elements, the method of calculation process is the unit network diagram schedule, the productivity computing and the scheduling sequence calculation. All calculations within the process need to enter the computing element, to use scheduling tools and the calculation results. Pursuant to the order of calculation collate as shown in Figure 3.

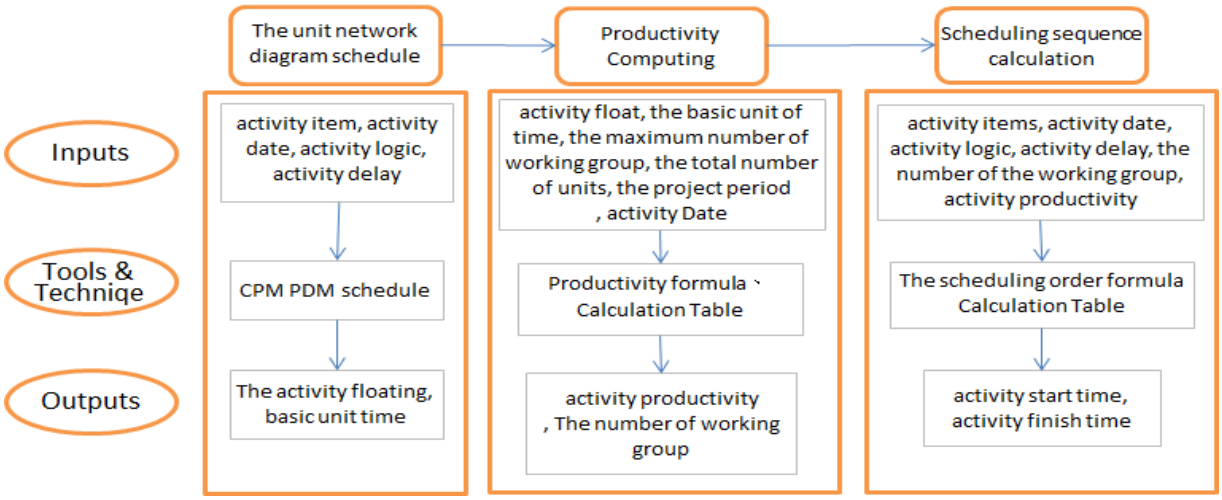

Figure 3: CPM/LOB scheduling calculation flowchart.

Above all, the simplified CPM/LOB method is a way that base on some man-made known variables from project information to use the simplified numerical formula that base on the graphic of the line-of-balance method for getting the start and finish time of any activity in project. Using this kind of numerical formula method to calculate schedule step by step is easily follow the logic of scheduling rules that many people are familiarly to understand in mathematics. That is a main topic in this research: how to use mathematic formula to calculate CPM/LOB method. All above mathematic formulas and the simplified CPM/LOB scheduling calculation flowchart are the soul of simplified CPM/LOB methodology, it is a easily way to get scheduling results in project in real practical application that likes the case as next section.

4. CASE DESCRIPTION

In order to fully demonstrate the key point of simplified CPM/LOB scheduling method, the following example is the demonstration of schedule to show how to calculate from known data to unknown results until get results. In numerical analysis method, every variables which be found in original method should become formulas to calculate for results. Basically calculated step by step, all variables are calculated from known data to unknown results in every formula. So the following example will follow the former rules to calculate for getting results: first to show every variable in table title; second put in every value of variables under the variable title in columns; third to calculate every unknown value of variables from related formulas and write down under the variable title in columns until every unknown variable are known data in table, just like table 1 form.

This case base on three formulas and a calculation flowchart of method in section 3, there are three steps and each step has three parts to calculate in all three FS relationships. In table 1, every known and unknown data will illustrate as follow four steps; every step has three calculating flowchart,

from left to right direction, includes inputting basic data, using calculation tool and method, and outputting calculating results; each bold letters is a known value.

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The calculation flow as follow: the first step is to confirm basic information, project period（T_L）=150 days, the total number of units（N）=5, the time of basic unit（T_1）=75, duration D is known, the maximum number of working group C_{MAX}=3; the second step is to calculate the element of the unit network diagram schedule which contains the total float Time TF (calculated value) and the maximum number of working group C_{MAX}; the third step is to compute Productivity R=（N-1）/（T_L-T_1+TF）, the number of working group C=D*R, actual working group Ca（the unconditional binary value of C）, actual productivity（Rai）=Ca / D_1; The fourth step is based on CPM/LOB scheduling formula (FS) calculated that the earliest start time ST and the latest finish time FT_L.

All unknown values be illustrated as follow: the TF value is calculated from CPM method; get R from R=（N-1）/（T_L-T_1+TF）; get C from R and D, then get Ca from C, then get Rai from Ca; get ST from every duration and the logic of the activity; get FT_L from formulas. All calculated values are compiled as shown in Table 1.

