RESWARA: Jurnal Riset Ilmu Teknik
2026, Vol. 4, No. 3, pp. 154-170
E-ISSN: 3025-9444

Delay Risk Factors in Foundation Works Using SEM and Multi-Group Analysis

Jonathan Natanael[1]✉, Hans Dermawan[2], Fenny Septiastuti[3]
(1,2,3) Department of Civil Engineering, Faculty of Smart Technology, Krida Wacana Christian University, Indonesia

Abstract: Delays in construction projects continue to be a significant problem in infrastructure development, especially in foundation works where field uncertainties are common. This study aims to identify the dominant delay risk factors and examine their influence on project time performance. A quantitative approach was applied using questionnaires distributed to construction professionals, and the collected data were analyzed using Partial Least Squares Structural Equation Modeling (PLS-SEM) and Multi-Group Analysis (MGA). The results indicate that equipment and productivity factors as well as financial and administrative factors have significant effects on project time performance, while other factors were not statistically significant. The structural model showed moderate explanatory power with an R^2 value of 0.471. The findings also revealed a discrepancy between perceived importance and actual impact, where technical factors were perceived as highly important but operational and financial factors showed stronger direct effects on project execution. In addition, no significant differences were found between contractors and consultants. It was concluded that mitigation strategies should prioritize operational and financial aspects to effectively reduce delays in foundation works.

Article history:
Received: 28 May 2026
Revised: 22 June 2026
Accepted: 25 June 2026
Published: 29 June 2026

Keyword:
Construction Delay;
Foundation Works;
Risk Factors;
Project Time Performance;
Structural Equation Modeling

This is an open-access article under the CC-BY-SA License.

How to cite: Natanael, J., Dermawan, H., & Septiastuti, F. (2026). Delay Risk Factors in Foundation Works Using SEM and Multi-Group Analysis. *RESWARA: Jurnal Riset Ilmu Teknik*, *4*(3), 154–170. https://doi.org/10.70716/reswara.v4i3.557

INTRODUCTION

Construction project delays remain a major issue in infrastructure development, as they lead to schedule deviations, cost overruns, decreased productivity, and conflicts among stakeholders (Gandi et al., 2025; Mohdar et al., 2024; Rashid, 2020; Tariq & Gardezi, 2023; Yin et al., 2025). This issue is more critical in high-uncertainty activities, where delays in one stage can affect subsequent project phases. In this context, foundation work is a critical stage that determines the continuity of the overall construction process. Foundation works are complex due to their dependence on soil conditions, construction methods, equipment, labor, and environmental factors. Discrepancies between soil investigation data and actual field conditions may reduce productivity and extend project duration. (Ahmed & Xu, 2023) indicate that delays result from interactions among multiple factors, including management, equipment, labor, and environment.

Foundation works involve high uncertainty and strong dependency on site conditions, making planning more complex. Errors often require immediate adjustments, leading to potential delays. Therefore, identifying key risk factors is essential to improve project time performance (Rachmawati et al., 2023). From a project risk management perspective, delay risk factors can be understood as uncertain conditions or events that may affect project objectives, particularly schedule performance. In foundation works, risks may arise from planning and design issues, geotechnical uncertainties, equipment productivity, managerial coordination, financial administration, weather conditions, and labor performance. These risk dimensions may disrupt work continuity, reduce productivity, and create

✉ *Corresponding author:* ***jonathan.242022004@civitas.ukrida.ac.id***
Copyright © 2026, the author(s)

deviations from the planned schedule. Therefore, the conceptual model in this study is developed to examine how multiple delay risk dimensions influence project time performance as the main project outcome.

Previous studies have identified various delay factors such as design changes, ineffective planning, delayed payments, equipment limitations, and unexpected site conditions (Fashina et al., 2021; Henindia & Suroso, 2022; Rachmawati et al., 2023; Sungkana et al., 2023). Similar findings have also been reported in Indonesian construction projects, highlighting the relevance of these factors in local contexts (Rauzana et al., 2022). However, most of them primarily focused on identifying and ranking factors using descriptive approaches. Limited studies have examined the simultaneous relationships among multiple delay risk factors and their influence on project time performance using structural modeling techniques. In addition, research specifically focused on foundation works remains relatively limited despite the unique uncertainties associated with geotechnical conditions and subsurface construction activities. Furthermore, comparative analyses between contractors and consultants are still rarely conducted, creating a gap in understanding stakeholder perceptions regarding delay risks. Based on these limitations, this study hypothesizes that the identified delay risk dimensions significantly influence project time performance and that differences may exist between contractor and consultant perceptions regarding these relationships.

Based on previous studies, this research analyzes the structural influence of delay risk factors in foundation works on project time performance using PLS-SEM and MGA. The novelty lies in integrating these methods to assess factor influence and perception differences. The study aims to identify key factors, analyze their effects, compare stakeholder perceptions, and support risk mitigation.

RESEARCH METHOD

This research uses a quantitative approach to analyze the influence of delay risk factors in foundation works on project time performance. Data were obtained through a structured questionnaire distributed using purposive sampling to construction practitioners involved in foundation works, specifically contractors and consultants. The minimum sample size was estimated based on statistical power analysis. Referring to Cohen (1992), with a significance level of 5%, statistical power of 80%, and a maximum of seven predictors, the minimum required sample size is 80 (Jhantasana, 2023). The minimum sample size requirement was established for the primary PLS-SEM analysis. In addition, Multi-Group Analysis (MGA) was performed to compare stakeholder perceptions between respondent groups. Following recommendations in PLS-SEM literature, MGA can be applied to explore potential group differences, although the results should be interpreted with caution when group sample sizes are relatively limited.

