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Reinventing Formulas for Construction Project Delay Index Due to Management and Production

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Abstract

The objective of this study is to construct a precise formula for the management and production delay indicators that are integrated into Ms. Project's dashboard. Two simulation techniques, such as the manual formula computation and calculation integrated into the Ms. Project dashboard, were employed. Due to management and the production team's tardiness, the data were obtained through trial-and-error methods. Excel was used to analyze the data, and Ms. Project was used to enter the calculations. The research showed that the Ms. Project dashboard formula gave more detailed information about the construction project, including: (1) contract value; (2) actual progress value during monitoring; (3) value of plan progress during monitoring; (4) progress deviation; (5) cause of delay; and (6) management delay index and production delay index. The novelty of this study is that project delays have traditionally been held against the production party (contractor), whereas implementation delays have never been taken against the management party (consultant). However, using this method makes it evident who is responsible for a project delay, whether it comes from management (a consultant) or the manufacturing side (a contractor).

Keywords: Formula; Index of Delay; Management; Production.

1. Introduction

Due to the additional funds required for rescheduling, a construction project completion delay invariably results in a loss for the construction service provider. Due to the construction project's delay, the contractor's, consultant's, and owner's activities would be hampered, which would further result in a loss [1, 2]. The contractor team suffers a loss due to the requirement to pay a lateness fine, which results in cost overruns [3–5]. The consultant misses the chance to take on other projects in the interim, and the owner is unable to utilize the construction site on schedule. Many large-scale projects regularly encounter delays as a result of various causes, including the design documentation, payment to contractors, and change of working premises [6–8]. Failure to adhere to the payment term that the owner and contractor previously agreed upon constitutes lateness in contractor payments [8, 9]. The failure of the contractor to provide complete shop drawings, bills of quantities, invoices, tax returns, and progress reports is the reason for the payment delay [10–12].

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The aforementioned research points out that the project owner is the main reason for tardiness. Furthermore, earlier research by de Araujo et al. (2017), Martens and Vanchoucke (2018), and Lee & Won (2021) [13–15] found additional variables contributing to construction project delays, such as inadequate planning, poor consultant performance, ineffective management, owner-related problems, bureaucracy, and subpar contracts. According to several studies by Korhonen (2020), Liu et al. (2022), and Chou et al. (2023) [16–18], the owner's actions have three main implications for the duration of a construction project: delaying payments to subcontractors, interfering with the contractor's cash flow, and having trouble obtaining the necessary materials. In the meantime, a complicated payment system, missing paperwork, and subpar labor are the main reasons why owners fail to pay their contractors. Numerous studies by Zahid et al. (2019), Wang et al. (2020), Arditi et al. (2017), and Chen et al. (2014) [19–22] also noted that owner late payment has a significant impact on other project lateness characteristics. As a result, a project's delay can be due to a variety of factors, but in actuality, the contractor should be held accountable for the construction project's lateness. This occurs as a result of the contract's lack of legally binding provisions governing sanctions for other stakeholders [23–25].

According to Indonesian Presidential Degree No. 16, issued in 2018, regarding government procurement of goods or services, Article 56 states that (1) the commitment-making officer (CMO) will give the service provider the chance to finish the job if they are unable to do so until the contract expires but the CMO believes they are capable of doing so; (2) the opportunity given to the service provider to finish the job depends on how quickly the contract is completed. The presidential decree makes it quite clear that only the service provider (the production team) is subject to the fine. According to the rule, even though multiple studies have shown that the owner and consultant might occasionally contribute to project delays, the penalties should only be placed on the contractor. Therefore, the weight of the delay penalty index serves as the foundation for calculating the amount of delay penalty that must be borne by each party (Management and Production) for the delay in the implementation of a building project. The cutting-edge aspect of this research is its ability to estimate the amount of late penalty costs that must be carried by management or production based on the weight of the delay index determined using a formula integrated with Ms. Project. As a result, the goal of this study is to develop a method to calculate the index of delay fines for each stakeholder participating in the construction project.

2. Material and Methods

Ex-post facto techniques and interviews were implemented in this study in order to find an accurate formula for calculating the index of a construction project delay from management and production. Therefore, we conducted an ex-post facto survey of 20 construction project scheduling experts and conducted interviews with scheduling experts who worked as construction project supervising consultants. The results of a questionnaire and interviews with two construction project scheduling experts were analyzed to identify the causes and warning signs of project delays. The simulation technique is then continued when a formula for the indicators is constructed based on the findings. During the experiment, we employed two simulation techniques: manual simulation and simulation utilizing a formula included in Ms. Project's dashboard. The management and production teams' perspectives on project lateness were used to obtain the data through a process of trial and error. The data was then manually evaluated with Ms. Excel and manually analyzed using the method built within the Ms. Project dashboard. The formula underwent a feasibility test using the TELOS approach based on the benchmark criteria and an operating feasibility assessment using the PIECES framework before the data analysis. [26–28]. The following sub-sections go into further detail about the feature that was assessed using the TELOS approach and the PIECES framework.