Table 1: Case scheduling results table

Activity	***Duration (DAY)***	***Lead logic***	*Total Float*	C_{MAX}	*R*	*C*	C_a	R_a	*(N-1) *D/C*	*ST*	FT_L
A	**15**	**-**	0	**3**	0.053	0.795	1	0.067	60	0	75
B	**10**	**A-FS(0)**	25	**3**	0.04	0.4	1	0.1	40	35	85
C	**25**	**A-FS(0)**	0	**3**	0.053	1.325	2	0.08	50	25	100
D	**10**	**B-FS(20)** **C-FS(20)**	10	**3**	0.047	0.47	1	0.1	40	60	110
E	**20**	**C-FS(10)**	0	**3**	0.053	1.06	2	0.1	40	60	120
F	**15**	**D-FS(30)** **E-FS(20)**	0	**3**	0.053	0.795	1	0.067	60	80	155

According to every value in table 1, it shows that used graphic way to calculate CPM/LOB method for the duration of project is not necessity. Because CPM/LOB scheduling is based on the assumptions which repetitive activity is complete continuously and uses the relative relationship between productivity and the number of working group to determine the activity application logic and buffer time. This method not only can be identified repetitive project facilities for the fewest amounts of required resources but also can modulate the number of working group to change the duration. In order to understand the application difference between the CPM/LOB method and the simplified CPM/LOB scheduling method, this research uses the same case to compare the schedule analysis and compression duration method, the drawing way of the schedule chart and scheduling

results. Conclusions about the application of two CPM/LOB method be collected and shown in Table 2.

Table 2: Compare with original CPM/LOB and simplified CPM/LOB

Compare Activity	Original CPM/LOB	Simplified CPM/LOB
Scheduled time	About 120 minutes （Hand-drew computing）	About 60 minutes （Hand-drew computing）
Analysis and Compression duration method	Adjusted through the graphical analysis	Adjusted through the numerical analysis
Drawing method for schedule chart	The traditional deduction consume time and work	Draw way is simple and fast
Scheduling result	155 days	155 days

In above table 2, this research compares with original CPM/LOB method and simplified CPM/LOB method about five aspects which are scheduled time, analysis and compression duration method, drawing method for schedule chart, and scheduling result; each aspect is a viewpoint which have to be compared with other method to prove the effect of that method, in other words, that means each viewpoints is the characteristic of method.

The information in table 2 shows that just because simplified CPM/LOB method uses the numerical analysis, not only it can get the same result of original CPM/LOB method more calculating speed of the former method is faster than the latter method's double. It means that using numerical analysis to calculate schedule is the reason that the simplified CPM/LOB method is excellence than original CPM/LOB method because of the faster calculating speed in this research.

5. CONCLUSIONS

The FS relationship formula derivation and application of the simplified CPM/LOB method have been identified in this research. The objective of this research includes proving the value and effect of numerical analysis in both graphic and logic of schedule method like CPM/LOB method, and making an example to show how to use the numerical analysis to derivate formulas calculating the period of relative project. The following are proposed:

1. The rationalized scheduling results could be got unless after combined LOB and CPM method of calculation methods and logic.
2. Using graphical scheduling to calculate will increase the complexity of complex projects, fore more caused scheduling difficulties; but using numerical analysis of simplified CPM/LOB method can simplify scheduling process and reduce scheduling time.
3. Unless foreknowing the information of the maximum value of repetitive activity working group and the scheduled planning of project deadline, Otherwise the CPM/LOB method even though the simplified LOB/CPM method are useless.

4. The simplified LOB/CPM method could apply unless the project complexity is not very high and the analysis information of project can supply to cut unit.
5. When repetitive activities less than three, the characteristics of simplified CPM/LOB method cannot be apparent in the project because the simplified CPM/LOB scheduling results are tantamount to the Critical Path Method's.
6. LOB method should consider resource allocation and scheduling of the activity logic to obtain more reasonable schedule results. But graphic stacked in the scheduling process of this method will affect the activity identification and could easily lead to the difficulties and errors of calculation. Numerical calculation method to solve the above-mentioned problems is a reasonable solution.
7. The application of simplified CPM/LOB schedule is limited because the integrity of the project information, the repeatability of project operation and the logic of cutting unit. How to combine LOB schedule visual effects and the advantages of the CPM schedule can be further discussion directions in the future . ◦
8. LOB and CPM scheduling method has its own strengths and weaknesses of rational and irrational, so the universality of research in practical engineering applications have their own growth and decline, but the real reasons are worth further explore applications of two ways.
9. Using Numerical analysis method re-interpretation of CPM, LOB and CPM/LOB scheduling method is the research direction which worth continually to develop.

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