The questionnaire was designed based on previous studies related to construction delay factors (Alshammari & Ghazali, 2024; Fashina et al., 2021; Sungkana et al., 2023). Prior to data collection, the questionnaire instrument was validated through expert judgment to ensure the relevance and clarity of the indicators. The initial instrument consisted of 32 exogenous indicators and 3 endogenous indicators; after expert validation, the instrument was refined to 21 exogenous indicators and 3 endogenous indicators. Respondents' perceptions were measured using a Likert scale, which is widely used to quantify subjective assessments in research (Likert, 1932; Sullivan & Artino, 2013). This

Copyright © 2026, the author(s). This is an open access article under the CC-BY-SA License.

approach has also been commonly applied in construction delay studies to evaluate and rank risk factors (Khatib et al., 2020). The variables and indicators used in this study are presented in Table 1.

Data analysis in this study consisted of descriptive and structural model analysis. Descriptive statistical analysis was conducted using SPSS to obtain respondent profile characteristics, mean values, and standard deviation values. Furthermore, relationships among variables were analyzed using Partial Least Squares-Structural Equation Modeling (PLS-SEM) with SmartPLS, which is suitable for predictive and complex research models. The measurement model evaluation focused on assessing construct validity and reliability, while the structural model evaluation was performed to analyze path relationships and explanatory power (Hair et al., 2021). In addition, measurement invariance was first assessed using the MICOM procedure before conducting Multi-Group Analysis (MGA) to compare the perceptions of contractors and consultants (Henseler et al., 2016).

Table 1. Variables and Indicators

Variable	Indicators	Sources
Planning & Design (X1)	Design changes (X1.1); Document approval delays (X1.2); Incomplete soil data (X1.3)	(Fashina et al., 2021; Rauzana et al., 2022; Sungkana et al., 2023)
Soil & Technical Conditions (X2)	Borehole instability (X2.1); Undetected underground utilities (X2.2); Unidentified hard layer (X2.3); Limited working area (X2.4)	(Alsanabani et al., 2023; Henindia & Suroso, 2022)
Equipment & Productivity (X3)	Equipment failure (X3.1); Inappropriate equipment (X3.2); Low equipment productivity (X3.3)	(Ahmed & Xu, 2023; Fashina et al., 2021; Rauzana et al., 2022)
Managerial & Coordination (X4)	Poor supervision (X4.1); Delayed decision-making (X4.2); Subcontractor delays (X4.3)	(Fashina et al., 2021; Rauzana et al., 2022)
Financial & Administrative (X5)	Payment delays (X5.1); Lack of BIM implementation (X5.2)	(Fashina et al., 2021; Rauzana et al., 2022)
Weather & Environment (X6)	High rainfall (X6.1); Extreme weather (X6.2); Site environment constraints (X6.3)	(Fashina et al., 2021; Kuo & Vo, 2025)
Labor (X7)	Insufficient workforce (X7.1); Low skill level (X7.2); Low labor productivity (X7.3)	(Ahmed & Xu, 2023; Fashina et al., 2021; Rauzana et al., 2022)
Project Time Performance (Y1)	Slow work progress (Y1.1); Execution constraints (Y1.2); Activity delay impact (Y1.3)	(Fashina et al., 2021; Irankunda et al., 2025; Mahirah Sharuddin et al., 2024)

Copyright © 2026, the author(s). This is an open access article under the CC-BY-SA License.

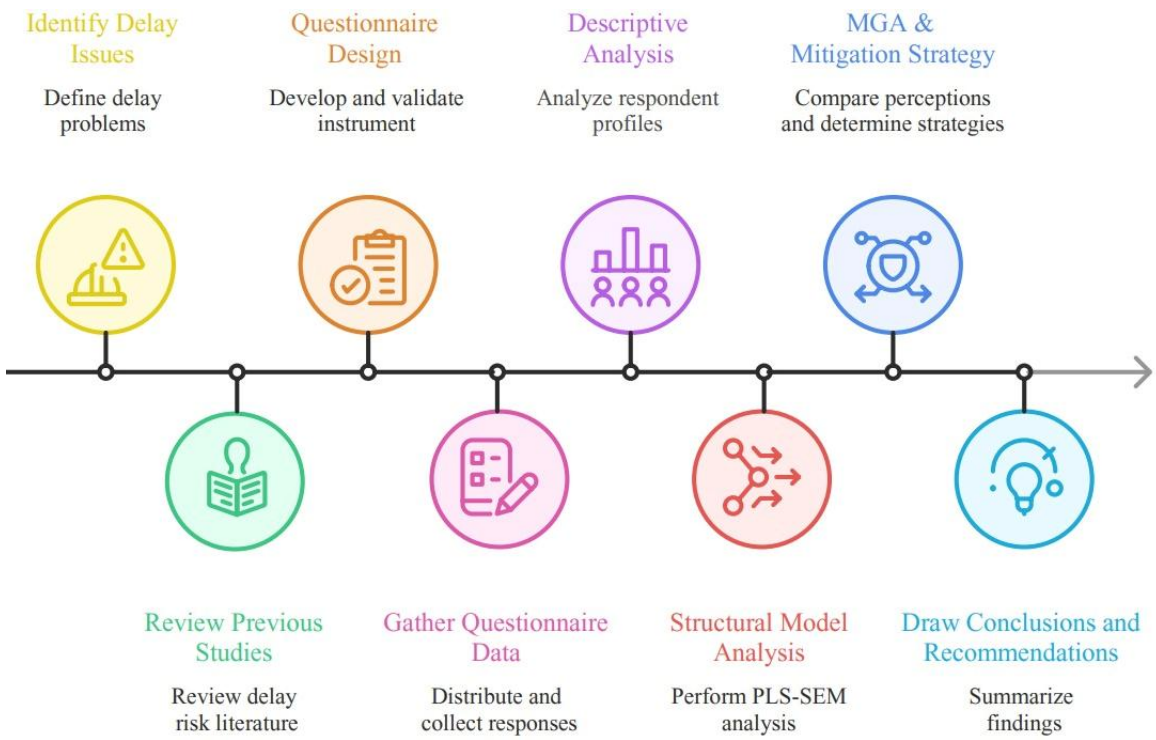

Figure 1. Research Methodology Process

The overall research methodology process used in this study is illustrated in Figure 1. The research began with the identification of delay issues in foundation works, followed by a literature review to determine relevant risk factors and research variables. The questionnaire instrument was then developed and validated before data collection was conducted through respondents involved in foundation works projects. After the data were collected, descriptive analysis and PLS-SEM analysis were performed to evaluate the relationships between variables. Finally, Multi-Group Analysis (MGA) and risk mitigation strategy development were carried out to compare stakeholder perceptions and formulate recommendations for reducing delay risks in foundation works.

