*Journal of Infrastructure, Policy and Development* 2024, 8(11), 8730.
https://doi.org/10.24294/jipd.v8i11.8730

Case Report

# A system dynamics modeling approach for improving engineering, procurement, and construction project performance: A case study

**Nida Fariza Maulanisa, Endang Chumaidiyah*, Iphov Kumala Sriwana**

Industrial Engineering Department, Telkom University, Bandung 40257, Indonesia
*** Corresponding author:** Endang Chumaidiyah, endangchumaidiyah@telkomuniversity.ac.id

**CITATION**

Maulanisa NF, Chumaidiyah E, Sriwana IK. (2024). A system dynamics modeling approach for improving engineering, procurement, and construction project performance: A case study. Journal of Infrastructure, Policy and Development. 8(11): 8730.
https://doi.org/10.24294/jipd.v8i11.8730

**ARTICLE INFO**

Received: 22 August 2024
Accepted: 20 September 2024
Available online: 23 October 2024



**Abstract:** Delay is the leading challenge in completing Engineering, Procurement, and Construction (EPC) projects. Delay can cause excess costs, which reduces company profits. The relationship between subcontractors and the main contractor is a critical factor that can support the success of an EPC project. The problematic financial condition of the main contractor can cause delay in payments to subcontractors. This research will set a model that combines the system dynamics and earned value method to describe the impact of subcontractor advance payments on project performance. The system dynamics method is used to model and analyze the impact of interactions between variables affecting project performance, while the earned value method is applied to quantitatively evaluate project performance and forecast schedule and cost outcomes. These two methods are used complementarily to achieve a holistic understanding of project dynamics and to optimize decision-making. The designed model selects the optimum scenario for project time and costs. The developed model comprises project performance, costs, cash flow, and performance forecasting sub-models. The novelty in this research is a new model for optimizing project implementation time and costs, adding payment rate variables to subcontractors and subcontractor performance rates. The designed model can provide additional information to assist project managers in making decisions.

**Keywords:** cost; delay; forecasting; financial; payment; subcontractor

## 1. Introduction

Delay remains an issue in completing Engineering, Procurement, and Construction (EPC) projects. An EPC project is characterized by high complexity, large scale, long periods, and interrelated variables (Shafiei et al., 2023). The EPC contractor is responsible for completing the project on time and cost (Powmya et al., 2023). An EPC project can be divided into smaller work packages and involve many subcontractors. The selection of subcontractors is crucial since it determines the quality of the project (Mohammadrezaytayebi et al., 2023). The delay problem can be caused by the main contractor's financial difficulties (Sanni-Anibire et al., 2022). The main contractor's financial difficulties can affect the subcontractor's payment schedule. This can disrupt the subcontractor's cash flow plans and impact progress. Decent payment determines the quality of work produced by subcontractors (Martin and Benson, 2021).

Increases in material prices, financial difficulties, payment issues, supply chain processes, effectiveness of resource control, job changes, and job complexity influence delay and cost overrun (Jahan et al., 2022; Kusuma Dewi and Ramadhani, 2023; Susanti, 2020). Lack of project monitoring and control can cause delay (Shrivas and Singla, 2022). Research (Omopariola et al., 2017) shows that a project risk mitigation to prevent cash flow deficit requires contractors to rearrange down payments, monitor cash flow, and avoid fee delays. Research (Dabirian et al., 2021) states that cash flow can be predicted from the bidding stage, resulting in maximum profits for the project. The system dynamics method is applied to determine the impact of prevention and failure costs on construction projects' Cost of Quality (COQ) and analyze design policies (Shafiei et al., 2023). System dynamics can also evaluate project change, error, and rework policies (2019). System dynamics can also be integrated with Building Information Modeling (BIM) to analyze project behavior cycles regarding changes in project scope (Porwal et al., 2023). Research on the financial aspect (Dabirian et al., 2021) is conducted by looking at the influence of monetary policy on project performance and increasing profitability. The two main strategies for achieving project success are resource and subcontractor management and technology adaptation to raise productivity (Powmya et al., 2023). The Lean Construction (LC) method is also applied to construction projects to reduce delay and inefficiencies (Anggraini et al., 2022). Advance payments can increase an organization's effectiveness, competitiveness, and profitability (Omopariola et al., 2022). Earned Value Method (EVM) is recommended as a standard method for measuring the performance of construction projects (Leon et al., 2018).

In previous research, only a few researchers combined system dynamics with EVM. Combining these methods will mutually strengthen the results of project forecasting. A system dynamics will look at the impact of interactions between variables, while EVM is a method that can integrate schedule, cost, and project performance (Omopariola et al., 2017). Creating simulations helps decision-makers to predict project status and determine project monitoring strategies (Shafieezadeh et al., 2019). No research has yet investigated the impact of payments on subcontractors by combining system dynamic methods and EVM. This research will fill this gap by examining the implications of subcontractor payments on project performance forecasting. The timely payment of subcontractors is a critical factor in ensuring the smooth progress of Engineering, Procurement, and Construction (EPC) projects. Payment delays can disrupt subcontractor performance, causing project bottlenecks, increased costs, and schedule overruns. Although previous research has examined these issues separately—using either System Dynamics or Earned Value Method (EVM)—the absence of a combined approach limits our ability to fully understand the systemic impact of payment delays across all project variables. Addressing this gap is urgent, as it will provide a more comprehensive understanding of how payment delays affect project outcomes, thereby enabling more effective decision-making and project management strategies.

By integrating System Dynamics with EVM, this study provides a more comprehensive model that captures the dynamic feedback loops between subcontractor payments and project performance. System Dynamics excels at modeling interactions between variables, offering insights into how these dynamics influence performance, while EVM tracks real-time cost and schedule variances. This combined approach enhances decision-making by predicting how different payment scenarios impact cost and time, allowing for more informed resource allocation and project momentum. The integrated model allows for scenario planning and real-time adjustments, helping to proactively mitigate delays and control costs. Addressing this gap is essential for optimizing EPC project management, improving efficiency, and increasing profitability.