2.1. Technical Aspect

If it received a high enough score, the technical component of the formula included in Ms. Project was deemed to be practical. Table 1 lists the technical feasibility requirements on a scale of 1 to 10.

Table 1. Feasibility criteria for technical aspect

No.	Criteria	Description	
		Sufficient	Not Sufficient
1	Utilizing simple technologies	8 – 10	3 – 6
2	Extremely flexible software	8 – 10	3 – 6
3	Robust technology	8 – 10	3 – 6

2.2. Economic Aspect

According to a scale of 1 to 10, the economic element was evaluated based on funding availability, as indicated in Table 2. This is because the study's sole objective is to create a mathematical model that will be used by the software to calculate the project lateness index using the management and production components. The ultimate mathematical model was added to the Ms. Project. Therefore, the analysis of the payback period, Return on Investment (ROI), Net Present Value (NPV), and Internal Rate of Return (IRR) was not necessary.

Table 2. Feasibility criteria for funding

Criteria	Description	
	Available	Not available
Source of funding	8 - 10	3 – 6

2.3. Legal Aspect

The feasibility of the legal element was evaluated using the criteria presented in Table 3, with a 1-10 range score.

Table 3. Feasibility Criteria for Legal Aspect

No.	Criteria	Description	
		Sufficient	Not Sufficient
1	Legality from the Director General of Vocational of the Ministry of Education and Culture	8 – 10	3 - 6
2	Legality from the Institution of research and Community Service of Universitas Negeri Medan	8 – 10	3 – 6
3	Legality from PT. Bentareka Cipta Consulting Group Jakarta	8 – 10	3 – 6

2.4. Operation Aspect

The feasibility test on the operation element was carried out using the PIECES framework, as is shown in Table 4.

Table 4. Feasibility Criteria for Operation Aspect

No.	Criteria		Description	
			Sufficient	Not Sufficient
1	Performance (P)	Speed of software performance	8 – 10	3 – 6
2	Information (I)	Accurate and dynamic information	8 – 10	3 – 6
3	Economy (E)	Efficiency of operational cost	8 – 10	3 – 6
4	Control (C)	Security level of software	8 – 10	3 – 6
5	Efficiency (E)	Software optimum suitability with the company goals	8 – 10	3 – 6
6	Service (S)	Provision of easy-to-understand service for user	8 – 10	3 – 6

2.5. Schedule Aspect

In the schedule aspect, we evaluated the formula integration into the software using the criteria of schedule presented in Table 5.

Table 5. Feasibility Criteria for Schedule Aspect

No.	Criteria	Description	
		Sufficient	Insufficient
1	Utilizing ethical time management	8 – 10	3 - 6
2	Time management that is appropriate for the planning	8 – 10	3 – 6
3	Synchronization of the time with the schedule	8 – 10	3 – 6

The TELOS method's average score was derived by adding together the scores for each factor and dividing the total by the number of feasibility factors, as shown in Equation 1.

$$TELOS\ Score = \frac{TS+ES+LS+OS+SS}{5} \tag{1}$$

Where: TS = Technical Score; ES = Economic Score; LS = Legal Score; OS = Operational Score; SS = Schedule Score.

The software formula integration was ultimately found to be possible if the final average score was greater than 6. However, the created method built into the program was considered to be unworkable if the score obtained is less than 6 points.

3. Results and Discussion

3.1. Formula for Estimating the Delay of Construction Project

In this study, the formula was built using indications that accurately reflected the actual field scenario. These metrics were discovered during a construction management field interview. The job's starting time, the actual start date, the planned start date, the actual completion time, the interlude after the work has begun, the inclusion of the actual field condition in the work schedule, the presence of free float, and the critical path deviation from the planned schedule make up the final set of indicators. Additionally, a mathematical model was created using the indicators to determine the index of delay brought on by the management and production teams. The formulas for delay induced by management time consist of formulas for: (1) delay from management factors; (2) delay time; and (3) index of delay from the management aspect, as presented in Equations 2 to 4.

3.1.1. Delays from Management Factors

$$DMF = (S1\text{-}S2) + \text{free float} - \text{pending} \tag{2}$$

Where:

DMF = Delay from management factors;

S1= Work starting time;

S2= Actual starting date.