RESULTS AND DISCUSSION

Descriptive Analysis

A total of 93 responses were collected and, after data screening, 88 valid responses were retained for further analysis. The respondent profile is presented in Table 2, while the distribution of project type and project location is illustrated in Figures 2 and 3. These profiles provide an overview of the diversity and relevance of the collected data, indicating that the respondents have varied professional backgrounds, project experiences, and geographic distributions related to foundation works projects. This diversity supports the representativeness of the data used in this study. In addition, the respondent characteristics indicate that the collected data are relevant for analyzing delay risk factors in foundation works from multiple stakeholder perspectives.

Copyright © 2026, the author(s). This is an open access article under the CC-BY-SA License.

Table 2. Respondent Profile

Category	Description	Frequency	(%)
Institution	Contractor	42	47.7
	Consultant	37	42.0
	Owner	9	10.2
Position	Geotechnical Engineer	21	23.9
	Project Manager	16	18.2
	Site Engineer	15	17.0
	Project Control & Planning	8	9.1
	Supervisor	7	8.0
	Site Manager	6	6.8
	Structure Engineer	4	4.5
	Construction Manager	2	2.3
	Others	9	10.2
Experience	5-10 years	36	40.9
	10-15 years	21	23,9
	>15 years	31	35.2

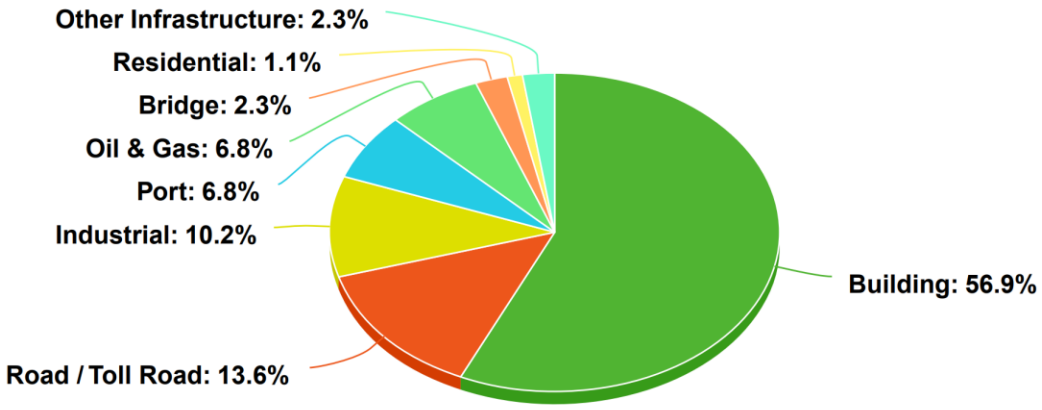

Figure 2. Distribution of Project Type

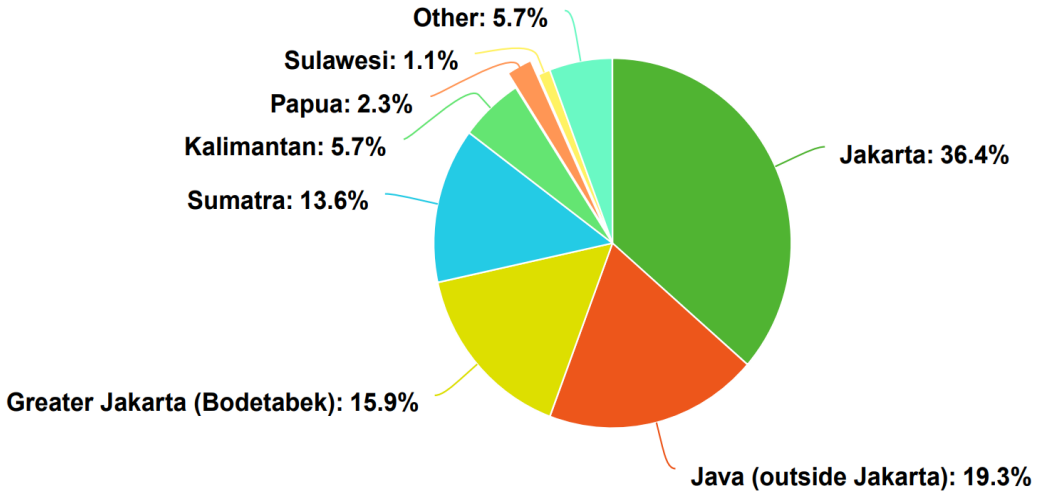

Figure 3. Distribution of Project Location

Copyright © 2026, the author(s). This is an open access article under the CC-BY-SA License.

The results show that the respondents are predominantly contractors (47.7%) and consultants (42.0%), with most having more than 5 years of experience. In addition, the respondents were involved in various project types, dominated by building projects, and originated from diverse project locations, particularly Jakarta and Java (outside Jakarta). This indicates that the respondents have relevant professional backgrounds and practical experience in foundation works, supporting the reliability of the data collected. The descriptive statistics of the variables are presented in Table 3.

Table 3. Descriptive Statistics

Indicator	Mean	Std. Dev
X1.1	3.4545	0.6048
X1.2	3.5455	0.5448
X1.3	3.7500	0.4854
X2.1	3.3864	0.6853
X2.2	3.6818	0.5152
X2.3	3.4091	0.7214
X2.4	2.9205	0.8870
X3.1	3.4205	0.6560
X3.2	3.4773	0.6061
X3.3	3.5227	0.5462
X4.1	3.4545	0.5854
X4.2	3.4659	0.5663
X4.3	3.3864	0.6330
X5.1	2.9205	0.8472
X5.2	2.3182	0.8516
X6.1	3.2955	0.7137
X6.2	3.4886	0.5871
X6.3	3.0455	0.8429
X7.1	3.1818	0.7199
X7.2	3.5114	0.5871
X7.3	3.3409	0.6043
Y1.1	3.1023	0.7587
Y1.2	3.2386	0.6947
Y1.3	3.1705	0.8055

As shown in Table 3, the highest mean value was observed in X1.3 (Mean = 3.7500), followed by X2.2 (Mean = 3.6818), indicating that incomplete soil investigation data and unidentified underground utilities are perceived as the most dominant risk factors. In contrast, the lowest mean value was found in X5.2 (Mean = 2.3182), followed by X5.1 (Mean = 2.9205), suggesting that financial and administrative factors are perceived as less influential.

