Advanced Science and Technology Letters
Vol.74 (ASEA 2014), pp.58-66
http://dx.doi.org/10.14257/astl.2014.74.13

Development of Optimization Algorithm for Establishing Effective LSM Process Plans

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Abstract. Construction projects are carried out mainly with either non-repetitive process or repetitive process according to the characteristics of project. In case of non-repetitive process, the network process management method is mainly used, and in case of repetitive process, LSM is often used. In case of network process management method, many studies regarding its optimization for carrying out the work efficiently have been carried out, but there is lack of studies regarding LSM. Therefore, the purpose of this study is to develop the optimization algorithm in consideration of construction cost and construction period for establishing LSM process plan. Also, the information regarding optimized process management is drawn through the verification of algorithm in this study using two road construction cases with many repetitive processes, and compared and analyzed with the prearranged process management information. As a result, the total construction cost of each case was reduced by 28% and 35% respectively, and the construction cost of each case was reduced by 3% and 21% respectively, confirming that rational and efficient construction project process management could be carried out.

Keywords: Repetitive Process, Optimization, Brute-Force Algorithm, LSM (Linear Scheduling Method)

1 Introduction

The production process of construction project may vary according to the type of project, and it can be divided into cases with non-repetitive process mainly for uneven shape and separate conditions for work space and cases with repetitive process such as apartment housing and road construction projects. There are also cases with both non-repetitive process and repetitive process.

In case the work is carried out with non-repetitive process, the work can be planned effectively through the network process management method models such as CPM (Critical Path Method) and PERT (Program Evaluation & Review method), but in case of repetitive process, the details of work are carried out repeatedly at the same place, so in case of expressing it as the network model, a large number of element works are required, it is difficult to connect between works and visualize spatial constraints, so LSM (Linear Scheduling Method) model is mainly used.

However, in case of network process management method, many studies regarding optimal relations between the construction period and construction cost for carrying

ISSN: 2287-1233 ASTL

out efficient works have been carried out [1, 2, 3], but there has been lack of domestic studies regarding the optimization of LSM except for studies regarding the method to create linear process table by applying the relationship of network process table [4, 5].

Therefore, the purpose of this study is to develop the optimization algorithm for establishing LSM-based effective process plans based on the studies regarding the optimization of network process management method and establish LSM process table with the optimized construction cost and construction period using the developed algorithm.

The optimization algorithm as shown above is carried out in the following order. First, previously established process plan activities are classified divided for each location and the equipment alternative to handle such activities are established. Second, the direct cost and construction period for the established equipment alternative are calculated. Third, the relationship between each activity is set using buffer which indicates the spare time between preceding and following activities among LSM elements in order to set the relationship between each activity such as CPM relationship. Fourth, the object function and limiting condition are established and the optimization process is carried out using Brute-Force Algorithm. Lastly, the information regarding construction cost and construction period and LSM process table are drawn using the optimal value.

2 Optimization algorithm for LSM process plans

2.1 Selection of equipment alternative and algorithm for optimization

In case of optimization of process plan for construction projects, the equipment alternative for the prearranged activity is established according to the number and specification of equipment to be used, and then the optimal value is drawn in consideration of expense and time. The optimization of LSM process plan in this study is carried out also after the equipment alternative to be used is established just as the previous studies on the optimization of CPM process management.

In this study, Brute-Force Algorithm which calculates the total distance of all paths from one point to another and then find the minimum path is used as the algorithm to solve problems occurred in the process to carry out the optimization to find the work plan with the lowest total construction cost after the equipment alternative being established according to the number and specification of equipment to be used.

Brute-Force Algorithm is the method to calculate the distance of all paths from one point to another so that it may be inefficient due to its high complexity in comparison to its small scale.

However, it was decided to apply the algorithm shown in this study to this study in consideration of the fact that the algorithm applied to construction projects with a lot of repetitive processes (high-rise and road construction works), a number of paths shown in the equipment alternative for many activities existed and this algorithm could be efficient for calculating all these paths.

Therefore, in this study the equipment alternative of activity for each location is established according to the number and specification of equipment to be used as shown in Figure 1 below, total construction cost of all paths is calculated using Brute-Force Algorithm in order to find the path with low total construction cost and the path with the lowest total construction cost is considered as the optimized process plan. At this time, the integer programming which takes 0 or 1 as the condition for selecting or not selecting decision making variables is used in the process to find the optimal equipment alternative among various equipment alternatives to select only one equipment alternative.