Note:

(1) If DMF < 0, then the delay of the construction project is caused by the management;

(2) If DMF > 0, then there is no delay in construction induced by the management.

Delay Time

$$DT = DMF + DPF \tag{3}$$

Where:

DT= delay time;

DMF= Delay from the management factors;

DPF = Delay from the production factors.

Index of Management Delay (MDI)

$$MDI = \frac{DT}{DMF} \tag{4}$$

Where:

DT= delay time;

DMF= delay from the management factors.

In addition, the formulas for delay caused by production factors consist of formulas for (1) delay from production factors, (2) delay time, and (3) index of a delay from the production team, as shown in Equations 5 to 8.

3.1.2. Delay Due to the Production Factor (DPF)

$$DPF = (D1 - D2) + MD\ (if\ MD > 0) \tag{5}$$

$$DPF = (D2 - D1) + MD\ (if\ MD < 0) \tag{6}$$

Where:

DPF = Delay from production factor;

D1 = Planned project completion time;

D2 = Actual time for completing the project;

DM = Management delay.

Notes:

(1) If DPF < 0, then the delay of the construction project is caused by the production factor;

(2) If DPF > 0, then there is no delay in the construction project caused by the production factors.

Delay Time

$$DT = DMF + DPF \tag{7}$$

Where:

DT= Delay time;

DMF= Delay from the management factors;

DPF = Delay from the production factors.

Index of Production Delay (PDI)

$$PDI = \frac{DT}{DPF} \tag{8}$$

Where:

DT= Delay time;

DPF= Delay caused by the production factors.

The results of estimation using the above formulas are interpreted using criteria presented in Table 6.

Table 6. Interpretation criteria for calculation results

PKM	PKP	Description
≥ zero	≥ zero	There is no delay in the project caused by management and production factors
Negative	≥ zero	The project delay is caused by the management factors The project delay is not caused by the production factor The project delay corresponds to the score of lateness from the management factor
≥ zero	Negative	The project delay is caused by the production factors The project delay is not caused by the management factor The project delay corresponds to the score of lateness from the production factor
Negative	Negative	The project delay is caused by the management factor The production factor also contributes to the delay The project delay is caused by both management and production factors

3.2. Feasibility Test for Formula Integrated into Ms. Project Dashboard

The results of the feasibility test using the TELOS method for the formula integrated into Ms. Project are summarized in Tables 7–11. Table 7 presents the average obtained score of 8.50 > 6.00, indicating that the developed formula integrated into the Ms. Project has fulfilled the technical criteria.

Table 7. Summary of results for technical criteria

No.	Criteria	Score	Description
1	Easy-to-use technology	8.33	Sufficient
2	Highly developable software	8.67	Sufficient
3	Stable technology	8.33	Sufficient
4	Applicable software for construction project	8.67	Sufficient
	Average score	**8.50**	**Sufficient**

In this study, the economic criteria were only investigated based on the availability of funding sources from the company for internet quota financing since the computer and internet network have been provided by the company. Thus, the estimation of the Return of Investment (ROI) and Payback Period are not included.

Table 8. Results for economic criteria

No.	Criteria	Score	Description
1	Availability of source of funding	7.33	Sufficient
	Average Score	**7.33**	**Sufficient**

According to Table 8, the obtained average result is 7.33 > 6.00, indicating that the economic criteria have been fulfilled.

Table 9. Results for legal criteria

No.	Criteria	Score	Description
1	Legality from Director General Vocation of the Ministry of Education and Culture	8.67	Sufficient
2	Legality from the Institution of research and Community Service of Universitas Negeri Medan	8.33	Sufficient
3	Legality from PT. Bentareka Cipta Consulting Group Jakarta	9.00	Sufficient
	Average Score	**8.67**	**Sufficient**

As is shown in Table 9, the obtained score in the legal criteria is 8.67 > 6.00, signifying that the formula integrated into Ms. Project has fulfilled the legal criteria.

Table 10. Results in operation criteria

No.	Indicators	Score	Description
1	Speed of software performance	7.67	Sufficient
2	Accurate and dynamic information	8.33	Sufficient
3	Efficiency of operational cost	8.67	Sufficient
4	Security level of software	8.33	Sufficient
5	Software optimum suitability with the company goals	8.33	Sufficient
6	Provision of easy-to-understand service for user	8.00	Sufficient
7	Speed of software performance	8.33	Sufficient
8	The need for the design of a formula to detect the delay index	8.67	Sufficient
	Average	**8.29**	**Sufficient**

The data in Table 10 shows that we obtained an 8.29 > 6.00 score for the operation criteria. Thus, the formula integrated into Ms. Project has fulfilled the operation criteria.