This finding is consistent with previous studies that identified soil uncertainty and incomplete site investigation as major causes of delays in foundation-related construction activities (Alsanabani et al., 2023; Henindia & Suroso, 2022). This may occur because uncertainties in subsurface conditions directly affect construction methods and productivity. Previous studies have been reported similar findings, although some research highlights financial and managerial factors as dominant contributors.

Copyright © 2026, the author(s). This is an open access article under the CC-BY-SA License.

Measurement Model Evaluation (Outer Model)

The validity and reliability of the constructs were assessed using the measurement model. The initial assessment indicated that one indicator had an outer loading below the recommended threshold. Therefore, in order to enhance the measurement quality, indicator X1.1 was eliminated from the model. After refinement, most indicator loadings exceed the suggested threshold of 0.70, indicating acceptable convergent validity, as presented in Table 4. According to PLS-SEM guidelines, outer loading values of 0.70 or above are generally regarded as appropriate, as they indicate that the construct explains a large portion of the variance of its indicators (Hair et al., 2021).

However, as shown in Table 4, indicator X4.1 achieved an outer loading of 0.586, which is still regarded as acceptable in exploratory research. According to Hair et al. (2021), if the overall construct meets the necessary validity and reliability criteria, indicators with loading values between 0.50 and 0.70 may be kept. Therefore, X4.1 was retained in the model. Discriminant validity was evaluated using the Heterotrait-Monotrait Ratio (HTMT) criterion. As presented in Table 6, all HTMT values were below the recommended threshold of 0.90, indicating adequate discriminant validity among the constructs (Hair et al., 2021). These results indicate that each construct is empirically distinct and measures a different conceptual domain within the proposed model.

As presented in Table 5, all constructs have Average Variance Extracted (AVE) values greater than 0.50, meaning that the construct accounts for more than half of the variance in its indicators. According to Hair et al. (2021), adequate convergent validity is indicated by AVE values of 0.50 or more. Additionally, as advised by PLS-SEM evaluation criteria, Composite Reliability (CR) values surpass the threshold of 0.70, suggesting strong internal consistency (Hair et al., 2021), as shown in Table 5. Although the Cronbach's Alpha value of X1 was below the commonly recommended threshold, it is still considered acceptable due to the limited number of indicators after refinement. Cronbach's Alpha is a conservative measure of reliability and may underestimate reliability in models with a small number of indicators (Hair et al., 2021). Overall, the measurement model satisfies the required criteria of validity and reliability, indicating that it is suitable for further structural model analysis.

Table 4. Outer Loading

Construct	Indicator	Outer Loading
X1	X1.2	0.802
X1	X1.3	0.813
X2	X2.1	0.761
X2	X2.2	0.712
X2	X2.3	0.705
X2	X2.4	0.736
X3	X3.1	0.781
X3	X3.2	0.793
X3	X3.3	0.826
X4	X4.1	0.586
X4	X4.2	0.784
X4	X4.3	0.897
X5	X5.1	0.865
X5	X5.2	0.883
X6	X6.1	0.811

Copyright © 2026, the author(s). This is an open access article under the CC-BY-SA License.

X6	X6.2	0.829
X6	X6.3	0.859
X7	X7.1	0.762
X7	X7.2	0.831
X7	X7.3	0.855
Y1	Y1.1	0.880
Y1	Y1.2	0.908
Y1	Y1.3	0.890

Table 5. Construct Reliability and Validity

Construct	Cronbach's Alpha	Composite Reliability	Average Variance Extracted
X1	0.467	0.789	0.652
X2	0.707	0.819	0.531
X3	0.722	0.842	0.640
X4	0.669	0.806	0.588
X5	0.692	0.867	0.765
X6	0.794	0.872	0.695
X7	0.755	0.857	0.668
Y1	0.873	0.922	0.797

Table 6. HTMT

Construct	X1	X2	X3	X4	X5	X6	X7	Y1
X1	-							
X2	0.506	-						
X3	0.324	0.646	-					
X4	0.559	0.839	0.605	-				
X5	0.206	0.341	0.368	0.578	-			
X6	0.349	0.502	0.660	0.564	0.476	-		
X7	0.241	0.594	0.723	0.698	0.504	0.633	-	
Y1	0.372	0.448	0.671	0.590	0.623	0.480	0.574	-

Structural Model Analysis (Inner Model)

To investigate the connections between project time performance and delay risk variables, the structural model was examined. The structural model with path coefficients is presented in Figure 4. The model produced an R^2 value of 0.471 meaning that the independent variables account for 47.1% of the variance in project time performance, with additional factors outside the model influencing the remaining 52.9%. According to PLS-SEM guidelines, R^2 values of 0.75, 0.50, and 0.25 are described as substantial, moderate, and weak, respectively. Therefore, the R^2 value in this study indicates a moderate explanatory power (Hair et al., 2021). The path coefficient results indicate that equipment and productivity factors (X3) and financial and administrative factors (X5) have significant effects on project time performance, with p-values of 0.003 and 0.005, respectively. In contrast, planning and design (X1), soil and technical conditions (X2), managerial factors (X4), environmental factors (X6), and labor factors (X7) do not show statistically significant effects.