The decision variable studied is the influence of receiving project advances from work owners and advance payments to subcontractors. The decision support system monitors project implementation so potential problems can be detected early and mitigated. Decision support system applications can also help management make decisions and provide an overview of the impact of decisions. The decision support system is expected to increase the success of project implementation so that it can increase customer satisfaction and other stakeholders and improve company performance. The novelty in this research lies in the development of a model by adding new variables in the system dynamics, namely payment rates to subcontractors and subcontractor performance rates, as well as calculating Estimate to Complete (ETC), Estimate at Completion (EAC), schedule variance, and cost variance. These variables are added based on the amount of work the subcontractor completes. The built decision support system model can help management make decisions more easily, quickly, and precisely to improve company performance and increase customer satisfaction and other stakeholders.

## 2. Materials and methods

### 2.1. Variable identification

In the initial research, questionnaires were distributed to 11 (eleven) project managers who implemented projects from 2019 to 2022. The questionnaire designed to capture the perceptions of project managers regarding key factors in project performance, particularly those related to subcontractor management and payment issues. The questionnaire used a 1 (strongly disagree) to 5 (strongly agree) Likert scale and contained 40 variables that influenced delay and increases in project implementation costs. The variables were prepared based on historical data on project risk management from 2018 to 2022. To ensure the validity and reliability of the questionnaire, a two-step process was employed. First, content validity was assessed through expert judgment. Several experts in the field were consulted to evaluate the relevance, clarity, and comprehensiveness of the items in the questionnaire. Their feedback ensured that the questions effectively captured the key variables related to subcontractor performance and project management. Second, to test the reliability of the instrument, Cronbach's Alpha was used. The reliability analysis yielded a Cronbach's Alpha value of 0.966, which is significantly higher than the commonly accepted threshold of 0.70 for good internal consistency (Cortina, 1993). This suggests that the questions on the Likert scale consistently measure the intended construct, providing confidence in the stability and accuracy of the results. The combination of expert validation and a high Cronbach's Alpha value confirms that the questionnaire is both valid and reliable for use in this research.

Two variables were considered to have the most influence on project schedules and costs: limited company cash and delay in the arrival of goods. These two variables had a score of 53 and an average of 4.82. The process continued with interviews to get to the root of the problems in project implementation. Information was discovered that late payments to the subcontractor caused a delay in the arrival of goods, so the subcontractor stopped the work. The delay in payments to subcontractors was also caused by limited company cash. One of the company policies that was implemented required every project to have a positive cash flow.

## 2.2. Case study

Project X is an EPC project with a scope of survey, procurement, installation, integration, and maintenance with a total job load of 100%. This project involves four subcontractors: two provide goods, and the other provides services. The project has a value of IDR 3972.17 million, with a target work duration of 12 months. The main contractor’s limited capital means it is necessary to simulate payments to subcontractors. The value of the down payment paid by the project provider will affect the time and cost of completing the project. Project X is the first stage of a development project to influence the progress of subsequent projects.

## 2.3. System characterization

The model built has five loops: project progress (Shafieezadeh et al., 2019) (Mayo-Alvarez et al., 2022), cash flow (Omopariola et al., 2020), cost realization (Dabirian et al., 2021), project performance (Leon et al., 2018), and performance forecasting (Leon et al., 2018). Project progress is depicted in an S curve, which is the accumulated value of work that has been completed. The cash flow loop describes money in and out to achieve progress. Cost realization is the total expense, including costs of material, service, personnel, bank, and fines if the project is delayed. The loops of project performance and performance forecasting are designed using the EVM method. The model provides an overview of project trends so project managers can make more comprehensive decisions (Oladimeji et al., 2020). This research uses two stages for modeling with the system dynamics method (Bottero et al., 2020). The first stage is the preparation of a Causal Loop Diagram (CLD), a conceptual model in research. CLD describes the causality relationship of variables in positive or negative polarity (Ecem Yildiz et al., 2020). The second stage is designing a Stock Flow Diagram, which changes the conceptual model into a quantitative model (Olivares-Aguila and ElMaraghy, 2021). The model built will be validated through expert judgment and output verification (Ecem Yildiz et al., 2020). Output verification is carried out by manually comparing the formulation results with the calculation of simulation results (Sriwana et al., 2020). Several assumptions are used in creating a system dynamics model to optimize project time and costs:

- There is no delay in payments received by the main contractor;
- No errors and rework occur in project completion;
- Materials are not stored in the warehouse, so they do not incur inventory costs.

## 2.4. Causal loop diagram

The cause-and-effect relationship in Project X is depicted in **Figures 1** and **2**. The realization of Project X’s progress depends on the performance of subcontractors and the accuracy of payment terms (Ahmadisheykhsarmast and Sonmez, 2020; Apbd et al., 2023; Susanti, 2020). The greater the cash-in received, the greater the payment rate to subcontractors. Delay in applying work will influence the fines imposed by the work owner (Hou et al., 2022; Kocakaya et al., 2019). The resulting penalties will increase the costs incurred for project implementation and the cash-out that the company must spend. Fines can also reduce the profit targets that have been set. The work progress is monitored using EVM to predict project completion time and costs. The schedule and cost performance indexes determine schedule conditions and project costs. In contrast, schedule and cost variance indicators forecast project costs (Mayo-Alvarez et al., 2022).

