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A CONSTRUCTION DELAY ANALYSIS APPROACH BASED ON LEAN PRINCIPLES

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Abstract: Delay is a quite common problem for construction projects. The existing practice of construction management is usually based on assessment of delays, liabilities and claims. However, this approach does not serve to remove the underlying causes of delay problems. In addition to estimation of delays, there is a need for a systematic method that will prevent delays in projects. Lean construction has tools and techniques that can serve for this purpose. However, a formal delay analysis procedure does not exist in lean practices since CPM adaptation is not well accepted. This paper advocates that integrated utilization of CPM and lean principles can help assessment of existing delays and minimization of delays in forthcoming stages.

The methodology proposed in this study has not been applied on a real project, however, in this paper, its implementation steps are demonstrated using real project data. The proposed methodology is expected to help construction practitioners in delay analysis and when lean principles are applied appropriately, it can prevent delays, enhance schedule accuracy, and improve communication between the parties.

Keywords: Lean construction, delay analysis, last planner system, critical path method, pull scheduling.

1 INTRODUCTION

Delay is one of the most typical consequences of performance problems in the construction industry. There are numerous reasons for construction delays, including problems related to design, labor, materials and equipment, subcontractors, weather, planning, and work execution (Gonzales et al. 2014).

Existing construction management practices are often oriented towards how delays can be calculated more precisely. There are many delay analysis techniques, which can be grouped as as-planned vs. as-built analysis, impact as-planned analysis, collapsed as-built analysis and time-impact analysis (Arditi and Pattanakitchamroon 2006). Each of these methods have different approaches for estimation of delays and assessment of liabilities. However, they lack of a systematic mechanism and protective approach that shields projects from further delays while analyzing the existing ones (Birgonul et al. 2014).

Delay analysis based on the Last Planner System (LPS) principles can make a significant contribution to overcoming this problem. Pull based approach of the LPS

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enhances both the flow of work packages and the level of communication on the construction site (Priven and Sacks 2013). With these features, LPS and lean principles can enable the minimization of delays. Nonetheless, there is not a formal delay analysis procedure in lean construction since lean philosophy does not advocate the utilization of CPM schedules in today's complex, uncertain, and quick construction projects (Koskela et al. 2002). This paper, on the other hand, proposes a methodology based on integrating CPM with LPS and lean principles. Forthcoming sections describe the proposed delay analysis methodology and its implementation.

2 INTEGRATING CPM INTO LEAN CONSTRUCTION

In current construction management practices, detailed CPM schedules are being prepared at the beginning of projects by considering the whole project duration although there are various uncertainties associated with the as-planned schedule. It is not a realistic approach to prepare a work schedule representing project conditions of the forthcoming years and considering it as the baseline throughout the project. Construction activities are prone to several risk factors, and it is very hard to predict future project conditions accurately at initial stages of the project. Validity of the baseline schedule may be restricted due to many reasons, including change of project scope, design documents, and even project teams. For these reasons, it is very common phenomenon in construction projects that a few months after the preparation of the baseline schedule, it becomes unpractical. Then, project team tries to adopt a new baseline schedule, which requires extra time and money. However, delay and other performance problems of the construction projects cannot be associated with CPM methodology only. They are rather related to the way CPM is implemented and utilized for decision-making. Moreover, the role of CPM in construction projects cannot be ignored due its widespread utilization and contractual requirements of owners (Olivieri et al. 2016).

In order to eliminate waste due to long and complex baseline schedules, a pull schedule approach similar to LPS should be adapted. Huber and Reiser (2003) indicate that CPM scheduling and the LPS can be complimentary to each other and utilization of them together can improve work and crew flow. An integrated planning system, which has been developed by a Norwegian building contractor, reveals that benefit of the LPS can be still maintained with the integration of CPM (Kalsaas et al. 2014). CPM, LPS, and their production control metrics are not conflicting with each other, but on the contrary, they can improve project management efficiency when they are used together (Ponz-Tienda et al. 2015). This paper also suggests an integrated approach for construction delay analysis by combining CPM with the principles of lean construction. Although LPS is adapted as core principle, other lean construction principles are also integrated to proposed methodology. Principles such as, including project participants to decision making process and organizing regular meetings are integral parts of the methodology. These lean principles increase the communication between the project stakeholders, so that the work schedules can be created more realistically and repeating delay events can be minimized. The methodology is believed to represent project conditions better with its communication-based continuous learning mechanism and provide a better benchmark for delay analysis.