Using the bootstrapping method, hypothesis testing was carried out by looking at the t-statistics and p-values, as shown in Table 7. When the t-statistic is greater than 1.96 or the p-value is less than 0.05, a path is considered significant (Hair et al., 2021). The results confirm that only X3 and X5 meet the significance criteria, while the remaining variables do not show significant relationships with

Copyright © 2026, the author(s). This is an open access article under the CC-BY-SA License.

project time performance. These findings indicate that delays in foundation works are more strongly influenced by operational and financial factors rather than technical or environmental conditions. Similar findings were reported by Ahmed & Xu (2023), who highlighted that equipment productivity and operational interruptions significantly affect pile construction performance. Previous studies also identified financial management and payment-related issues as major contributors to construction delays due to their direct influence on resource continuity and project execution (Fashina et al., 2021; Rauzana et al., 2022). This may occur because equipment performance and financial flow have a direct impact on project execution and resource availability, thereby affecting project duration.

From a project management perspective, foundation works are highly dependent on resource continuity and operational efficiency. Equipment breakdowns or reduced productivity can immediately interrupt critical construction activities, leading to idle time and schedule deviations. Similarly, financial and administrative constraints may delay procurement, subcontractor payments, and resource mobilization, thereby disrupting project workflows. As a result, operational and financial issues tend to exert a more direct and measurable influence on project time performance compared to other risk dimensions that may be mitigated through planning adjustments or management interventions.

In addition, the effect size (f^2) results indicate that all variables have relatively small effects, although X3 and X5 show comparatively higher contributions than other variables. According to the guideline, f^2 values of 0.02, 0.15, and 0.35 represent small, medium, and large effects, respectively (Hair et al., 2021). This indicates that although the effects are statistically significant, their magnitude remains relatively small. Additionally, the PLS-Predict method was used to evaluate predictive significance. The findings demonstrate that the model has predictive relevance since all Q^2_predict values are greater than zero. In addition, the RMSE values of the PLS model are lower than those of the linear model (LM), suggesting that the model has good predictive capability (Hair et al., 2021).

Planning, soil, and environmental factors are perceived as critical but are not statistically significant, suggesting they are manageable or have indirect effects. This result differs from several previous studies that identified technical and site condition factors as dominant contributors to construction delays (Henindia & Suroso, 2022; Sungkana et al., 2023). The difference may be attributed to variations in project characteristics, respondent perceptions, and construction management practices across different project environments. In contrast, equipment performance and financial flow have a direct impact, as delays in equipment or payments can immediately disrupt project execution and scheduling. This finding highlights that perceived importance does not always reflect actual impact, where operational and financial issues cause direct delays, while other factors can be mitigated through adjustments.

Copyright © 2026, the author(s). This is an open access article under the CC-BY-SA License.

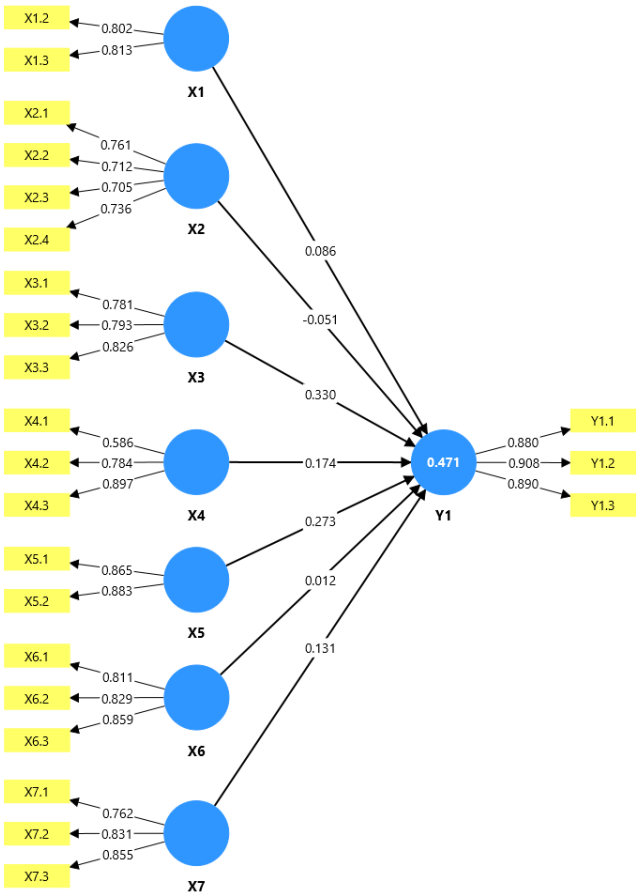

Figure 4. Structural Model Results

Table 7. Hypothesis Bootstrapping Results

Relationship	Path Coefficient	t-statistic	p-value	Significance
X1 → Y1	0.086	0.971	0.332	Not Significant
X2 → Y1	-0.051	0.440	0.660	Not Significant
X3 → Y1	0.330	2.961	0.003	Significant
X4 → Y1	0.174	1.048	0.295	Not Significant
X5 → Y1	0.273	2.823	0.005	Significant
X6 → Y1	0.012	0.110	0.912	Not Significant
X7 → Y1	0.131	1.293	0.196	Not Significant

Comparison of Technical and Non-Technical Risk Factors

The comparison between perceived importance and actual impact is summarized in Table 8. Perceived importance is determined based on the mean score of each variable using a three-level classification derived from the Likert scale (1-4), where values of 1.00-2.00 are categorized as low, 2.01-3.00 as moderate, and 3.01-4.00 as high. The risk factors are further grouped into technical and non-technical categories. Technical factors include planning and design (X1) and soil and technical conditions (X2), while non-technical factors include equipment and productivity (X3), managerial and coordination (X4), financial and administrative (X5), weather and environment (X6), and labor (X7).

Based on Table 8, technical factors show high perceived importance but do not have a statistically significant effect on project time performance. In contrast, non-technical factors, particularly equipment and productivity (X3) and financial and administrative factors (X5), have

Copyright © 2026, the author(s). This is an open access article under the CC-BY-SA License.

significant effects. This indicates that perceived importance does not always reflect actual impact, where technical factors are more visible in practice, while operational and financial factors have a more direct influence on project execution. Similar discrepancies between perceived importance and statistical influence have also been observed in construction risk studies, where highly perceived risks do not always demonstrate significant structural relationships within predictive models (Irankunda et al., 2025). Therefore, mitigation strategies should prioritize non-technical factors, while technical factors should be managed as preventive risks.