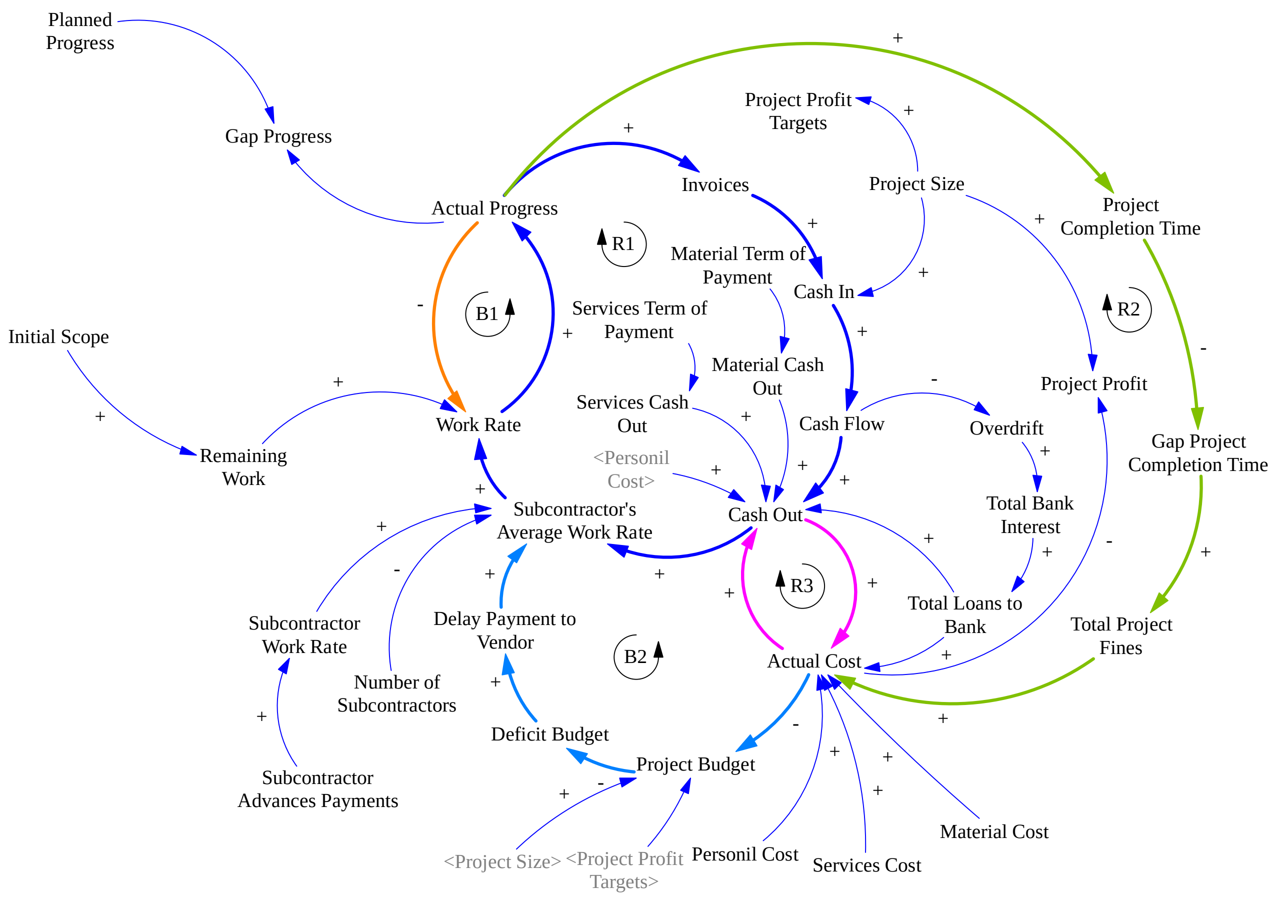



**Figure 1.** Causal loop diagram of project time and cost optimization model.

The time and cost optimization model for Project X in **Figure 1** has three reinforcing and two balancing loops. Loop R1 describes the relationship between project progress and cash flow. The relationship that occurs in Loop R1 is positive and reinforcing. Positive cash flow impacts subcontractor payments on time. The timeliness of payment will influence the average rate of subcontractor work. Loop R2 reinforces and describes the relationship between delay and total cost. If the project has a delay, a daily fine of 5‰ the project value will be imposed. Loop R3 describes the relationship between costs and cash-out. The higher the project costs incurred, the greater the cash-out the project must spend. Loop B1 is balancing, meaning that the work rate will decrease as the realization of progress becomes higher (Shafiei et al., 2023). Loop B2 describes the relationship between the remaining budget and the realization of progress. The larger the budget deficit, the greater the delay in subcontractor payments. Loop B2 has a negative connection and is balancing.