3 PROPOSED METHODOLOGY

This section describes implementation steps of the proposed methodology. As explained in previous sections, the methodology is based on the idea of integrating CPM with core principles of the LPS and lean construction. Figure 1 illustrates the overview of the proposed delay analysis methodology.

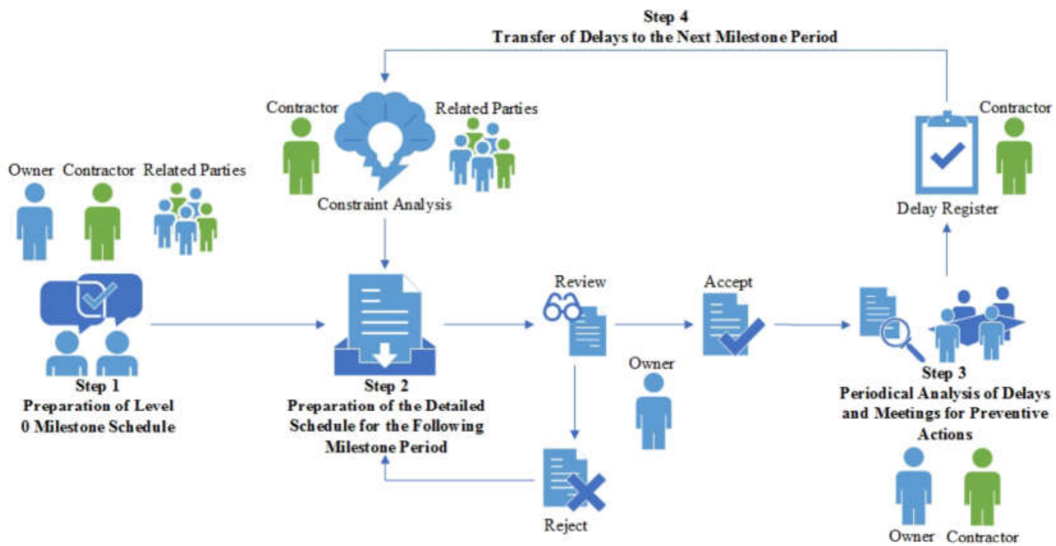

Figure 1: Implementation Steps of the Delay Analysis Methodology

The methodology has four steps. First step is similar to the master planning phase of the LPS. A milestone schedule should be prepared based on contractual documents and requirements of the Owner. This work schedule should contain the dates of milestone activities that physically exist in the project. It would be more appropriate for delay analysis if time interval between two milestone activities is not too long. Although it depends on the type of the project and frequency of the updating periods, 6 weeks time intervals can be utilized as suggested by the LPS (Ballard et al. 2002). Milestone activities should be selected so that milestone periods should not be intertwined. If nature of the works or limited experience of the contract parties prevent determination of milestone activities explicitly, a more detailed schedule with CPM logic can be used to estimate them. Milestone schedule should be prepared by participation of all project stakeholders. From the perspective of lean construction, the approach of consensus based milestone scheduling will help to establish better communication between the contract parties at the very early stage of the project.

Second step is preparation of a detailed schedule for the period between first two milestone activities. This steps includes procedures of lookahead planning in LPS. Before preparing the schedule, a constraint analysis should be carried out by the project team and alternative plans should be developed for the expected problems. A formal risk analysis procedure will serve for these purposes. Constraint analysis will not only protect work flow from uncertainties, but also improve participation and project integration of the stakeholders. As an output of this analysis, work packages to be completed in milestone period should be pulled and execution plan of the activities should be estimated with CPM logic. Even though this delay analysis approach is based on integration of CPM with lean principles, complicated network relationships should be avoided. For example, utilization of Start-to-Finish relationship should be prevented, and Start-to-Start and Finish-to-Finish relationships should be restricted. Furthermore, relationship lags and constraints should not be preferred. The pull based scheduling approach will support lean construction principles by constituting a continuous work flow. The work schedule finalized by the Contractor should be submitted to approval of the Owner for a sufficient period of time. The schedule will be the basis for delay analysis throughout the period.