Table 11. Results for schedule criteria

No.	Criteria	Score	Description
1	Using fair time management	8.33	Sufficient
2	Using time management suitable with the planning	8.33	Sufficient
3	Conformity between the time and scheduling	8.33	Sufficient
4	Obtain information rapidly	9.00	Sufficient
	Average Score	**8.50**	**Sufficient**

Table 11 shows that the obtained 8.50 > 6.00 score, signifying that the formula integrated into the Ms. Project has fulfilled the schedule criteria. Further, we also calculated the average scores for all criteria, resulting in an 8.26 score. Therefore, the formulated formula for estimating the index of a delay from management and production aspects is highly feasible and accurate.

3.3. The First Simulation: Manual Formula Calculation using Ms. Excel

The formula was applied to several instances of building project lateness caused by management and production issues in the first simulation. According to management, delays occur when work starts but is still within the free float, when it starts but is outside the free float, when it starts but stops in the middle of the work, when it starts but stops outside the free float, when it starts but stops during the work but is still within the free float, and when it starts but stops in the middle of the work and (7) The work starts following the free float and is terminated in the middle of it. The simulation was carried out for those seven examples using the accepted formula, and the simulation results are displayed in Table 12.

Table 12. Summary of simulation for delay of construction project formula caused by management team

Case	Plan			Actual Data			KM	KP	Results				
							(S1-S2) + slack - pending	(D1-D2) + (KM Minus =0)	DMF	DPF	DT	MDI	PDI
1	S1=1	D1-4	FF=3	S2=3	P=0	D2=4	1	1	0	0	0	0	0
2	S1=1	D1-4	FF=3	S2=5	P=0	D2=4	-1	0	(-)	0	-1	1	0
3	S1=1	D1-4	FF=3	S2=3	P=1	D2=4	0	0	0	0	0	0	0
4	S1=1	D1-4	FF=3	S2=3	P=2	D2=4	-1	0	(-)	0	-1	-1	0
5	S1=1	D1-4	FF=3	S2=1	P=2	D2=4	0	0	0	0	0	0	0
6	S1=1	D1=4	FF=3	S2=1	P=4	D2=4	-1	0	-1	0	-1	-1	0
7	S1=1	D1=4	FF=3	S2=5	P=2	D2=4	-3	0	(-)	0	-3	-3	0

In order to account for the production team's role in the construction project's lateness, we also ran simulations in four different scenarios. First off, labor doesn't begin with any production; rather, it builds over a few days, lengthening the period while continuing to occur inside the free float. Second, productivity increases after a few days, extending the time beyond the free float. Third, low productivity results in longer workdays while keeping free float. Fourth, low duration improves working duration after free float. Table 13 shows the outcomes of applying the algorithm to estimate those four situations.

Table 13. Summary of simulation results for construction project delay formula caused by production team

Cases	Plan			Actual Data			KM	KP	Results				
							(S1-S2) + slack -pending	(D1-D2) + (KM Minus =0)	DMF	DPF	DT	MDI	PDI
1	S1=1	D1-4	FF=3	S2=1	P=0	D2=6	3	1	0	(+)	0	0	0
2	S1=1	D1-4	FF=3	S2=1	P=0	D2=8	3	-1	0	-1	-1	0	0
3	S1=1	D1-4	FF=3	S2=1	P=0	D2=6	3	1	(+)	(+)	0	0	0
4	S1=1	D1-4	FF=3	S2=1	P=0	D2=8	3	-1	(+)	(-)	-1	0	1

Both the management and the production teams might be responsible for lateness during the construction project. In light of this, we also ran a simulation of how the management and production teams contributed to construction project delays. In the first scenario, the management team begins the task after its scheduled start time but while it is still in the free float, and the output is higher than expected. Second, the management team begins the job after it should have, exceeding the free float and producing little in the process, lengthening the project's duration and causing it to finish late. Third, the management team starts the project later than expected but is still in free float, and there are breaks throughout the project, thus productivity exceeds expectations. The algorithm was used to simulate those four scenarios, and the outcomes are shown in Table 14.