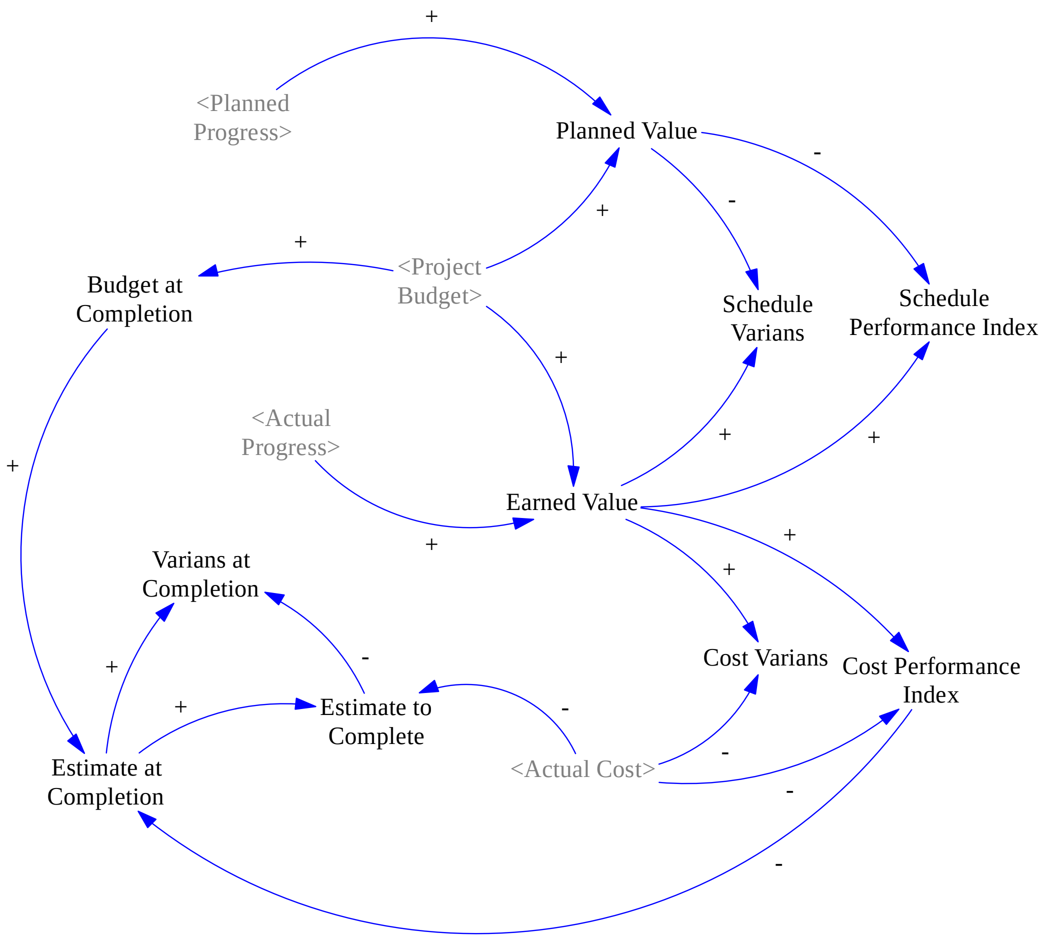



**Figure 2.** Causal loop diagram of earned value method model of project time and cost optimization.

**Figure 2** shows the cause-and-effect relationship in the earned value method. The earned and planned values will influence the schedule performance index and schedule variance. The schedule performance index value is inversely proportional to the value of the project progress plan and directly proportional to the value of project progress realization. The cost performance index and cost variance values are inversely proportional to the project cost realization value and directly proportional to the earned value. Forecasting calculation for project cost is shown by the variables: budget at completion, estimate to complete, estimate at completion, and variance at completion. The project budget determines the budget at completion value. The higher the project budget, the higher the budget at completion. The project cost realization influences the estimate to complete value, and the cost performance index value and budget at completion values influence the estimate at completion.

## 2.5. Stock flow diagram

Simulation modeling is divided into three sub-models: project progress, cost, and forecasting. In **Figure 3**, a stock-flow diagram is prepared to calculate project progress. Project progress is influenced by the total scope prepared during planning. The total scope is the total job load depicted in the project S curve. Project scope is an auxiliary variable type with an initial constant value. The project scope will decrease as the work is completed. The project progress realization is described using a level variable type and is an accumulation of the work rate. Progress realization will be billed to the owner via invoice. The value and time for billing invoices have been agreed upon at the contract's start. The invoice will be cash-in and will be used to work on the following progress. Project monitoring is carried out every month by comparing plans with realization.

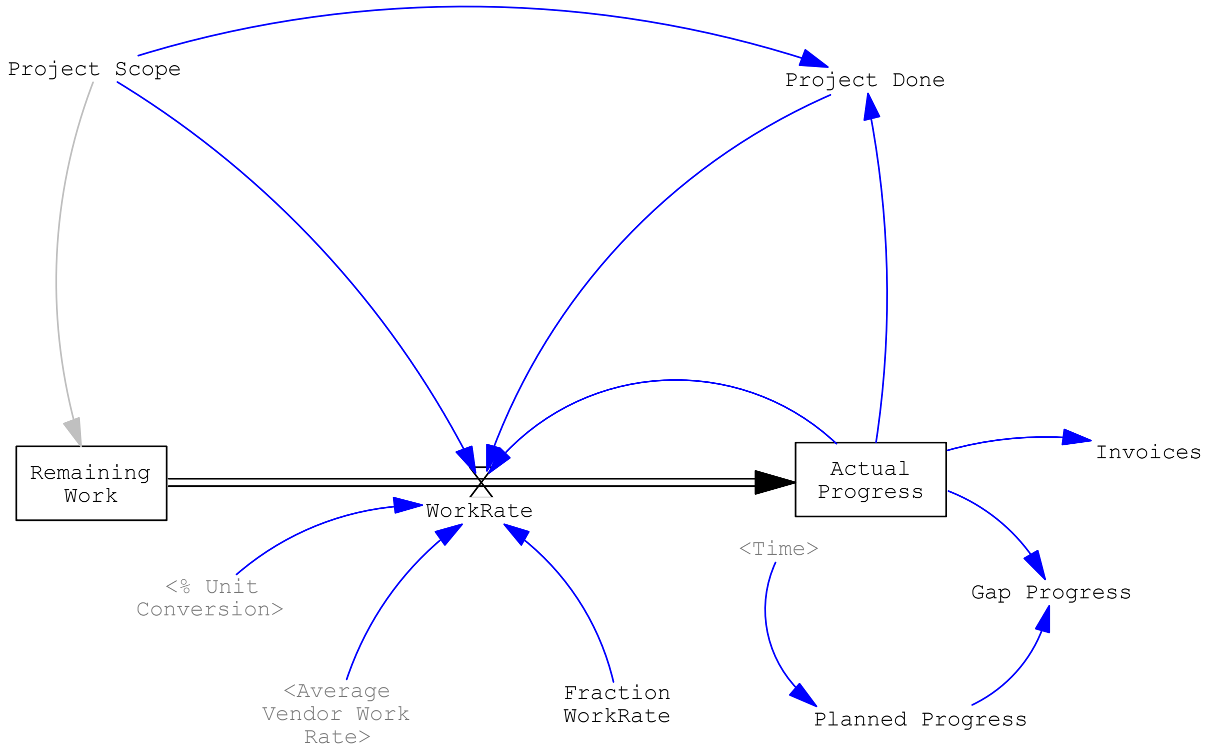



**Figure 3.** Stock flow diagram of actual progress.

**Table 1** shows the simulation formula used in the project progress sub-model. The scenario is to adjust the average subcontractor work rate. The average work rate of subcontractors will influence the overall project work rate. The accumulated work rate will be calculated based on the actual project progress. The remaining work is calculated from the difference between the total scope and the actual progress.

**Table 1.** Project progress sub-model formulation.

| No | Variable | Formula | Definition |
|---|---|---|---|
| 1 | Work rate | = Fraction work rate × (project scope − actual progress) × average subcontractor work rate × actual progress × % unit conversion × % unit conversion | The value of the ability of all resources committed to complete the project progress. |
| 2 | Actual progress | = INTEG (Work rate, 1) | Work that has been completed and approved by the owner. |
| 3 | Remaining work | = Project scope − actual progress | The remaining work remains to be completed by the project team. |

**Figure 4** is a stock-flow diagram designed for calculating project costs. Cost realization accumulates costs for purchasing goods and services, personnel, and project fines. Cost realization will stop collecting when the project is declared

complete. In the cost model, there is a delay criterion; namely, a budget deficit will cause a delay in cash-out payments to subcontractors. **Table 2** shows the cost calculation formulation.