Third step has two main processes: periodical analysis of delays and meetings for preventive actions. Similar to commitment planning phase of LPS, success of the lookahead schedule is measured by estimating delays periodically. Before delays are examined, duration difference between the original milestone period and as-planned schedule should be estimated as initial delay. It should be calculated at the beginning of the period and be granted to the Contractor as a positive or negative delay. Then, a window based delay analysis approach can be utilized to estimate delays throughout the regular update intervals. Results of the delay analysis are directly influenced by the size of window span. Using large intervals causes the dynamic changes in the critical path to be missed. Therefore, accuracy of the analysis will be better when window size is as small as possible (Hegazy and Zhang 2005). Following the quantification of delays at each window, delay meetings should be organized between the project team and the Owner representatives. Delay meetings correspond to the learning phase of LPS. A delay register should be the output of these meetings. Subjects of the delay register may include; delay reasons, responsible parties, preventive actions for similar delays, supportive strategies to prevent further delays, impacts of third party delays, and reduction strategies. Main contribution of the delay meetings to lean principles is improved communication between the contract parties throughout the project. In addition, lessons learned from the current delays will be transferred to following period while preparing its schedule. By this way, information will be updated at all phases of the project.

Last step of the proposed methodology is transfer of delays. Inexcusable delays, excusable-compensable delays, and excusable-non compensable delays estimated at the end of third step are transmitted to the following period. This operation is repeated for each period until the end of project.

Using this methodology, delay amounts and liabilities will be established at each phase of the project without the need for a forensic schedule analysis. More importantly, as fundamental principle of this delay analysis approach, delays and their impacts will be minimized in the forthcoming phases of the project. Following section demonstrates the implementation procedure of the methodology with a numerical example.

4 IMPLEMENTATION PROCEDURE

This section explains how the proposed delay analysis methodology can be used in a construction project. Although the methodology has not been implemented directly in the project, its implementation is demonstrated using real project data and actual delays happened in this project. The example project involves the construction of towers for an energy transmission line. There are 34 towers in the project. Basic activity groups are foundation works, erection works, and wiring of the transmission line. The project has estimated duration of 8 weeks and includes 171 activities in total. There is not any non-working day or holiday in the calendar. The work schedule of the project is updated weekly. Therefore, the delay analysis is performed on a weekly basis.

In order to implement the proposed methodology in the project, a milestone schedule is created as shown in Figure 2. The milestone schedule is composed of four milestone activities and three milestone periods whose durations are also indicated in Figure 2.

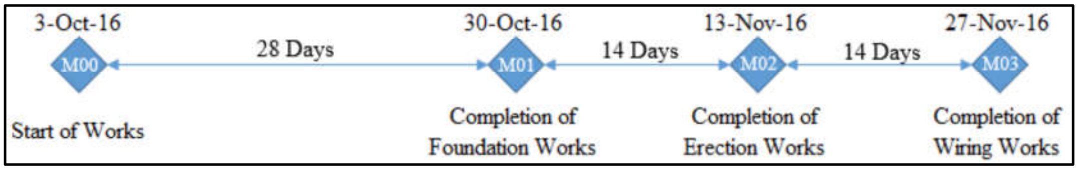

Figure 2: Milestone Schedule

Before the initiation of first milestone period, a detailed schedule is prepared for this period. It should be noted that work packages should be pulled as a result of a detailed constraint analysis for real cases. Figure 3 depicts approved schedule for this period. According to as-planned schedule; the start date of construction is 3rd of October, which is same as the first milestone date. However, finish date shows that the Contractor expects to complete foundation works 5 days earlier than the second milestone date. This duration difference will be granted to the Contractor as an initial negative delay.

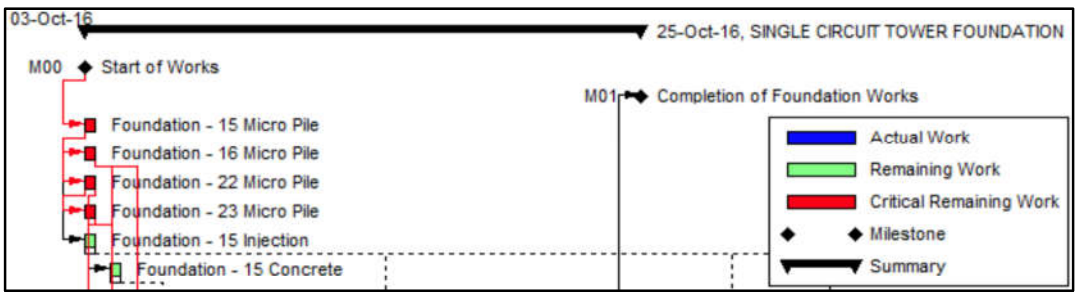

Figure 3: As-Planned Schedule of Period 1

Delay analyses are performed for the first period throughout the weekly updates. As-built schedule obtained at the end of this period can be seen in Figure 4. Completion date of the first period indicates that there is a considerable amount of delay in the project. Works are expected to be completed on 25th of October in the as-planned schedule, whereas actual date is 22nd of November.