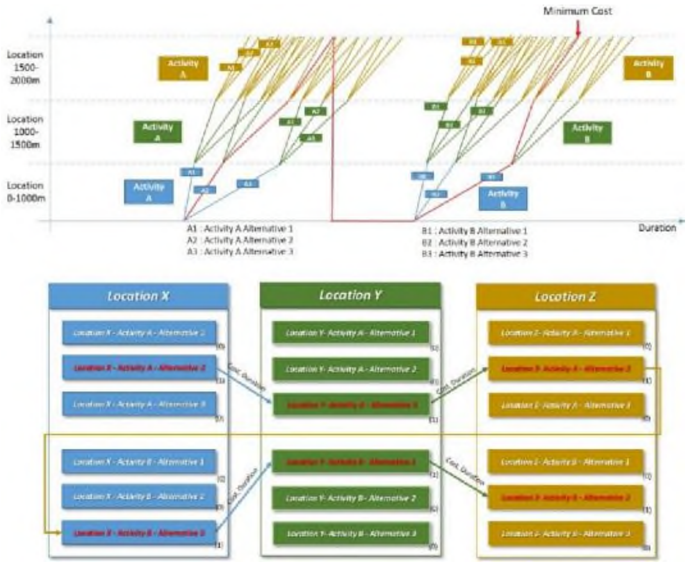

Fig. 1. Process to establish the process plan using the equipment alternative of activity.

2.2 Setting of relationship between activities in construction work

In this study, the total construction cost of all work paths is calculated using the Brute-Force Algorithm, and in case of work paths, the path to begin and complete the work is created only after the preceding and following relationship between activities is set. However, in case of LSM, no element which limits the preceding and following relationship such as CPM relationship exists.

In order to solve the problem as shown above, the concept of buffer which limits the interference of slope between preceding and following activities and indicates spare time between preceding and following activities among LSM elements is interpreted as same as the concept of CPM relationship and used as the limiting condition of relationship setup required for the development of LSM optimization algorithm.

Figure 2 shows that the preceding and following relationship is limited using the buffer. The sum of the finish time of preceding activity and buffer is limited to be same or smaller than the start time of the following activity, and the start time of the following activity is set to begin at the finish time of the preceding activity plus 1.

The preceding and following relationship between each activity is established by applying such limit.

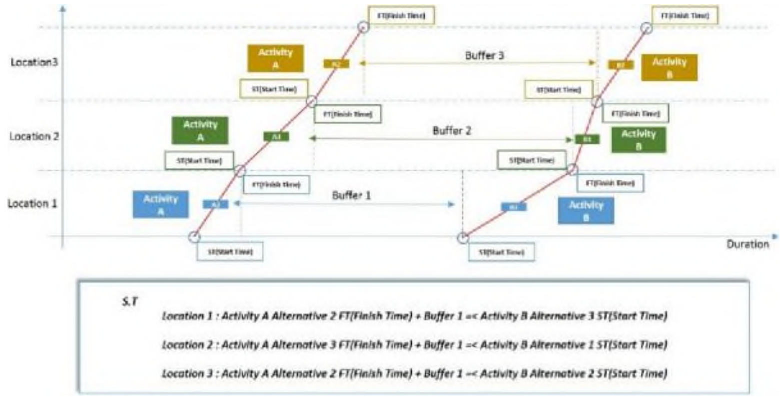

Fig. 2. Limiting the preceding and following relationship between activities using buffer.

3 Calculation of minimum total construction cost and establishment of LSM process plan

The process for calculating minimum construction cost and establishing LSM process plan which are the final goal of this study is as shown in Figure 3 below.

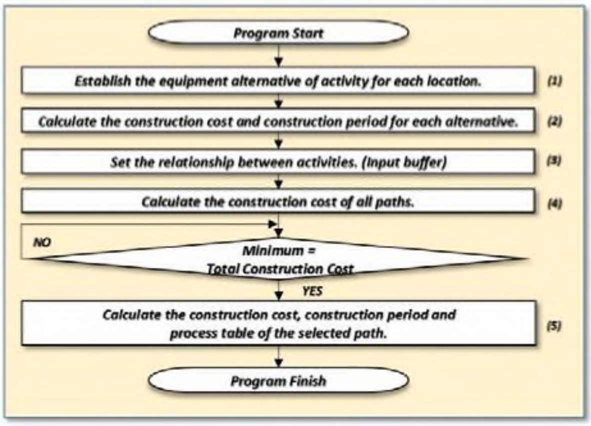

Fig. 3. Process for establishing optimized LSM process plan

The equipment alternative for each activity in the previously planned construction project process plan is established (1) and the construction period and construction cost occurred due to the equipment used are calculated. The construction period is calculated using the productivity of equipment used and the quantity information of relevant activity, and the construction cost is calculated using the number of equipment used, unit price and construction period. (2)

