A Delay Liquidated Damages (DLD) Mitigation Model based on Earned Schedule (ES) and Earned Value Management System (EVMS) Concepts

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Abstract

After a slowdown in growth following COVID-19, the global engineering, procurement, and construction (EPC) market has been recovering and experiencing sustained growth since 2021. Nevertheless, the profit margins in the global EPC plant industry continue to decline. This study proposes the earned schedule-delay liquidated damages (ES-DLD) model that integrates the ES concept into the earned value management system (EVMS) to manage project schedules and DLD risks. The model was developed and tested using the project data from the Korean 'P' construction company. The result of applying the model to a single critical path of the Hanoi project was to shorten 12 days, saving $450K compared to the total DLD of $3.6M. Ten days of acceleration were found to be optimal in assessing multiple critical paths, reducing the potential loss by $746K among the total DLD of $3.6M. The model is expected to contribute to lowering DLD risks by accurately predicting project schedule delays through quantitative forecasting during the project execution.

Keywords –

Engineering, procurement, and construction (EPC); ES-DLD Mitigation Model; Delay Liquidated Damages (DLD); Earned Value Management System (EVMS); Earned Schedule (ES)

1 Introduction

The global Engineering, Procurement, and Construction (EPC) market temporarily experienced a decline in growth due to the impact of COVID-19. However, it has been recovering since 2021, and sustained growth is anticipated until 2030 with a projected compound annual growth rate (CAGR) of 5.5% [1].

Nevertheless, despite this overall positive trend, major global EPC players have consistently faced losses since the oil price collapse in 2014. According to KPMG, a global consulting firm, only 25% of EPC projects met their original deadlines within the past 36 months, and merely 31% of these projects adhered to their budgets during the same period [2]. Despite market growth, EPC companies faced stagnant profits due to delay liquidated damages (DLD) and challenges in managing schedule risks [3].

The key drivers of project losses are attributed to two factors: 1) expensive construction acceleration and 2) significant DLD. These delays negatively impact the owner's critical path (CP) and project success. Critical path means the longest path when each construction activity is connected. Therefore, a delay in this path negatively affects the entire construction period. This schedule management form is called the critical path method (CPM). EPC contractors must apply accurate schedule delay prediction and advanced project management techniques.

When the construction schedule is delayed, the contractor is obliged to refund the client for any damages caused, called DLD [3]. DLD is calculated by multiplying the contract amount, delayed schedule, and DLD Rate, as shown in Equation (1). This value cannot exceed the result of multiplying Contract Amount by Cap.

$$DLD = Contract\ Amount \times Delay\ Schedule \times DLD\ Rate \quad (1)$$

This study aims to predict construction delays despite budget and resource constraints during the construction phase and support project managers in their decision-making process. The authors proposed an DLD mitigation model by integrating the concept of earned schedule (ES) into the earned value management system (EVMS), naming it the ES-DLD mitigation model. This model is aimed at managing project schedule delays and DLD risks.

The ES concept considers DLD, acceleration costs, and construction productivity to output construction delay and EVMS schedule data, which is converted into time units to improve the accuracy of delay prediction [4].

2 Literature Review

The authors reviewed the prior research in three categories: scheduling models for predicting delays, improving schedule management by optimizing EVMS, and automation tools and techniques.

Kim et al. [5] and Narbaev et al. [6] applied an ES concept to earned value management (EVM) to understand the schedule performance of a project better. Kim et al. [7] developed the DECRIS model for EPC contractors to mitigate risk by examining the adequacy of engineering resources and predicting construction costs and schedule performance. Kim and Lee [8] analyzed the project status regarding cost and schedule by completing the detailed design developed according to the front-end loading theory. Their findings are still relevant as a build-on point towards preventing cost and schedule overrun.