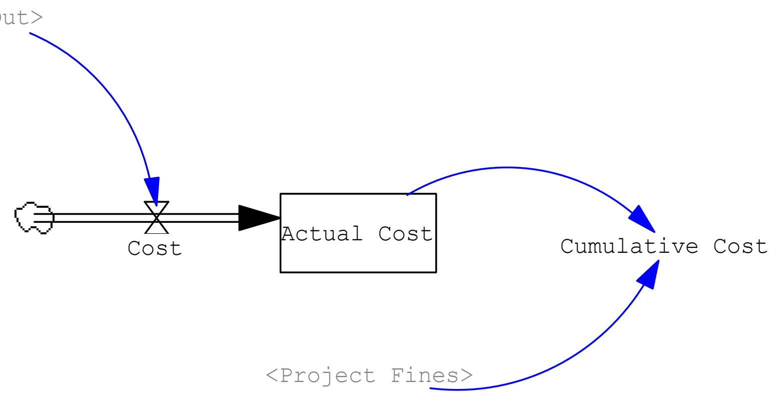
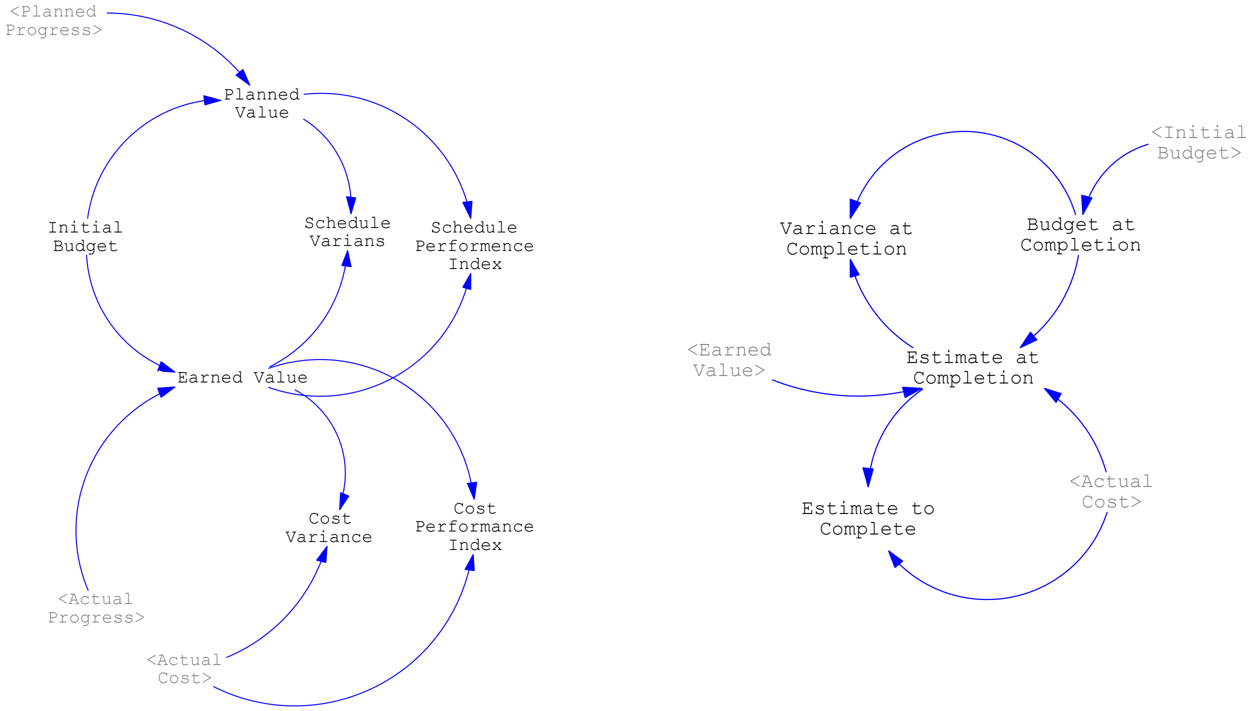



**Figure 4.** Stock flow diagram of project cost.

**Table 2.** Cost sub-model formulation.

| No | Variable | Formula | Definition |
|---|---|---|---|
| 1 | Cost | = Cash out goods 1 + cash out goods 2 + cash out services 1 + cash out services 2 + total personnel costs. | The financial value spent to complete the project. |
| 2 | Actual cost | = INTEG (Cost, 0) | Realization of costs incurred for work performed on an activity during a specific period (operational cost). |
| 3 | Cumulative cost | = Actual cost + project fines | Total operational cost realization and project fines. |




**(a)** Schedule and cost performance **(b)** Estimation for completion

**Figure 5.** Stock flow diagram of project earned value method.

The performance measurement and forecasting sub-models in **Figure 5** are done after obtaining project progress and cost realization. Performance assessment uses the following variables: schedule performance index, cost performance index, schedule variance, and cost variance. This project performance measurement is used to see project trends and can be used to predict performance. Schedule and cost performance indexes are used to measure the efficiency of using time and costs in a project by calculating the ratio of plans and realization. Schedule and cost variances measure the difference between realization and plan values. Performance forecasting is calculated using the variables: budget at completion, estimate at completion, variance at completion, and estimate to complete. The budget at completion is the total budget to complete the project, and the estimate at completion is the total cost required to complete the project based on current performance. Estimate at completion estimates the costs needed to complete the project. Variance at completion provides information on the calculated difference between plan and realization costs. All variables in performance measurement and forecasting use the auxiliary variable type.

## 2.6. Verification and validation

The verification techniques used in this research are animation and Absolute Percentage Error (APE). The animation verification technique looks at the graphical results of the simulation results with actual project data. APE measures the absolute difference between predicted and actual values. This method uses absolute values, so it does not pay attention to polarity or direction of difference. The lower the absolute value percentage, the more accurate the forecasting data. The accuracy scale used for forecasting in this research is based on Lewis's research, as in **Table 3** (Montaño Moreno et al., 2013). Validation aims to see that the simulation results are by the actual system. The validation technique used is fast validation, which involves five experts. The experts involved have 4–13 years of project experience.

**Table 3.** APE method forecasting error scale.

| No | Error score | Scale |
|---|---|---|
| 1 | <10% | Highly accurate |
| 2 | 10%–20% | Good forecast |
| 3 | 21%–50% | Reasonable forecast |
| 4 | >51% | Inaccurate forecast |

## 2.7. Scenario of decision

Scenario development is a simulation stage to obtain alternative decisions for optimizing project implementation. The simulation is done with two scenarios and three conditions. Scenario 1 is that the project does not have capital and requires a bank loan. Scenario 2 is that the project has initial capital worth 20% of the project value. These two scenarios are combined with three conditions: payment to subcontractors. Payment to subcontractors is divided into advance payment and payment terms. Changes in payment values will see their impact on model behavior. **Table 4** shows the alternative payment decision scenarios.