Table 14. Summary of simulation results for construction project delay formula caused by both management and production aspects

Case	Plan			Actual Data			KM	KP	Results				
							(S1-S2) + slack -pending	(D1-D2) + (KM Minus =0)	DMF	DPF	DT	MDI	PDI
1	S1=1	D1-4	FF=3	S2=3	P=0	D2=5	(+)	-1	+	-	-1	0	-1
2	S1=1	D1-4	FF=3	S2=4	P=0	D2=5	-1	-1	(-)	(-)	-2	0.5	0.5
3	S1=1	D1-4	FF=3	S2=3	P=1	D2=5	0	-1	0	-1	-1	0	-1
4	S1=1	D1-4	FF=3	S2=4	P=2	D2=5	-2	-1	(-)	(-)	-3	0.67	0.33

3.4. The Second Simulation: Calculation Using Formula Integrated with Ms. Project Dashboard

The management and production-related formulas for construction project delays were incorporated into Ms. Project. The simulation employing these integrated formulas also made use of indications from the management and production aspects, as well as indicators from both of these aspects. Figure 1 displays the outcomes that were acquired from the dashboard display.

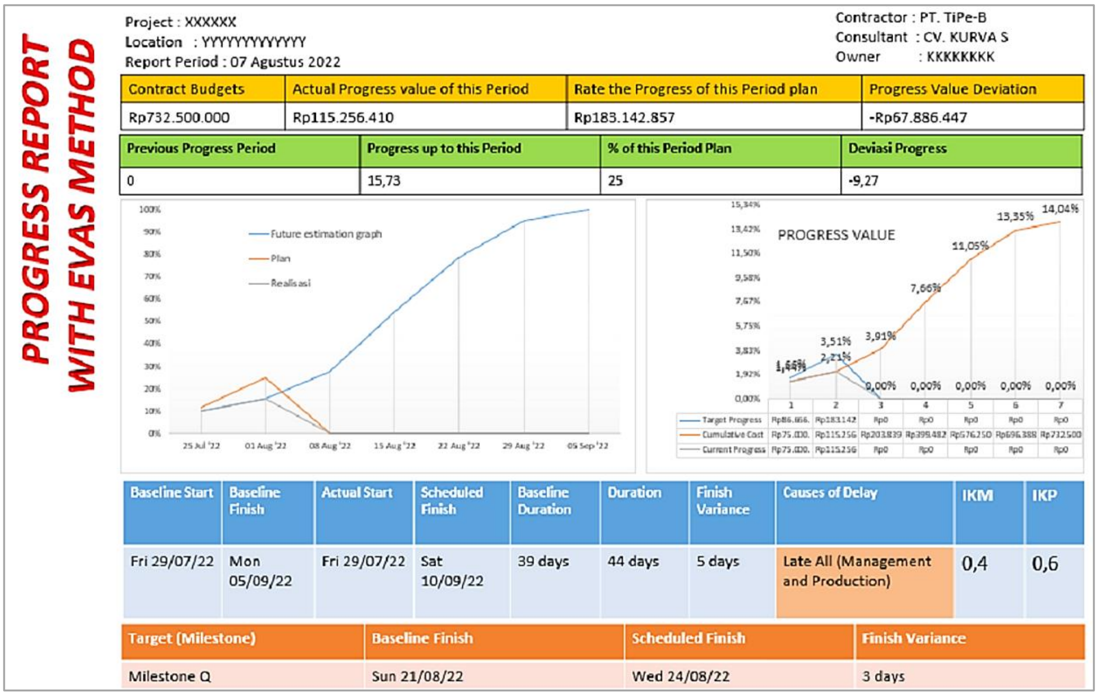

Figure 1. Prototype of construction project lateness due to management and production aspects

Figure 1 shows the more thorough outcomes of the computation utilizing the formulas included in Ms. Project's dashboard. The outcomes comprise the contract value, actual progress during the monitoring, expected progress during the monitoring, deviation of progress, causes of project lateness, as well as the indices of project lateness resulting from management and production factors. Based on the aforementioned research findings, it is clear that the formula used in this study can determine the amount of fines that management (consultants) and production parties (contractors) are required to pay based on the weight of the project delay index obtained from using a formula that is integrated with Ms. Project. The novelty of our research is that the production party (contractor) has always been held accountable for project delays, while the management party (consultant) has never been penalized for implementation delays. However, with this formula, the party accountable for a project delay is clearly identified, regardless of whether it originates from management (a consultant) or the production party (contractor). Additionally, this formula gives the total amount of fines that will be paid depending on the weight determined by calculations made using the formula discovered through this study.

4. Discussion

Based on the results of the formula simulation carried out and the resulting prototype on the dashboard design, which provides information, namely: (1) contract value; (2) actual progress value when reviewed; (3) assess the progress of the plan when it is reviewed; (4) progress value deviation; (5) causes of delays; and (6) MDI and PDI. The value of the contract functions against the value of MDI and PDI to determine the value of late fines as stipulated in Presidential Regulation Number 16 of 2018 concerning Procurement of Government Goods/Services Article 79, Paragraph 4, stipulated by the Commitment Making Officer (CMO) set forth in the contract of 1 0/00 (one per mil) of the contract value or the value of the portion of the contract for each day of delay. The dashboard's plan progress value and actual progress value are used to calculate the difference between the planned work and the actual work [29–31]. The deviance value is accurate. When it's negative, it means the work is behind schedule; when it's zero, it's on schedule; and when it's positive, it means the work has accelerated [32–35].