The second category was to improve the construction schedule management by enhancing the function of EVMS. Pascual et al. [9] proposed the enhanced-EVM model, which can detect delayed and advanced projects by converting time into monetary units. Aramali et al. [10] provided a holistic and up-to-date literature review after reviewing 160 publications related to EVM and EVMS over the past decade. In recent literature, "forecasting/prediction" accounted for largest share, followed by "application of EVMS". Avlijaš [11] provided a state-of-science review and critical analysis of the EVM technique by integrating statistical analysis and Monte Carlo simulation.

The third category concerns automation tools and techniques for EVM and EVMS. In recent years, various studies have been conducted using artificial intelligence (AI) technology for schedule management through EVMS. Wauters and Vanhoucke [12] introduced five AI methods for predicting the final duration of a project and then evaluated their performance in comparison to EVM methods. Acebes et al. [13] proposed a stochastic earned duration methodology (SEDM) for monitoring and controlling stochastic projects by applying earned duration management (EDM), and compared SEDM and SEVM through a case study on actual residential house structural work. Nagendra and Rafi [14] analyzed various applications of AI to identify the optimal domains for applying AI in the construction industry.

Despite the above analysis, there were no research cases on an approach that directly links DLD mitigation and EVMS. This study proposes a model integrating EVMS and ES concept to predict DLD delays occurring in EPC projects. Building upon Kim and Lee's research [8], the authors developed a decision model for schedule acceleration for each activity.

3 Research Process

This study consists of three stages: 1) data collection, 2) modelling, and 3) model testing.

Section 4 introduced the data for this study. Section 5 explained a detailed ES-DLD mitigation model developed through this study. The authors explain the theoretical background and development procedure for the ES-DLD mitigation model applying the ES concept to EVMS. In addition, the detailed mechanisms of option model 1 (CP is 1) and option model 2 (CP is n), which are options of the ES-DLD mitigation model, were explained. In Section 5, the authors tested ES-DLD mitigation model using actual project data, and the expected DLD was estimated in case of delay. Figure 1 schematically shows the model development process of this study.

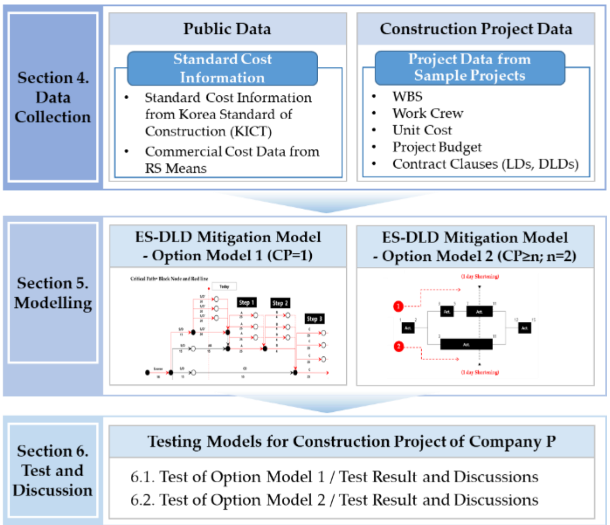

Figure 1. The model development procedure

4 Data Collection

The study used public data such as Korean construction standards and general data from RS Means. The authors also collected the actual EPC project schedule data from P Construction Company in South Korea.

The unit cost information for each assigned work crew was collected through two public datasets. The first was the 2020 Korean Construction Standard [15], organized by the Korea Institute of Construction Technology (KICT) and released yearly. The second was RS Means in the United States [16]. Both datasets were applied to construct the scenario of each working group.

The data required for the construction acceleration assessment was based on the 'A' project executed in Hanoi, Vietnam, undertaken by the 'P' construction company. The test was implemented with EPC coal-fired power plant project data from Company H, Korea's construction management company. The authors used Work Breakdown Structure (WBS), work crew, budget, the unit price of the work crew, planned value, and earned value information to shorten the project schedule from 'P' company.