Furthermore, although foundation works are inherently influenced by geotechnical conditions, the statistical insignificance of technical factors may indicate that such factors occur less frequently but can have high impacts when they arise. In contrast, operational and financial factors tend to occur more frequently and directly affect project execution, making them more dominant in the model. However, in certain situations, such as unexpected soil conditions or insufficient soil investigation, technical factors can become critical and lead to significant delays. This suggests that technical factors should not be disregarded but managed as potential high-impact risks under specific conditions, while non-technical factors remain the primary drivers of delay in routine project execution.

This finding can also be explained from a risk management perspective, where risk significance is influenced not only by impact severity but also by the frequency of occurrence. Technical and geotechnical risks are often characterized as low-frequency but high-impact events. Consequently, respondents may perceive such risks as important because of their potential consequences; however, these risks may not emerge as statistically significant predictors when they occur infrequently across projects. In contrast, operational and financial issues tend to occur more regularly during project execution, increasing their observable influence on project time performance.

Table 8. Comparison of Perceived Risk Level and Structural Significance

Risk Group	Factor	Mean	Perceived Importance	SEM Result	Interpretation
Technical	X1	3.6477	High	Not Significant	Highly perceived but not statistically significant
Technical	X2	3.3495	High	Not Significant	Frequently perceived but manageable through technical planning
Non-Technical	X3	3.4735	High	Significant	Directly affects construction execution and productivity
Non-Technical	X4	3.4356	High	Not Significant	Important in perception but not statistically strong in the model
Non-Technical	X5	2.6194	Moderate	Significant	Significant impact due to influence on cash flow and resource continuity
Non-Technical	X6	3.2765	High	Not Significant	Perceived as important but can be mitigated through planning
Non-Technical	X7	3.3447	High	Not Significant	Important in perception but not statistically significant

Copyright © 2026, the author(s). This is an open access article under the CC-BY-SA License.

Multi-Group Analysis

MGA was conducted to examine whether there are differences in the relationships between delay risk factors and project time performance between contractors and consultants. Prior to conducting MGA, the Measurement Invariance of Composite Models (MICOM) procedure was performed. The results indicate that configural invariance and compositional invariance were achieved, as the data collection procedures, model specifications, and composite scores were consistent across both groups. However, the third step, which assesses the equality of means and variances, shows that some constructs do not fully meet the required criteria. This indicates that the model satisfies partial measurement invariance, which is sufficient to proceed with MGA.

The MGA results are presented in Table 9. All path relationships show p-values greater than 0.05, indicating that there are no significant differences between contractors and consultants in the relationships between delay risk factors and project time performance (Hair et al., 2021). This finding suggests that both groups share a similar perception regarding the factors influencing project delays, despite their different roles in project execution and management. Comparable findings were also reported in previous construction management studies, where contractors and consultants demonstrated relatively similar perceptions regarding project delay factors despite differences in professional responsibilities (Aldammak et al., 2025). This may occur because both contractors and consultants are directly involved in the planning, coordination, and supervision of foundation works, leading to a comparable understanding of delay risk factors. These results indicate that the identified delay risk factors can be considered generally applicable across different project stakeholders, without significant variation between groups. Therefore, risk mitigation strategies can be developed without the need for substantial differentiation between contractors and consultants.

From a practical perspective, this finding suggests that project stakeholders may adopt a common risk management framework when addressing delay risks in foundation works. Since contractors and consultants demonstrate similar perceptions regarding the influence of delay factors, coordination efforts, communication procedures, and mitigation planning can be implemented more consistently across stakeholder groups. This may reduce misunderstandings during project execution and support more integrated decision-making processes in managing schedule-related risks.

In addition, although the MGA results are not statistically significant, several path coefficients show numerical differences between groups. This indicates that contractors and consultants may place different levels of emphasis on certain delay risk factors in practice, even though these differences are not strong enough to be statistically confirmed within the current sample. For example, operational or managerial factors may be perceived differently depending on each stakeholder's responsibilities and involvement during project execution. Therefore, the findings still provide practical insights into stakeholder perspectives in foundation works projects and may support the development of more adaptive risk management strategies in construction practice.

Copyright © 2026, the author(s). This is an open access article under the CC-BY-SA License.

Table 9. Multi-Group Analysis Results

Relationship	p-value
X1 → Y1	0.291
X2 → Y1	0.352
X3 → Y1	0.931
X4 → Y1	0.127
X5 → Y1	0.512
X6 → Y1	0.842
X7 → Y1	0.404

Risk Mitigation Implication

The proposed risk mitigation strategies are summarized in Table 10. The priority order was derived from the structural model results. Factors that demonstrated statistically significant effects on project time performance, namely equipment and productivity (X3) and financial and administrative factors (X5), were assigned the highest priority because they directly influence project execution and schedule performance. The remaining factors were prioritized based on their perceived importance and potential consequences, particularly in situations where their impacts may be substantial despite the absence of statistically significant relationships.. This approach aims to ensure that mitigation efforts focus on factors that have the most direct influence on project time performance. Previous studies also reported that operational issues, equipment productivity, and financial management are among the primary contributors to construction delays because they directly affect construction continuity, resource availability, and field productivity (Ahmed & Xu, 2023; Chandra et al., 2023; Fashina et al., 2021). These findings are consistent with the structural model results of this study, where equipment and productivity factors (X3) as well as financial and administrative factors (X5) showed significant effects on project time performance.

Therefore, preventive strategies such as routine equipment maintenance, proper equipment selection, cash flow planning, and improved administrative coordination are considered essential to reduce delay risks. Specifically, the significant influence of X3 supports mitigation measures aimed at maintaining equipment availability and productivity continuity, whereas the significance of X5 justifies stronger emphasis on cash flow management, payment control, and administrative coordination. These strategies were prioritized because the SEM results indicate that disruptions in operational and financial processes have the most direct effect on project time performance. In addition, effective communication and coordination among project stakeholders are necessary to ensure that operational and financial issues can be addressed promptly before causing broader impacts on project progress.