The variation for the delay, which impacts whether the delay is the result of MDI or PDI, is -9.27 on the dashboard. When work is encountering difficulties, the dashboard also provides information on the causes of those delays. Thus, in a sequence of dependence relationships, the task will be an issue that needs to be addressed right away; if it is on a critical route, it must be finished before; if it is on free float, it will be obvious how much time is left to complete the project [25, 36, 37]. In order for the dashboard to automatically produce an index value for each delay that occurred and how long the delay occurred, the cause of the delay will be tied to the MDI and PDI values, where work activities will reveal what or who is the source of the delay. The dashboard displays a 3-day delay, despite the fact that it was supposed to be finished on August 21, 2022.

The work could only be finished on August 24, 2022, as a result of delays; hence, the score of the MDI was 0.4 and the PDI was 0.6. If the MDI and MDI scores are still 0.4 and 0.6 at the conclusion of the work, the management was responsible for paying a fine of (1 0/00 × IDR. 732,500,000) × 0.4, which is equivalent to IDR 293,500, while the production party is responsible for paying a fine of (1 0/00 × IDR 732,500,000) × 0.6, which is equal to IDR 439,500. It gives details on the amount that each team will have to pay based on a dashboard that was created using a formula for each index. The advantage is that, whereas production-related fines have historically been calculated, management-related fines have never been computed [38–40]. One of the advantages of the Ms. Project display is that details that were previously only partially published have now been disclosed by the project in full, even though production is not solely to blame for the delay.

5. Conclusion

The formula found in this study produces accurate and useful findings that can be used to compute IKM and IKP in a construction project, as can be inferred from the results and discussion. The Ms. Dashboard formula is superior to the manual approach in this case. Project offers more thorough information about how construction project work is being carried out, including: (1) Contract value; (2) Actual progress value when reviewed; (3) Assess the progress of the plan when it is reviewed; (4) Progress Value Deviation; (5) Delay Causes; and 6) Management Delay Index and Production Delay Index. The party accountable for project delays will have a clearer understanding of the fines that will be paid by the management (consultant) or production party (contractor), depending on the index weight generated from the formula found in this study. The findings of this study also directly assist the Commitment Making Officer (CMO) of a government agency in making more equitable judgments on fines for tardy project completion as well as in the advancement of project/construction management knowledge.

6. Declarations

6.1. Author Contributions

Conceptualization, P.L. and N.S.; methodology, P.L., N.S., and S.S.; software, P.L.; validation, P.L., N.S., and S.S.; formal analysis, P.L.; investigation, N.S.; resources, P.L.; data curation, N.S.; writing—original draft preparation, P.L.; writing—review and editing, N.S.; visualization, P.L.; supervision, S.S.; project administration, P.L.; funding acquisition, P.L and N.S. All authors have read and agreed to the published version of the manuscript.

6.2. Data Availability Statement

The data presented in this study are available on request from the corresponding author.

6.3. Funding

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6.5. Institutional Review Board Statement

Not applicable.

6.6. Informed Consent Statement

Not applicable.

6.7. Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

7. References

[1] Olanrewaju, A., Tan, S. Y., & Kwan, L. F. (2017). Roles of Communication on Performance of the Construction Sector. Procedia Engineering, 196, 763–770. doi:10.1016/j.proeng.2017.08.005.

[2] Fashina, A. A., Omar, M. A., Sheikh, A. A., & Fakunle, F. F. (2021). Exploring the significant factors that influence delays in construction projects in Hargeisa. Heliyon, 7(4), 6826. doi:10.1016/j.heliyon.2021.e06826.

[3] Silaghi, F., & Sarkar, S. (2021). Agency problems in public-private partnerships investment projects. European Journal of Operational Research, 290(3), 1174–1191. doi:10.1016/j.ejor.2020.08.050.

[4] Li, F., Xu, Z., & Li, H. (2021). A multi-agent based cooperative approach to decentralized multi-project scheduling and resource allocation. Computers and Industrial Engineering, 151, 106961. doi:10.1016/j.cie.2020.106961.

[5] Modi, K., Lowalekar, H., & Bhatta, N. M. K. (2019). Revolutionizing supply chain management the theory of constraints way: a case study. International Journal of Production Research, 57(11), 3335–3361. doi:10.1080/00207543.2018.1523579.