5 Modelling

5.1 Integrating ES and EVMS

The authors applied the ES concept to EVMS. The ES is used to overcome the prediction of the time concept in terms of cost, a limitation of EVMS, thus improving the model's accuracy [4].

The ES outputs the planned value (PV) corresponding to the last month (L) and the earned value (EV) corresponding to the current time (AT). Figure 2 shows the EV-L curve in grey and PV-AT in black. At a chosen AT, there is an associated EV and PV. The month delta between these two points is shown in Figure 2 as the horizontal blue dotted line. The month value for each point is shown as a vertical yellow dotted line and a blue dotted line. The month duration between these two points is the I value, also shown as SV_T in Figure 2, a day concept. The derived ES values provide the schedule performance and check for construction delay. For example, if the L value is six and the I value is 0.52, the ES value is 6.52 months. Thus, the earned value duration is 6.52 months, or it is done in 6.52 months' worth of work. If the project has a current L of 7 (ex., started at the beginning of the year and assessed at the end of July), the project has a -0.48 month delay. Figure 2 shows the ES principle and its calculation examples.

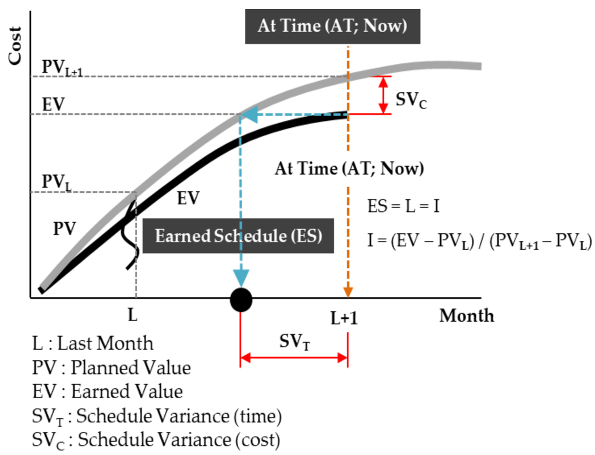

Figure 2. Incorporating ES concept in EVMS

5.2 Developing the ES-DLD Mitigation Model

Through this study, the authors developed an ES-DLD mitigation model, a DLD mitigation model that combines EVMS and ES concept.

First, project managers estimate the schedule delay through EVMS with the ES concept, described in Figure 2. If the construction schedule is ahead of schedule on time, no further analysis is required, and the construction continues according to the schedule. However, if a schedule delay has occurred, the analysis proceeds through the ES-DLD mitigation model. The project manager chooses either Option Model 1 or Option Model 2 based on the number of critical paths. If there is one critical path, select Option Model 1; if not, choose Option Model 2. These models are described below in Section 4.3.1.

The simulation DLD/day and accelerated cost/day (or extra budget/day) are. If the value of DLD per day is less than the average daily shortened costs, the decision to pay DLD is supported. Alternatively, if the DLD per day is larger than the cost to accelerate, schedule acceleration is the supported decision. In case of delayed compensation due to failure to shorten, the provision of credit loss provision supports decision-making.

5.2.1 Option Model 1 (CP=1)

In this study, Option Model 1 is the case where the number of CPs is one. Option Model 1 shortens one CP step by step. Reduction priority is based on the cost reduction per day. The shortening scope of the construction activity is based on the available budget and the maximum number of days. The second shortened activity is shortened based on the remaining budget after the first curtailed activity.

Shown in Table 1 is the input data acquired from P Company Construction of the unit cost of the work crew, execution productivity, and daily work volume of one work crew for each construction activity.