**Table 4.** Alternative decision-making scenarios.

| **Description** | | **Advance payment** | **Term I** | **Term II** | **Term III** |
|---|---|---|---|---|---|
| Cash in | Scenario 1 | 0% | 40% | 24% | 36% |
| | Scenario 2 | 20% | 40% | 24% | 16% |
| Term of payment | Condition 1 | 20% | 40% | 40% | - |
| | Condition 2 | 30% | 40% | 30% | - |
| | Condition 3 | 40% | 40% | 20% | - |

## 3. Results and discussion

### 3.1. Result

**Table 5** shows the results of the system dynamics model verification. The variables Actual Progress, Actual Cost, Cash In, and Cash Flow have an error of <10%, so the forecasting is highly accurate. The calculations of the schedule performance index and estimate at completion have an error of 10% to 20%, so the forecasting accuracy is considered good. The indicators of the cost performance index and estimate to complete have accuracy within the reasonable forecast. All variables can be used in project performance forecasting based on the verification results.

**Table 5.** Time and project optimization model verification results.

| **No** | **Variable** | **Average percentage error** | **Scale** |
|---|---|---|---|
| 1 | Actual progress | 9.77% | Highly accurate |
| 2 | Actual cost | 8.94% | Highly accurate |
| 3 | Cash in | 8.15% | Highly accurate |
| 4 | Cash out | 0.00% | Highly accurate |
| 5 | Schedule performance index | 16.22% | Good forecast |
| 6 | Cost performance index | 29.55% | Reasonable forecast |
| 7 | Estimate at completion | 14.35% | Good forecast |
| 8 | Estimate to complete | 23.96% | Reasonable forecast |

**Table 6.** Simulation results of decision-making.

| **Variable** | **Scenario 1** | | | **Scenario 2** | | |
|---|---|---|---|---|---|---|
| | **Condition** | | | **Condition** | | |
| | **1** | **2** | **3** | **1** | **2** | **3** |
| Project completion time (month) | 12.6 | 11.1 | 10.6 | 12.6 | 11.1 | 10.6 |
| Total cost (million IDR) | 3420.57 | 3120.65 | 2876.2 | 3259.73 | 2986.89 | 2750.84 |
| Project fines (million IDR) | 367.73 | - | - | 367.73 | - | - |
| Profit (million IDR) | 183.87 | 851.51 | 1,095.97 | 344.70 | 985.28 | 1221.33 |
| Estimate to complete (ETC) | 12.23 | 2.82 | 1.57 | 12.23 | 2.82 | 1.57 |
| Estimate at completion (EAC) | 3414.92 | 3399.69 | 3394.53 | 3266.64 | 3250.18 | 3244.8 |
| Schedule variants | −12.23 | −2.82 | −1.57 | −12.23 | −2.82 | −1.57 |
| Cost variants | 467.56 | 433.35 | 383.33 | 172.131 | 188.59 | 193.97 |

Based on the simulation results presented in **Table 6**, a detailed comparison of each scenario reveals that Condition 3 in both Scenario 1 and Scenario 2 is the most effective in optimizing project performance. In terms of project completion time, Condition 3 reduces the duration to 10.6 months, which is notably shorter than the 12.6 months observed in Condition 1. This demonstrates that Condition 3 provides the best time efficiency, which is critical for minimizing project delays and ensuring timely delivery. Moreover, Condition 3 also offers the most significant cost savings, with total costs of 2876.2 million IDR in Scenario 1 and 2750.84 million IDR in Scenario 2. These figures are considerably lower than the costs associated with Condition 1, making Condition 3 the most cost-effective option. The avoidance of project fines in Conditions 2 and 3 further strengthens the case for these conditions, as they mitigate the risk of incurring additional expenses due to delays.

Finally, the profitability analysis highlights that Condition 3 yields the highest profits, with 1095.97 million IDR in Scenario 1 and 1221.33 million IDR in Scenario 2. This increase in profit is a direct result of the reduced completion time and lower costs. Additionally, the Estimate to Complete (ETC) and Estimate at Completion (EAC) are minimized in Condition 3, reflecting the efficient use of resources and cost management. Overall, Scenario 2-Condition 3 is the most optimal scenario in project implementation is to receive a project advance of 20% and down payments to subcontractors of 40%. The scenario resulted in a project simulation completed in 10.6 months, a cost of IDR 2750.84 million, and a profit of IDR 1221.33 million. The condition of paying a down payment of 0% to subcontractors will result in the project being late for 0.6 months and a fine of IDR 367.73 million. With an advance payment to subcontractors of 20%, the project does not have delay, but the costs incurred are more significant.

To build on these findings, prior studies emphasize the critical role that early payments to subcontractors play in preventing delays and reducing financial strain in construction projects (Bolton et al., 2022). Delayed payments have been shown to negatively affect cash flow, which can result in project setbacks and elevated costs due to liquidity issues (Haron and Arazmi, 2020). Research conducted in both the UK and Malaysia highlights that payment delays remain a recurring problem, often causing financial instability and lower performance among subcontractors. In this study, providing down payments, particularly the 40% to subcontractors as seen in Condition 3, effectively alleviates financial pressures, supporting steady cash flow and contributing to shorter project timelines and reduced costs. The outcomes from Scenario 2 illustrate how early financial distribution can improve resource management and streamline processes, leading to more favorable project results.

Moreover, the significance of these findings becomes clearer when comparing other payment strategies, such as the 0% or 20% advances to subcontractors, which led to either delays or increased costs. These observations are consistent with previous studies that stress the importance of cash flow stability in achieving project success (Haron and Arazmi, 2020). Prompt payment releases, as evidenced in Condition 3, not only lower the likelihood of fines resulting from delays but also enhance profitability by improving cost control and resource efficiency. By integrating such early payment methods, projects can better avoid the financial bottlenecks that often lead to delays, which is also supported by research from

Trinidad and Tobago, where timely interim payments were found to be essential in maintaining project progress (Peters et al., 2019).