Although technical factors such as planning, design, and soil conditions do not show statistically significant effects in the structural model, these factors should not be disregarded. Consequently, these factors were positioned as secondary priorities in Table 10, emphasizing preventive rather than primary corrective interventions. In foundation works, technical issues may still cause high-impact delays under specific conditions, particularly when soil investigation data are incomplete or field conditions differ from initial assumptions (Henindia & Suroso, 2022; Liu et al., 2023). Therefore, technical risks should continue to be managed through preventive measures, including adequate site investigation, design verification, and continuous field monitoring, to minimize the potential impact on project execution. Furthermore, early identification of technical uncertainties may help project teams prepare more adaptive construction strategies and reduce the likelihood of unexpected disruptions

Copyright © 2026, the author(s). This is an open access article under the CC-BY-SA License.

during foundation work activities. The proposed mitigation strategies were developed by integrating the statistical findings of this study with recommendations from previous construction delay and risk management studies.

Table 10. Risk Mitigation Strategies Based on Priority

Factor	Preventive Strategies	Corrective Strategies	Supporting Sources
X3 - Equipment & Productivity	Scheduled equipment maintenance; proper equipment selection based on site conditions; equipment productivity planning and mobilization control.	Immediate repair or replacement of damaged equipment; deployment of backup equipment; adjustment of work methods to maintain production rate.	(Alshammari & Ghazali, 2024; Chandra et al., 2023)
X5 - Financial & Administrative	Cash flow planning; timely payment control; contract administration monitoring; implementation of BIM or digital coordination systems to reduce approval and documentation delays.	Acceleration of delayed payments; budget reallocation to critical activities; simplification of administrative procedures and approval workflows.	(Assaf et al., 2022)
X1 - Planning & Design	More detailed planning; early design review; faster approval of shop drawings and method statements; improved design coordination before execution.	Design revision based on actual field conditions; acceleration of approval processes; adjustment of schedule and method statement after design changes.	(Alshammari & Ghazali, 2024)
X4 - Managerial & Coordination	Strengthening supervision; clearer coordination among owner, contractor, and consultant; regular monitoring of subcontractor progress.	Faster decision-making; corrective coordination meetings; stricter control of subcontractor delays and field execution problems.	(Aldammak et al., 2025)
X2 - Soil & Technical Conditions	Comprehensive soil investigation; early utility mapping; geotechnical and geophysical investigation for underground obstruction detection; risk assessment before foundation work.	Adjustment of drilling or piling method; redesign based on field conditions; implementation of contingency plans for hard layers, utilities, or unstable ground.	(Liu et al., 2023)
X7 - Labor	Workforce planning; training and skill development; productivity monitoring; adequate crew allocation.	Increasing labor allocation; replacing unqualified workers; productivity improvement actions such as overtime or work resequencing.	(Alshammari & Ghazali, 2024; Hassan & Riaz, 2024)

Copyright © 2026, the author(s). This is an open access article under the CC-BY-SA License.

X6 - Weather & Environment	Weather monitoring; adaptive scheduling; preparation of temporary protection and site access planning; adjustment of work sequence during high-risk weather periods.	Rescheduling work during extreme weather; adjusting working hours; reallocating activities to less weather-sensitive tasks.	(Alshammari & Ghazali, 2024)

CONCLUSION

This study aims to analyze the influence of delay risk factors in foundation works on project time performance using the PLS-SEM and Multi-Group Analysis (MGA) approaches. The results indicate that equipment and productivity factors (X3) as well as financial and administrative factors (X5) have significant effects on project time performance, while planning and design, soil and technical conditions, managerial, environmental, and labor factors do not show statistically significant effects. The findings also reveal a discrepancy between perceived importance and actual impact, where technical factors are perceived as highly important but do not significantly influence project time performance, whereas operational and financial factors have more direct impacts on project execution. In addition, the MGA results show no significant differences between contractors and consultants, indicating that both groups share similar perceptions regarding delay risk factors in foundation works. These findings suggest that risk mitigation strategies should prioritize operational and financial aspects, while technical factors should continue to be managed as preventive risks due to their potential high impact under certain conditions. This study contributes to the literature by integrating PLS-SEM and MGA approaches in evaluating delay risk factors and highlighting the distinction between perceived importance and actual impact in project risk management. However, this study is limited by the sample size and geographic scope; therefore, future research is recommended to expand the number of respondents, include additional variables, and apply the model to different types of construction projects or develop predictive and decision-support models related to construction delay risk management.

ACKNOWLEDGMENT

The authors would like to thank all respondents, including contractors and consultants, who contributed valuable data to this study. The authors also express their sincere appreciation to the academic supervisors and the Civil Engineering Department, Faculty of Smart Technology, Krida Wacana Christian University, for their support, guidance, and encouragement throughout the research process.

REFERENCES

Ahmed, M., & Xu, W. (2023). Investigation of pile construction and productivity loss: An analysis of macro impact factor. *World Journal of Engineering and Technology*, *11*(4), 932–964. https://doi.org/10.4236/wjet.2023.114062

Aldammak, M. M., Hamzah, N. B., & Khoiry, M. A. (2025). Pilot study on delay factors and solutions strategies in government buildings projects in Kuwait: Stakeholders' perspectives using confirmatory factor analysis (CFA). *Buildings*, *15*(14), 2420. https://doi.org/10.3390/buildings15142420

Copyright © 2026, the author(s). This is an open access article under the CC-BY-SA License.