Table 1. Construction activity information used in the scenario

Items	Information on Construction Activity (Ex. Earthwork)
Unit	m3
The total number of work crews available for procurement	40 Groups
1 work crew unit price (daytime)	$150
1 work crew unit price (3hr nighttime, holiday)	$84
1 work crew unit price (8hr nighttime, holiday)	$225
Execution productivity (daytime)	70 %

Execution productivity (nighttime, holiday)	53%
Planned value of 1 work crew (daytime)	$2,000
Planned value of 1 work crew with execution productivity (daytime)	$1,400
Planned value of 1 work crew with execution productivity (3hr nighttime)	$394
Planned value of 1 work crew with execution productivity (daytime+ 3hr nighttime)	$1,794
Planned value of 1 work crew with execution productivity (daytime+ 11hr nighttime)	$2,844
Limiting work crew	10 Groups

Based on the input data, the authors calculate the construction period in progress and the remaining construction period and estimate the number of work crews to be put into the planned value in the planned schedule delay scenario. The estimated number of work crews is based on project estimations, shown in Table 2 for this publication. The estimated delayed days and the maximum daily workload based on the work amount are calculated for each working period. The Equation (2) calculates the expected delay date, and the maximum possible reduction is calculated by the Equation (3):

$$\text{Remaining Construction Period-(Remaining Work} \div \text{ 1day Planning Workload)} \quad (2)$$

$$\text{Remaining Construction Period} \times \text{(Maximum Daily Workload} \div \text{1day Planning Workload)-1} \quad (3)$$

The following process calculates the shortened construction period if construction acceleration is chosen. Divide the number of concurrent activities by the total work performed through the changed construction plan. Then divide by the daily work and subtract 1. Subtracting 1 determines the number of days shortened, except for the daytime work. Next, the total result is calculated by listing the possible reduction dates and the cost of the construction schedule, as represented by the following Equation (4).

$$(\sum \text{Construction Workload} \div \text{Number of Concurrent Activities)} \div \text{1day Planning Workload-1} \quad (4)$$

Based on the information of one work crew, it is possible to calculate the construction period delay prediction, the remaining work amount, and the maximum work amount. The cost of the work amount is compared to the DLD to support a decision of acceleration or DLD payment.

5.2.1 Option Model 2 (CP≥n; n=2)

In the case of Option Model 2, the number of CPs is two or more, and the model applies to a plurality of instances. If shortening is performed only in one critical path among several critical paths, no shortening is made in the remaining critical paths, as shown in Figure 3. Therefore, no change occurs in the overall construction schedule. All critical paths will need to be reduced to reduce project duration.

In Option Model 2, the project manager (user) enters the schedule data. In Option Model 2, execution productivity is expressed as labor productivity per work area per unit area. (Equation (5))

$$\text{Planned Value} \div \text{Work Area} \quad (5)$$

As shown in Equation (5), if the planned value assigned to the activity is divided by the construction area to which the activity belongs, it can be considered as the labor productivity of the working group per unit area. The premise is not to apply 100% of the planned productivity of the entire activity as in Option Model 1 when establishing Planned Value. Next, the authors find the delay in each activity. Option model 2, unlike 1, looks for deferred activities and derives low priority. The reason for targeting only delayed activities is that there is a risk of being unable to shorten construction due to uncontrollable events such as force majeure. Equation (6) allows Option Model 2 to find the construction work done until the cut-off time.

$$\text{Maximum Workload Per Day x Period since construction began x SPI} \quad (6)$$

The current work speed is reflected when calculating the construction work because current working speeds indirectly reflect the workforce's capabilities and working environment. SPI is an index defined by the Project Management Body of Knowledge (PMBOK) divided by EV and PV [17]. (Equation (7))

$$\text{Remaining Construction Workload} \div \text{Maximum Workload Per Day} \quad (7)$$

In Equation (7), Option Model 2 predicts the completion time from the remaining construction workload based on the maximum workload per day of the current work crew.

Figure 3 presents a principle for shortening that is applicable in multiple cases.