### 3.2. Practical application

Based on the findings of this study, several actionable recommendations can be made for project managers and policymakers in the construction industry. Firstly, to mitigate the risk of project delays and cost overruns, project owners should consider implementing a structured advance payment system. This study has shown that providing a 20% advance payment to main contractors and a 40% down payment to subcontractors can significantly reduce cash flow bottlenecks, leading to improved project timelines and profitability. To further enhance project performance, future projects should consider implementing staggered payment systems that align with project milestones, as this would allow better synchronization of cash flow with project progress. Such an approach could be especially beneficial in industries with tight deadlines, like infrastructure or public sector projects.

Furthermore, contractors should also explore the integration of digital contract management tools, such as smart contracts, to automate payment releases based on pre-agreed milestones. This can further ensure timely payments and minimize disputes that often cause delays. Finally, policymakers may need to revisit existing payment legislation and contractual solution to provide stronger legal frameworks that enforce prompt payments in EPC projects.

The following suggestions can be considered in optimizing project time and costs:

- use past performance data for project forecasting;
- consider the smallest cost if the project completion time is faster than planned;
- increase work rate to reduce gaps if schedule variance is negative;
- review the project cash flow if the cost variance is negative;
- use a real time project monitoring to accelerated decision-making;
- increasing the down payment to subcontractors can help prevent cash flow disruptions and project delays.

### 3.3. Model limitation

The system dynamics model will be more useful when an intervention is introduced to illustrate the impact of decision-making. In this study, the intervention is represented by changes in the cash-inflow scenarios and terms of payment, as illustrated in **Table 4**. This model cannot describe all factors that arise during the project cycle. The forecasting process is based on documented project data and does not consider unexpected factors such as errors, rework, weather changes, exchange rate fluctuations, etc. The model built can provide insight to the project team as additional information in making decisions.

### 3.4. Implication

The implication resulting from this research is to obtain a new model for optimizing time and costs. The model is designed by adding variable payment rates to subcontractors and subcontractor performance rates. Decision support systems can help project managers make better decisions regarding management, project scheduling, and appropriate resource allocation. Controlling down payments can also help project managers to control project cash flow and avoid financial disruption. The decision support system can also help companies see real-time project performance and support accelerated decision-making. This supports companies to optimize project schedules and costs so that they can improve company performance.

## 4. Conclusion

Delay is a significant challenge in completing EPC projects. Delay in completion often causes losses to the company. Subcontractors have an essential role in completing projects. Delay in payments to subcontractors can slow down progress. This research designs a model to describe the impact of subcontractor down payments on project performance. The model is designed by combining the system dynamics method and the earned value method to provide a more comprehensive understanding of how payment delays affect project outcomes. The system can be used to select the most optimal project time and cost scenario. The most optimal scenario for Project X is scenario 2 and condition 3. Scenario 2 is when the project has the capital to run the project by receiving a 20% down payment. Condition 3 is a 40% down payment to the subcontractor. Scenario 2 and condition 3 result in a project simulation completed in 10.6 months, a cost of IDR 2750.84 million, and a profit of IDR 1221.33 million. The most unfavorable scenario is condition 1 since the project has delay and is subject to fines. Based on the research results, to avoid problems with delay, it is best to conduct forecasting analysis and performance monitoring periodically, considering the value of down payments to subcontractors.

Further research can be continued by analyzing the work breakdown structure. Identification is helpful for the simulation to focus on critical project activities. Another limitation of this research is that the data on the number of personnel is only based on project plan data. Future research can use real data of total personnel and analyze the productivity of each personnel. This research can be used to monitor projects to reduce the risk of delay so that further research can combine performance measurement analysis with the addition of critical path method analysis.

**Author contributions:** Conceptualization, NFM and EC; methodology, NFM, EC and IKS; software, NFM; validation, NFM and IKS; formal analysis, NFM; investigation, NFM; resources, NFM; data curation, NFM; writing—original draft preparation, NFM; writing—review and editing, EC and IKS; visualization, NFM; supervision, EC and IKS; project administration, NFM; funding acquisition, EC. All authors have read and agreed to the published version of the manuscript.

**Conflict of interest:** The authors declare no conflict of interest.

## References

Ahmadisheykhsarmast, S., & Sonmez, R. (2020). A smart contract system for security of payment of construction contracts. Automation in Construction, 120, 103401. https://doi.org/10.1016/j.autcon.2020.103401

Anggraini, W., Harpito, Siska, M., & Novitri, D. (2022). Implementation of Lean Construction to Eliminate Waste: A Case Study

Construction Project in Indonesia. Jurnal Teknik Industri, 23(1), 1–16. https://doi.org/10.22219/jtiumm.vol23.no1.1-16

Ansari, R. (2019). Dynamic Simulation Model for Project Change-Management Policies: Engineering Project Case. J. Constr. Eng. Manage, 145(7). https://doi.org/10.1061/(ASCE)

Apbd, A., Anggaran, D., Tunggal, T., & Mengurangi, U. (2023). Determination of delay factors in implementation time apbn/apbd projects with single year budget to reduce claims (Indonesian). Available online: https://journal.unj.ac.id/unj/index.php/menara/article/view/35422/15268 (accessed on 3 May 2024).

Bolton, S., Wedawatta, G., Wanigarathna, N., & Malalgoda, C. (2022). Late Payment to Subcontractors in the Construction Industry. Journal of Legal Affairs and Dispute Resolution in Engineering and Construction, 14(4). https://doi.org/10.1061/(asce)la.1943-4170.0000552

Bottero, M., Datola, G., & De Angelis, E. (2020). A System Dynamics Model and Analytic Network Process: An Integrated Approach to Investigate Urban Resilience. Land, 9(8), 242. https://doi.org/10.3390/land9080242

Cortina, J. M. (1993). What is coefficient alpha? An examination of theory and applications. Journal of Applied Psychology, 78(1), 98–104. https://doi.org/10.1037/0021-9010.78.1.98

Dabirian, S., Ahmadi, M., & Abbaspour, S. (2021). Analyzing the impact of financial policies on construction projects performance using system dynamics. Engineering, Construction and Architectural Management, 30(3), 1201–1221. https://doi.org/10.1108/ecam-05-2021-0431

Ecem Yildiz, A., Dikmen, I., & Talat Birgonul, M. (2020). Using System Dynamics for Strategic Performance Management in Construction. Journal of Management in Engineering, 36(2). https://doi.org/10.1061/(asce)me.1943-5479.0000744

Haron, R. C., & Arazmi, A. L. H. (2020). Late payment issues of subcontractors in Malaysian construction industry. Planning Malaysia, 18(1), 78–91. https://doi.org/10.21837/pm.v18i11.711