[6] Muriana, C., & Vizzini, G. (2017). Project risk management: A deterministic quantitative technique for assessment and mitigation. International Journal of Project Management, 35(3), 320–340. doi:10.1016/j.ijproman.2017.01.010.

[7] Guo, S., Xiong, C., & Gong, P. (2018). A real-time control approach based on intelligent video surveillance for violations by construction workers. Journal of Civil Engineering and Management, 24(1), 67–78. doi:10.3846/jcem.2018.301.

[8] Kong, L., Li, H., Luo, H., Ding, L., & Zhang, X. (2018). Sustainable performance of Just-In-Time (JIT) management in time-dependent batch delivery scheduling of precast construction. Journal of Cleaner Production, 193, 684–701. doi:10.1016/j.jclepro.2018.05.037.

[9] Hsu, P. Y., Aurisicchio, M., & Angeloudis, P. (2017). Investigating Schedule Deviation in Construction Projects through Root Cause Analysis. Procedia Computer Science, 121, 732–739. doi:10.1016/j.procs.2017.11.095.

[10] Milička, P., Šůcha, P., Vanhoucke, M., & Maenhout, B. (2022). The bilevel optimisation of a multi-agent project scheduling and staffing problem. European Journal of Operational Research, 296(1), 72–86. doi:10.1016/j.ejor.2021.03.028.

[11] Alsuliman, J. A. (2019). Causes of delay in Saudi public construction projects. Alexandria Engineering Journal, 58(2), 801–808. doi:10.1016/j.aej.2019.07.002.

[12] Liu, M., Le, Y., Hu, Y., Xia, B., Skitmore, M., & Gao, X. (2019). System dynamics modeling for construction management research: Critical review and future trends. Journal of Civil Engineering and Management, 25(8), 730–741. doi:10.3846/jcem.2019.10518.

[13] de Araújo, M. C. B., Alencar, L. H., & de Miranda Mota, C. M. (2017). Project procurement management: A structured literature review. International Journal of Project Management, 35(3), 353–377. doi:10.1016/j.ijproman.2017.01.008.

[14] Martens, A., & Vanhoucke, M. (2018). An empirical validation of the performance of project control tolerance limits. Automation in Construction, 89, 71–85. doi:10.1016/j.autcon.2018.01.002.

[15] Lee, C., & Won, J. (2021). Analysis of construction productivity based on construction duration per floor and per gross area, with identification of influential factors. Journal of Civil Engineering and Management, 27(3), 203–216. doi:10.3846/jcem.2021.14514.

[16] Korhonen, T., Jääskeläinen, A., Laine, T., & Saukkonen, N. (2023). How performance measurement can support achieving success in project-based operations. International Journal of Project Management, 41(1), 102429. doi:10.1016/j.ijproman.2022.11.002.

[17] Liu, Y., You, K., Jiang, Y., Wu, Z., Liu, Z., Peng, G., & Zhou, C. (2022). Multi-objective optimal scheduling of automated construction equipment using non-dominated sorting genetic algorithm (NSGA-III). Automation in Construction, 143, 104587. doi:10.1016/j.autcon.2022.104587.

[18] Chou, J. S., Chen, Y. H., Liu, C. Y., & Chong, W. O. (2023). Quality Management Platform Inspired During Covid-19 Pandemic for Use By Subcontractors in Private Housing Projects. Journal of Civil Engineering and Management, 29(5), 398–417. doi:10.3846/jcem.2023.18687.

[19] Zahid, T., Agha, M. H., & Schmidt, T. (2019). Investigation of surrogate measures of robustness for project scheduling problems. Computers and Industrial Engineering, 129, 220–227. doi:10.1016/j.cie.2019.01.041.

[20] Wang, X., Li, Z., Chen, Q., & Mao, N. (2020). Meta-heuristics for unrelated parallel machines scheduling with random rework to minimize expected total weighted tardiness. Computers and Industrial Engineering, 145, 106505. doi:10.1016/j.cie.2020.106505.

[21] Arditi, D., Nayak, S., & Damci, A. (2017). Effect of organizational culture on delay in construction. International Journal of Project Management, 35(2), 136–147. doi:10.1016/j.ijproman.2016.10.018.

[22] Chen, C. S., Tsui, Y. K., Dzeng, R. J., & Wang, W. C. (2015). Application of project-based change management in construction: A case study. Journal of Civil Engineering and Management, 21(1), 107–118. doi:10.3846/13923730.2013.802712.