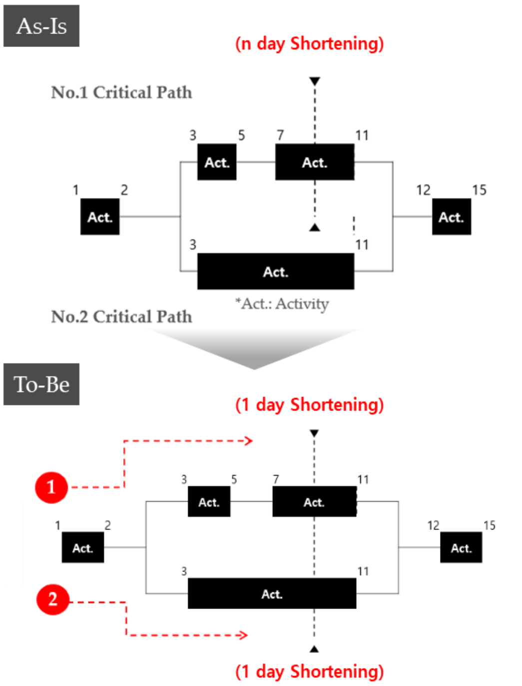

Figure 3. The Developed Principle of Shortening of Multiple Critical Paths

6 Model Test and Discussion

The results of applying the ES-DLD mitigation model to the actual project of P Construction Company are shown below. The test was divided into option models 1 and 2.

6.1 Option Model 1

In the sample project, 72 days are delayed at 75 months into the project, with a cut-off date of April 1, 2021. The developed ES-DLD mitigation model was used to simulate 72 days and derive the results.

In running the ES-DLD mitigation model, the authors assumed there were no problems in procurement and set the total number of work crews to 40. The marginal work crew is introduced by a threshold value that may not reduce the execution productivity of each work crew when additional work crews are added to shorten the construction period. In Equations (2) to (4), the estimated delay days and the maximum daily workload are calculated for each working period of the sample project. The results are shown in Table 2.

Table 2. Applying delay scenario to existing construction plans

Items	Information on construction activity
Total construction period	25 Days
Completed construction period	10 Days
Remaining construction period	15 Days
The number of work crews to the planned value (workload)	5 Groups
Planned value	$175,000
execution productivity	50%
Completed planned value	$35,000
Remaining planned value	$140,000
Estimated delayed day	-25 Days
Maximum daily workload with limited work crews	$7,000
Maximum daily workload with limiting work crews (3hr nighttime)	$1,969
Maximum daily workload with limiting work crews (8hr nighttime)	$5,250

The project manager analyses the case study based on delay forecast, remaining work, etc. One of the hallmarks of Option Model 1 is that it tells project managers (users) which activities the ES-DLD mitigation model wants to shorten among those that have not come from now. In other words, it does not only consider activities that have delayed the construction schedule. The next step is to reduce the selected construction activity based on the available budget. In the scenario, the construction activity effectively increased the working time (8 hours at night) and shortened the work without adding a working group. The maximum daily workload is then 9,750. If the remaining construction period is three days, the maximum possible reduction date is 12 days.

In this scenario, 12 of the 72 expected total delays were reduced. In short, it costs $149,863, and the remaining budget is $100,137. The late compensation was set at $50,000 per day. The 60-day delay in the construction period led to a delay compensation, with a total cost of $3,149,863. If not shortened, this results in a savings of $450,137 over $3,600,000. Through this simulation, the validity of the quick decision can be ensured. In addition, it is of great significance to support decision-making by analyzing the DLD settled after the end of the project.

6.2 Option Model 2

This section presents the results of applying the ES-DLD mitigation model to Option Model 2. Table 3 depicts the delay forecasts based on existing construction plan data, using Equations (5) to (7).