Hou, C., Lu, M., Deng, T., et al. (2022). Penalizing Lateness or Sharing Cost: Project Outsourcing via Request-for-Quote. SSRN Electronic Journal. https://doi.org/10.2139/ssrn.4252328

Jahan, S., Khan, K., Thaheem, M. J., et al. (2022). Modeling Profitability-Influencing Risk Factors for Construction Projects: A System Dynamics Approach. Buildings, 12(6), 701. https://doi.org/10.3390/buildings12060701

Kocakaya, M. N., Namlı, E., & Işıkdağ, Ü. (2019). Building Information Management (BIM), A New Approach to Project Management. Journal of Sustainable Construction Materials and Technologies, 4(1), 323–332. https://doi.org/10.29187/jscmt.2019.36

Kusuma Dewi, S., & Ramadhani, Z. S. (2023). An Integrated ANP and MARCOS for Green Supplier Selection: A Case Study on Contruction Industry. Jurnal Teknik Industri, 23(2), 133–148. https://doi.org/10.22219/jtiumm.vol23.no2.133-148

Leon, H., Osman, H., Georgy, M., & Elsaid, M. (2018). System Dynamics Approach for Forecasting Performance of Construction Projects. Journal of Management in Engineering, 34(1), 04017049. https://doi.org/10.1061/(asce)me.1943-5479.0000575

Martin, L., & Benson, L. (2021). Relationship quality in construction projects: A subcontractor perspective of principal contractor relationships. International Journal of Project Management, 39(6), 633–645. https://doi.org/10.1016/j.ijproman.2021.05.002

Mayo-Alvarez, L., Alvarez-Risco, A., Del-Aguila-Arcentales, S., et al. (2022). A Systematic Review of Earned Value Management Methods for Monitoring and Control of Project Schedule Performance: An AHP Approach. Sustainability, 14(22), 15259. https://doi.org/10.3390/su142215259

Mohammadrezaytayebi, S., Sebt, M. H., & Afshar, M. R. (2023). Introducing a system dynamic–based model of quality estimation for construction industry subcontractors' works. International Journal of Construction Management, 23(4), 586–595. https://doi.org/10.1080/15623599.2021.1899592

Montaño Moreno, J. J., Palmer Pol, A., & Sesé Abad, A. (2013). Using the R-MAPE index as a resistant measure of forecast accuracy. Psicothema, 25(4), 500–506. https://doi.org/10.7334/psicothema2013.23

Oladimeji, O. O., Keathley-Herring, H., & Cross, J. A. (2020). System dynamics applications in performance measurement research. International Journal of Productivity and Performance Management, 69(7), 1541–1578. https://doi.org/10.1108/ijppm-12-2018-0453

Olivares-Aguila, J., & ElMaraghy, W. (2021). System dynamics modelling for supply chain disruptions. International Journal of Production Research, 59(6), 1757–1775. https://doi.org/10.1080/00207543.2020.1725171

Omopariola, E. D., Lowe, G. J., & Windapo., A. (2017). The effects of construction delays on project delivery in Nigerian construction industry. International Journal of Project Management, 20(8), 593–599. https://doi.org/10.1016/S0263-7863(02)00028-5

Omopariola, E. D., Windapo, A., Edwards, D. J., et al. (2020). Contractors' perceptions of the effects of cash flow on construction projects. Journal of Engineering, Design and Technology, 18(2), 308–325. https://doi.org/10.1108/jedt-04-2019-0099

Omopariola, E. D., Windapo, A. O., Edwards, D. J., & Chileshe, N. (2022). Attributes and impact of advance payment system on cash flow, project and organisational performance. Journal of Financial Management of Property and Construction, 27(3), 306–322. https://doi.org/10.1108/JFMPC-03-2021-0022

Peters, E., Subar, K., & Martin, H. (2019). Late Payment and Nonpayment within the Construction Industry: Causes, Effects, and Solutions. Journal of Legal Affairs and Dispute Resolution in Engineering and Construction, 11(3), 1–12. https://doi.org/10.1061/(asce)la.1943-4170.0000314

Porwal, A., Parsamehr, M., Szostopal, D., et al. (2023). The integration of building information modeling (BIM) and system dynamic modeling to minimize construction waste generation from change orders. International Journal of Construction Management, 23(1), 156–166. https://doi.org/10.1080/15623599.2020.1854930

Powmya, A., Nazirah, Z. A., & Nurul Sakina, M. A. (2023). Determination of Contractor Strategies in Delivering Construction Projects in Oman. Journal of Construction in Developing Countries, 28(1), 293–316. https://doi.org/10.21315/jcdc-12-21-0203

Sanni-Anibire, M. O., Mohamad Zin, R., & Olatunji, S. O. (2022). Causes of delay in the global construction industry: a meta analytical review. International Journal of Construction Management, 22(8), 1395–1407. https://doi.org/10.1080/15623599.2020.1716132

Shafieezadeh, M., Kalantar Hormozi, M., Hassannayebi, E., et al. (2019). A system dynamics simulation model to evaluate project planning policies. International Journal of Modelling and Simulation, 40(3), 201–216. https://doi.org/10.1080/02286203.2019.1596779

Shafiei, I., Eshtehardian, E., Nasirzadeh, F., et al. (2023). Dynamic modeling to reduce the cost of quality in construction projects. International Journal of Construction Management, 23(1), 24–37. https://doi.org/10.1080/15623599.2020.1845425

Shrivas, A., & Singla, H. K. (2022). Analysis of interaction among the factors affecting delay in construction projects using interpretive structural modelling approach. International Journal of Construction Management, 22(8), 1455–1463. https://doi.org/10.1080/15623599.2020.1728486

Sriwana, I. K., Erni, N., & Abdullah, R. (2020). Design of Purple Sweet Potato Raw Material Inventory Model in Purple Potato Chips Production with Dynamic System Simulation Method (Spanish). Jurnal Teknologi Industri Pertanian, 30(2), 167–179. https://doi.org/10.24961/j.tek.ind.pert.2020.30.2.167

Susanti, R. (2020). Cost overrun and time delay of construction project in Indonesia. Journal of Physics: Conference Series, 1444(1), 012050. https://doi.org/10.1088/1742-6596/1444/1/012050