[23] Al-Hazim, N., Salem, Z. A., & Ahmad, H. (2017). Delay and Cost Overrun in Infrastructure Projects in Jordan. Procedia Engineering, 182, 18–24. doi:10.1016/j.proeng.2017.03.105.

[24] Yap, J. B. H., Goay, P. L., Woon, Y. B., & Skitmore, M. (2021). Revisiting critical delay factors for construction: Analysing projects in Malaysia. Alexandria Engineering Journal, 60(1), 1717–1729. doi:10.1016/j.aej.2020.11.021.

[25] Kale, S., & Karaman, A. E. (2012). Benchmarking the knowledge management practices of construction firms. Journal of Civil Engineering and Management, 18(3), 335–344. doi:10.3846/13923730.2012.698910.

[26] Ssegawa, J. K., & Muzinda, M. (2021). Feasibility assessment framework (FAF): A systematic and objective approach for assessing the viability of a project. Procedia Computer Science, 181, 377–385. doi:10.1016/j.procs.2021.01.180.

[27] Rashidi, S., Naghshineh, N., Fahim Nia, F., Izadkhah, Y. O., & Saghafi, F. (2022). How feasible is creating a natural disaster information management open-access repository (NDIM-OAR) in Iran? Library and Information Science Research, 44(4), 101203. doi:10.1016/j.lisr.2022.101203.

[28] Ma, G., Wu, M., Wu, Z., & Yang, W. (2021). Single-shot multibox detector- and building information modeling-based quality inspection model for construction projects. Journal of Building Engineering, 38, 102216. doi:10.1016/j.jobe.2021.102216.

[29] Eriksson, P. E., Larsson, J., & Pesämaa, O. (2017). Managing complex projects in the infrastructure sector - A structural equation model for flexibility-focused project management. International Journal of Project Management, 35(8), 1512–1523. doi:10.1016/j.ijproman.2017.08.015.

[30] Xu, X., Wang, J., Li, C. Z., Huang, W., & Xia, N. (2018). Schedule risk analysis of infrastructure projects: A hybrid dynamic approach. Automation in Construction, 95, 20–34. doi:10.1016/j.autcon.2018.07.026.

[31] Demirkesen, S., & Ozorhon, B. (2017). Impact of integration management on construction project management performance. International Journal of Project Management, 35(8), 1639–1654. doi:10.1016/j.ijproman.2017.09.008.

[32] Abduh, M., Soemardi, B. W., & Wirahadikusumah, R. D. (2012). Indonesian construction supply chains cost structure and factors: A case study of two projects. Journal of Civil Engineering and Management, 18(2), 209–216. doi:10.3846/13923730.2012.671259.

[33] Abbasianjahromi, H., Rajaie, H., & Shakeri, E. (2013). A framework for subcontractor selection in the construction industry. Journal of Civil Engineering and Management, 19(2), 158–168. doi:10.3846/13923730.2012.743922.

[34] Daboun, O., Abidin, N. I., Khoso, A. R., Chen, Z. S., Yusof, A. M., & Skibniewski, M. J. (2023). Effect of Relationship Management on Construction Project Success Delivery. Journal of Civil Engineering and Management, 29(5), 372–397. doi:10.3846/jcem.2023.18827.

[35] Olawumi, T. O., & Chan, D. W. M. (2018). Building information modelling and project information management framework for construction projects. Journal of Civil Engineering and Management, 25(1), 53–75. doi:10.3846/jcem.2019.7841.

[36] Ahmad, Z., Thaheem, M. J., & Maqsoom, A. (2018). Building information modeling as a risk transformer: An evolutionary insight into the project uncertainty. Automation in Construction, 92, 103–119. doi:10.1016/j.autcon.2018.03.032.

[37] Chen, J. H., & Chen, W. H. (2012). Contractor costs of factoring account receivables for a construction project. Journal of Civil Engineering and Management, 18(2), 227–234. doi:10.3846/13923730.2012.671272.

[38] Abuimara, T., Hobson, B. W., Gunay, B., O'Brien, W., & Kane, M. (2021). Current state and future challenges in building management: Practitioner interviews and a literature review. Journal of Building Engineering, 41, 102803. doi:10.1016/j.jobe.2021.102803.

[39] Sierla, S., Pourakbari-Kasmaei, M., & Vyatkin, V. (2022). A taxonomy of machine learning applications for virtual power plants and home/building energy management systems. Automation in Construction, 136, 104174. doi:10.1016/j.autcon.2022.104174.

[40] Cheng, J. C. P., Liu, H., Gan, V. J. L., Das, M., Tao, X., & Zhou, S. (2023). Construction cost management using blockchain and encryption. Automation in Construction, 152, 104841. doi:10.1016/j.autcon.2023.104841.