Table 3. Applying delay scenario to existing construction plans

Items	Information on

	construction activity
Work crews	3 Group
1 Work crew unit price	\$1,803/Daytime
Cost per day	\$5,408/Daytime
Labor productivity of 1 work crew per 1m2	40 Unit/Day
Work area	100 m2
Maximum workload per day	12,000 Unit/Day
Remaining construction workload	225,600 Unit
Planned workload	360,000 Unit
Total construction period	30 Day
Completion construction workload	134,400 Unit
The period since construction began	14 Day
Performance index (SPI=EV/PV) against the plan	80 %
Remaining construction period	16 Day
Estimating the period required to complete the construction	19 Day
Delay forecast	-3 Day

The project manager changes the work crew and working hours to develop a new construction plan. At this time, the minimum difference between the target construction work and the construction execution work for 1-day reduction is selected. Here, the shortening success means when the estimated work volume due to the new construction plan exceeds the target work volume for reducing the day. Divide activities with main duplicate processes by the one-day reduction in cost. Through this, it derives the cost of lowering the actual day. Equation (8) finds the activity priority for the catch-up plan in Cost Analysis.

$$\textit{Cost for 1-day reduction} \div \textit{Number of Concurrent (Overlap) Activities in Critical Path} \tag{8}$$

In Equation (8), activity with duplicate critical paths is divided by the number of identical critical paths from the 1-day reduction cost to find the actual reduction cost. Based on this value, priorities for catch-up are derived. When the calculation is completed, information on the activity to be shortened and the budget required is provided. Finally, with a scenario of \$50,000 DLD, the shortened construction period is ten days, and the cost of shortening the construction period is \$2,853,602. If the construction period is not shortened, \$746,398 can be saved compared to the full DLD.

7 Conclusions

Inadequate management of construction delays in the early stages of EPC projects leads to DLD issues, excessive resource investments, and cost escalation at the project's completion.This study aims to manage project schedule delays and mitigate DLD risks through the application of the earned value management system (EVMS) integrated model incorporating the concept of earned schedule (ES). As a result, the authors proposed an ES-DLD mitigation model to manage project schedules delays and DLD risks. The ES theory can overcome the limitations of EVMS by converting the cost unit into a time unit when estimating a project's schedule. As a result, it enables highly accurate construction duration predictions depending on the application purpose.

The proposed model is divided into Option Model 1 and Option Model 2 according to the number of critical paths left in the construction stage. The reason for dividing by the number of main processes is because of differences in the shortening model. Also, considering that Option Model 1, which is applied when CP is 1, is near CP when a plurality of main processes are formed during the shortening, the shortening is stopped, and the process proceeds to Option Model 2.

In the result of model test with a case project, the one-day liquidated damage was \$50,000, the budget available to EPC contractors was \$250,000, and the total delay was 72 days. Option Model 1 reduced the simulation by 12 days and \$450,137 compared to the total DLD (\$3.6M). Option Model 2 enabled shorter simulations to save ten days and \$746,398 compared to the total DLD of \$3.6M. These results confirm the developed models' superiority because shortening has not exceeded the total delay compensation.

The ES-DLD mitigation model developed through this study targets the initial execution phases of the EPC projects. The model uses construction information to predict schedule delays and support decision-making. The ES-DLD mitigation model can support project managers in moving beyond experience-based qualitative decision-making to quantitative predictions for project execution. It is expected to contribute to reducing schedule delay risks in EPC projects characterized by complex resource allocation and tight construction schedules.

The limitations and future works of this study are as follows: The validation of the model proposed in this study is based on a single project undertaken by Company P. This raises concerns about the generalizability of the findings. A multi-case study targeting different disciplines and various EPC projects is needed to enhance the broader applicability and robustness of the model. Furthermore, the ES-DLD mitigation model heavily relies on quantitative methods for managing project delays. While such methods offer valuable insights, they have limitations in fully capturing the complexities of real-world projects. There is a need for research into a more comprehensive approach that integrates qualitative factors such as qualitative elements affecting project delays and unforeseen external events. Finally, it is anticipated that applying machine learning technology to enhance the predictive capabilities of the model could strengthen the DLD mitigation effect and expand the actual application scope in the EPC industry.

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