Before the optimization is carried out with the established equipment alternative, the preceding and following relationship between each activity is set as the buffer element of LSM. The sum of the finish time of preceding activity and buffer is limited to be same or smaller than the start time of the following activity, and the start time of the following activity is set to begin at the finish time of the preceding activity plus 1 (3)

When the preceding and following relationship is set as buffer as shown above, no interference between the preceding and following activities occurs in the LSM process table and field managers can manage the work by limiting the start time of following activity after the preceding activity.

Also, the limiting condition is set for selecting only one out of various equipment alternatives. Among various equipment alternatives, a measure which is selected is indicated with 1 and a measure which is not selected is indicated with 0, and the sum of all equipment alternatives in the activity is restricted to 1 as shown in Formula (1).

$$\sim\ \sim_{ij} = 1 \qquad = \{0,1\} \tag{1}$$
$$= \quad =1$$

i and j in Formula (1) indicate "Activity Name" and "Alternative Number" respectively, and X=0 indicates “Does not select the equipment alternative” and X=1 indicates “Select the equipment alternative”.

After the equipment alternative for all activities is established and the information is entered, the construction cost for all paths is calculated using the object function (2) and Brute-Force Algorithm and the information of path for minimum construction cost is drawn.

$$= (\sim\sim(_{ij} \times {}_{ij})) + (_{D} \times D_{T}) \tag{2}$$
$$= \quad =1$$

DC_{ij} in Formula (2) indicates the construction cost for equipment alternative j in Activity i, IDC_D indicates the indirect cost per day and D_T indicates the construction period. Such object function is the method to calculate the total expense of construction work which has the same meaning with sum of total direct cost and total indirect cost.

It is possible to calculate the construction period, number of equipment to be used and LSM process table using the path of minimum construction cost drawn with the object function as shown above, and field managers can carry out the rational and economical work management by comparing and analyzing the construction period and construction cost with previous construction project process plans.

4 Case Study

In order to verify the validity of algorithm presented in this study, a case study targeting two typical road construction works including repetitive process is carried out. Table 1 below shows the information regarding quantity, equipment and construction period of road construction work A for each activity.

Table 1. Information of quantity, equipment and construction period of Case (A) for each activity.

	Quantity					Equipment	Construction period
	Location 1	Location 2	Location 3	Location 4	Location 5		
A	200 m^3	150 m^3	200 m^3	200 m^3	250 m^3	2 Unit	30
B	150 m^3	200 m^3	180 m^3	200 m^3	150 m^3	4 Unit	20
C	200 m^3	200 m^3	200 m^3	200 m^3	200 m^3	3 Unit	25

Next, the information regarding the total construction cost and construction period of this case (A) are confirmed. The total construction cost is \$ 240,600 based on the overhead cost of \$ 800 per day, and the construction period is 32 days.

At first, the information of previous road construction process plan as shown above is confirmed, the equipment alternative of activity for each location is established and the construction period and construction cost are calculated using the quantity information in Table 1 and the productivity of equipment to be used.

After the equipment alternative for all activities is established and the information is entered, the object function and limiting condition are established and the optimization is carried out using Brute-Force Algorithm.

As a result of optimization, the total construction cost and construction period were estimated as \$ 234,400 and 23 days respectively. Figure 4 below shows the comparative analysis between the previous road construction process plan and the optimized process plan.

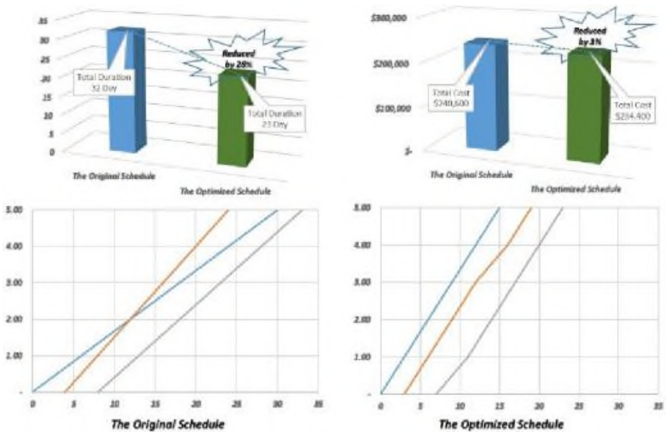

Fig. 4. Comparative analysis of optimization result of case A.