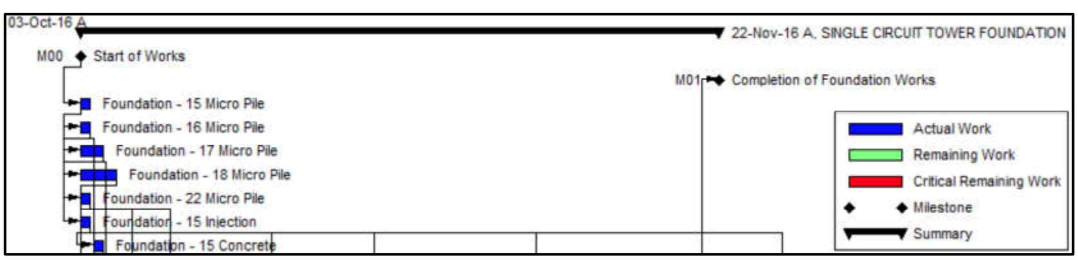

Figure 4: As-Built Schedule of Period 1

When this methodology is used in real projects, assessment meetings should be conducted following each delay analysis window. As a result of these meetings, a detailed register of delays should be created in order to illuminate the other phases of the project. An example of delay register for the major delay items is shown on Table 1 in which responsible parties are determined according to the contract conditions. Table 2, on the other hand, presents the delay analysis calculations and results for the first period according to delay register data in Table 1. Delays estimated in this period will be transferred to second milestone period.

Table 1: Delay Register Example

#	Delay Item	Delay Cause	Delay Amount	Responsible Party	Strategies for Similar Delays
1	Slow work progress	Inadequate resources	3 days	Contractor	Resource increase
2	Suspension of piling works	Default of piling subcontractor	12 days	Contractor	Changing the prequalification criteria for subcontractors
3	Prevention of site usage	Expropriation problems for the 31st and 32nd tower	5 days	Owner	Completion of expropriation prior to start of works
4	Administrative disturbance	Delay in getting permission from the local electricity authority	8 days	Third Party	Establishing better relationships with local authorities

Table 2: Delay Analysis of Period 1

Delay Parameter	Quantity
Original Duration of Period 1 [1]	28 Working Days
As-Planned Duration of Period 1 [2]	23 Working Days
Initial Contractor Delay in Period 1 [3]=[2]-[1]	23-28 = -5 Days
As-Built Duration of Period 1 [4]	51 Working Days
Total Delay for Period 1 [5]=[4]-[2]	51-23 = 28 Days
- Inexcusable Delay [5.1]	15 Days
- Excusable-Compensable Delay [5.2]	5 Days
- Excusable-Non Compensable Delay [5.3]	8 Days
Total Contractor Delay in Period 1 [C1]=[3]+[5.1]	-5+15 = 10 Days
Total Owner Delay in Period 1 [O1]=[5.2]+[5.3]	5+8 = 13 Days

In order to carry out delay analysis for the second period, detailed schedule for this period should be ready. It should be prepared before the completion of first period. However, very early preparation of the work schedule will restrict the utilization of lessons learnt in the first period. Late preparation, on the other hand, will shorten the approval process. There should be an appropriate time interval between the completion of the first milestone period and schedule submission of the second milestone period. Figure 5 demonstrates the approved as-planned schedule for the second period. As shown in the schedule, the Contractor plans to accelerate works. As-planned duration of this period is 9 days, whereas original milestone period equal to14 days. It means that, there will be 5 days initial negative delay for the Contractor.