Alsanabani, N. M., Al-Gahtani, K. S., Almohsen, A. S., & Alsharef, A. (2023). Risk interdependency network model for the cost and time of pile installation in Saudi Arabia using partial least squares structural equation modeling. *Applied Sciences*, *13*(19). https://doi.org/10.3390/app131910886

Alshammari, A., & Ghazali, F. E. M. (2024). A comprehensive review of the factors and strategies to mitigate construction projects delays in Saudi Arabia. *The Open Construction & Building Technology Journal*, *18*(1). https://doi.org/10.2174/0118748368318470240806113627

Assaf, M., Hussein, M., Alsulami, B. T., & Zayed, T. (2022). A mixed review of cash flow modeling: Potential of blockchain for modular construction. *Buildings*, *12*(12). https://doi.org/10.3390/buildings12122054

Chandra, S. S., Sepasgozar, S. M. E., Kumar, V. R. P., Singh, A. K., Krishnaraj, L., & Awuzie, B. O. (2023). Assessing factors affecting construction equipment productivity using structural equation modeling. *Buildings*, *13*(2). https://doi.org/10.3390/buildings13020502

Cohen, J. (1992). A power primer. *Psychological Bulletin*, *112*(1), 155–159. https://doi.org/10.1037/0033-2909.112.1.155

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). https://doi.org/10.1016/j.heliyon.2021.e06826

Gandi, A., Yusuf Tululi, M., & Usman Sumaga, A. (2025). Evaluation of costs and time for the implementation of bore pile foundation work for the BPK RI apartment project in Gorontalo City. *Research Review Jurnal Ilmiah Multidisiplin*, *3*(2), 289–298.

Hair, J. F., Hult, T. M., Ringle, C., Sarstedt, M., Danks, N. P., & Ray, S. (2021). *Partial least squares structural equation modeling (PLS-SEM) using R: A workbook*. Springer. https://doi.org/10.1007/978-3-030-80519-7

Hassan, A., & Riaz, A. (2024). Analysis of skilled labor shortage in the construction industry of developing countries. *Building Engineering*, *3*(1), 1–12. https://doi.org/10.59400/be2054

Henindia, R., & Suroso, A. (2022). Analysis of the factors causing delay in pile foundation work for medium-story building project. *Journal of Applied Science, Engineering, Technology, and Education*, *4*(1), 27–38. https://doi.org/10.35877/454RI.asci850

Henseler, J., Ringle, C. M., & Sarstedt, M. (2016). Testing measurement invariance of composites using partial least squares. *International Marketing Review*, *33*(3), 405–431. https://doi.org/10.1108/IMR-09-2014-0304

Irankunda, G., Zhang, W., Abdullahi, U. I., Fernand, M., David, B., & Jean-Petit, S. (2025). Understanding critical delay causative factors and their mitigation measures in Burundi communal construction projects: A factor analysis and structural equation modeling approach. *Buildings*, *15*(3), 473. https://doi.org/10.3390/buildings15030473

Jhantasana, C. (2023). Should a rule of thumb be used to calculate PLS-SEM sample size. *Asia Social Issues*, *16*, 1–23.

Khatib, B., Poh, Y. S., & El-Shafie, A. (2020). Delay factors management and ranking for reconstruction and rehabilitation projects based on the relative importance index (RII). *Sustainability*, *12*(15). https://doi.org/10.3390/su12156171

Kuo, C. P., & Vo, D. H. (2025). Causes of delays occurring in linear projects: A survey of prestressed concrete sheet pile retaining wall constructions in Taiwan. *Slovak Journal of Civil Engineering*, *33*(2), 11–25. https://doi.org/10.2478/sjce-2025-0008

Likert, R. (1932). *A technique for the measurement of attitudes*. Columbia University Press.

Liu, Y., Ng, Y. C. H., Zhang, Y., Yang, P., & Ku, T. (2023). Incorporating geotechnical and geophysical investigations for underground obstruction detection: A case study. *Underground Space*, *11*, 116–129. https://doi.org/10.1016/j.undsp.2022.12.003

Copyright © 2026, the author(s). This is an open access article under the CC-BY-SA License.

Mahirah Sharuddin, N., Azrai Azman, M., Abdul Samad, Z., & Mohd Rodzi, R. (2024). Relationship between schedule delay factors and project performance in civil engineering works. *Built Environment Journal*, *21*, 23–36. https://doi.org/10.24191/bej.v21iSpecial

Mohdar, W., Serang, R., & Titaley, H. D. (2024). Analysis of factors causing work delays bore pile on the school construction project using fault tree analysis (FTA) methods. *PARAMETER: Jurnal Matematika, Statistika, Dan Terapannya*, *3*(1), 19–32.

Rachmawati, F., Ramadhani, H. D., & Nurhidayah, A. S. (2023). Project delay risk assessment. *IPTEK The Journal for Technology and Science*, *34*(1), 60–71. https://doi.org/10.12962/j20882033.v34i1.16263

Rashid, Y. (2020). Analysis of delay factors and their effects on construction projects. *Management Science Letters*, *10*(6), 1197–1204. https://doi.org/10.5267/j.msl.2019.11.039

Rauzana, A., Zahrah, A., & Dharma, W. (2022). Critical delay factors for construction projects in Central Aceh District, Indonesia. *F1000Research*, *11*, 474. https://doi.org/10.12688/f1000research.110024.1

Sullivan, G. M., & Artino, A. R. (2013). Analyzing and interpreting data from Likert-type scales. *Journal of Graduate Medical Education*, *5*(4), 541–542. https://doi.org/10.4300/JGME-5-4-18

Sungkana, S. R. K., Ratnaningsih, A., & Soetjipto, J. W. (2023). Analisis faktor penyebab keterlambatan pelaksanaan pondasi bore pile menggunakan metode fault tree analysis. *Bulletin of Civil Engineering*, *3*(1), 25–30. https://doi.org/10.18196/bce.v3i1.17491

Tariq, J., & Gardezi, S. S. (2023). Study the delays and conflicts for construction projects and their mutual relationship: A review. *Ain Shams Engineering Journal*, *14*(1). https://doi.org/10.1016/j.asej.2022.101815

Yin, H., Khoo, T. J., Liu, Q., & Li, Y. (2025). Factors influencing schedule management delays on residential projects in China: A case study of Yun Yue Dong Fang Project. *Turkish Journal of Civil Engineering*, 1–25. https://doi.org/10.18400/tjce.1571706

Copyright © 2026, the author(s). This is an open access article under the CC-BY-SA License.