As a result of comparison between the previous road construction process plan and the optimized process plan, it was confirmed that the construction period was reduced by 28% from 32 days to 23 days and the construction cost was reduced by 3% from $240,600 to $234,400.

Also, in case of LSM process table of previous road construction process plan, interference occurs during the progress of construction process, and if interference occurs, it causes confusion in operation traffic and work efficiency loss so that it is difficult to carry out the work properly, but the LSM process table drawn through the optimization enables carrying out the work efficiently without any interference.

Table 2 below shows the information regarding quantity, equipment and construction period of road construction work B for each activity.

Table 2. Information of quantity, equipment and construction period of Case (B) for each activity.

Activity	Equipment	Construction period	Quantity	
			Location 1	Location 2
A	3 Unit	26	1,000 m^3	1,000 m_3
B	4 Unit	18	750 m^3	750 m_3
C	3 Unit	30	1,000 m^3	1,000 m_3
D	2 Unit	16	500 m^3	500 m_3
E	4 Unit	40	1,250 m^3	1,250 m_3
F	4 Unit	34	1,000 m^3	1,000 m_3

Next, the information regarding the total construction cost and construction period of this case (B) are confirmed. The total construction cost is $725,500 based on the overhead cost of $1,500 per day, and the construction period is 105 days. The optimization for case (B) was also carried out in the same way with case (A), and the result is as shown in Figure 5.

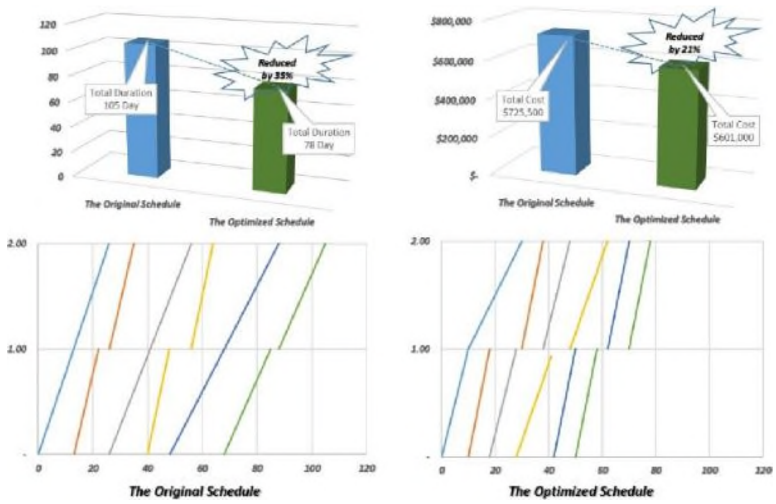

Fig. 5. Comparative analysis of optimization result of case B.

As a result, it was confirmed that the total construction cost and construction period were estimated as $ 601,000 and 78 days respectively, and the construction period was reduced by 35 % from 105 days to 78 days in comparison to the previous road construction process plan and the total construction cost was reduced by 21 % from $725,500 to $601,000.

Also, LSM process table was drawn just as Case (A) for carrying out the work efficiently.

5 Conclusion

In this study, the equipment alternative for each activity in construction project process plan with many repetitive processes was established and the construction cost for all paths was calculated. The algorithm to find the minimum construction cost was developed, and the useful information for decision making of field managers was drawn using such algorithm. The effectiveness and validity of the algorithm was verified by conducting the verification of this study using two road construction cases.

As a result, it was confirmed that the construction period and construction period of Case (A) were reduced by 28% and 9% respectively in comparison to the previous road construction process plan, and the construction period and construction period of Case (b) were also reduced by 30% and 15% respectively in comparison to the previous road construction process plan.

Also, the optimized LSM process table was drawn by using information of previous road construction process plan as the result of case verification, and the possibility to carry out the work effectively was confirmed by drawing the information for decision making of field managers through the analysis of such process table.

Lastly, the optimization of CPM as well as the optimization of LSM showing high efficiency in repetitive works became possible by using the result of this study, and it was confirmed that the optimization of all processes in a general construction work consisting of a combination of non-repetitive process and repetitive process became possible from the viewpoint of construction companies.

Acknowledgments. This research was supported by a grant (11 CTIP 04) from construction Technology Innovation Program funded by Ministry of Land, Transport & Maritime Affairs of Korean government.

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