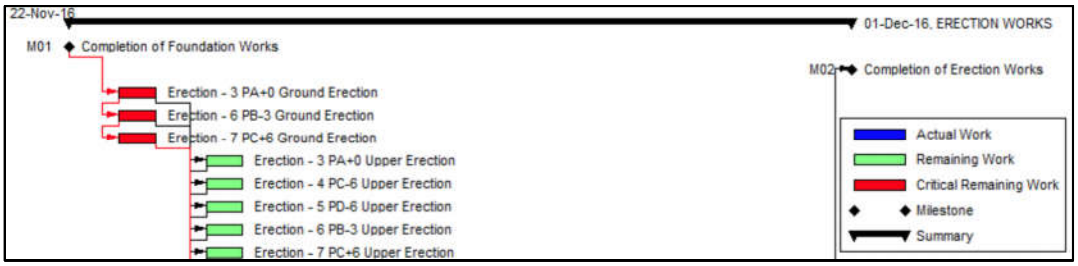

Figure 5: As-Planned Schedule of Period 2

Similar to the first period, delay analyses are performed in each updating period. As-built schedule of the second milestone period is given in Figure 6. It indicates that the Contractor performed better than planned. The erection works have been completed in 6 days. There is a negative delay for the Contractor realized by the increase of resources.

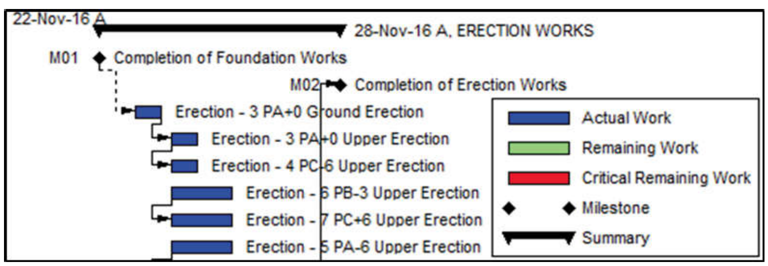

Figure 6: As-Built Schedule of Period 2

Delay analysis calculations and results for the second period are represented in Table 3. The Contractor has succeeded to reduce the delay amount, but the project is still behind the schedule due to delay in the first period. According to the schedule, foundation works and erection works have been completed on the 28th of November. Related completion date was 13th of November in original milestone schedule. As of the end of the second period, there is 15 days delay in total. 2 days delay belongs to the Contractor, while 13 days delay is under the liability of the Owner. These delays should be passed to following period by repeating the same steps.

Table 3: Delay Analysis of Period 2

Delay Parameter	Quantity
Total Contractor Delay in Period 1 [C1]	10 Days
Total Owner Delay in Period 1 [O1]	13 Days
Original Duration of Period 2 [1]	14 Working Days
As-Planned Duration of Period 2 [2]	9 Working Days
Initial Contractor Delay in Period 2 [3]=[2]-[1]	9-14 = -5 Days
As-Built Duration of Period 2 [4]	6 Working Days
Total Delay for Period 2 [5]=[4]-[2]	6-9 = -3 Days
- Inexcusable Delay [5.1]	-3 Days
- Excusable-Compensable Delay [5.2]	0 Day
- Excusable-Non Compensable Delay [5.3]	0 Day
Total Contractor Delay in Period 2 [C2]=[C1]+[3]+[5.1]	10-5-3 = 2 Days
Total Owner Delay in Period 2 [O2]= [O1]+[5.2]+[5.3]	13+0+0 = 13 Days

As a result, this example demonstrates how the proposed methodology can be implemented under real project conditions. Results reveal that it can be used at different stages of the project to estimate delays. In traditional practice, delays are analyzed through unrealistic baseline schedules, and claims arise during and after the project. This methodology, on the other hand, can analyze delays based on more realistic schedules and minimize the non-value adding processes, such as disputes and claims. Moreover, the methodology focuses on establishing a continuous learning mechanism in the project. Delay register example aims to demonstrate that lessons learned at a certain stage of the project can be used in the future. Although how the project parties can communicate could not been demonstrated in the example, proposed methodology is believed to advocate a consensus-based decision making at each step of delay analysis. This approach can serve to reduce communication barriers and disputes between the project stakeholders.

5 CONCLUSIONS

This article recommends an integrated methodology for delay analysis based on lean construction principles. It has a potential to improve the performance of construction projects by providing a delay-preventive mechanism, accurate and contemporaneous schedule information, and improved communication.

The proposed methodology depicted in this paper is the initial step of an on-going research project. In the future, the applicability this methodology is planned to be tested on real cases by using action research methodology and its advantages/disadvantages will be tried to be evaluated by conducting interviews with construction professionals. It is also believed that development of a tool that facilitates the implementation of the methodology can increase its applicability. Utilization of such a tool can help recording the constraint analysis and delay registers of projects, and it may be used for assessment and minimization of delays in forthcoming projects.

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