RESEARCH PAPER

Analysis of Factors Affecting Construction Quality in Large-Scale Thermal Power Plant EPC Projects in Indonesia from a Subcontractor Perspective

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1. ABSTRACT
The quality of construction results in large-scale thermal power plant Engineering, Procurement, and Construction (EPC) projects in Indonesia faces challenges of technical and managerial complexity, where subcontractors play a vital role as the main implementers in the field. This study aims to analyze the influence of human resources, construction materials, work equipment, finance, communication and collaboration, field supervision, and occupational health and safety (OHS) factors on construction quality from the perspective of subcontractors. This study uses a quantitative approach with the Partial Least Squares - Structural Equation Modeling (PLS-SEM) method for hypothesis testing and Importance-Performance Map Analysis (IPMA) to determine strategic improvement priorities. Data were collected through questionnaires distributed to subcontractor respondents involved in power plant projects with a capacity above 100 MW. The results show that the model explains 70.6% of the variance in construction quality. The findings prove that the factors of Finance, Human Resources, Work Equipment, Communication and Collaboration, and Field Supervision have a positive and significant effect on construction quality, while the factors of Construction Materials and HSE (Health, Safety, and Environment) have no significant effect. Based on IPMA analysis, the Financial factor was identified as the most dominant factor with the highest level of importance but the lowest performance, making it a top priority for improvement. This study recommends improving cash flow management by subcontractors and ensuring accurate payments by main contractors as key strategies for quality improvement.
Keywords: Construction Quality, EPC Project, Thermal Power Plant, Subcontractor, PLS-SEM, IPMA, Finance.
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1. Introduction
Electricity plays an important role in modern human life and is the backbone of civilization, enabling high productivity and work efficiency. In Indonesia, electricity demand is projected to continue to increase from 430 TWh in 2024 to 1,813 TWh in 2060, in line with population growth and increased per capita consumption. To meet this demand, the national power generation capacity, which was 101 GW in 2024, is projected to increase to 443 GW in 2060. The development of this infrastructure is dominated by large-scale thermal power plants (>100 MW) such as coal-fired power plants and gas-fired power plants, which are generally implemented using an Engineering, Procurement, and Construction (EPC) contract scheme.

In practice, EPC projects face significant challenges in maintaining the quality of construction results, where failure to control quality can lead to delays, cost overruns, and project owner dissatisfaction. The complexity of EPC projects involves many parties, including main contractors and subcontractors. Subcontractors play a strategic role as direct implementers in the field who handle specific tasks such as mechanical, electrical, civil, or commissioning work. The active involvement of subcontractors in the quality control system is key to the success of a project, but their role has often been overlooked in previous studies that focused more on the main contractor or project owner.

Various factors are thought to influence construction quality. Previous studies have identified human resources, materials, equipment, finance, communication, supervision, and occupational health and safety as determining factors. However, there is a research gap regarding how these factors interact simultaneously in the context of EPC power plant projects in Indonesia, particularly from the perspective of subcontractors. Common quality issues include technical specification non-compliance, delays in completion, and occupational safety issues.

This study aims to analyze the influence of these factors on construction quality and identify the most dominant factors using the Partial Least Squares - Structural Equation Modeling (PLS-SEM) and Importance-Performance Map Analysis (IPMA) methods. This approach is expected to contribute theoretically to the construction management literature and provide practical benefits for strategies to improve the quality of EPC projects in Indonesia.

2. **Methods**

2.1. Research Design

This study uses a quantitative approach with a causal and explanatory design. This approach was chosen to measure the magnitude of the influence between variables and explain the mechanism of the cause-and-effect relationship between the determining factors (human resources, materials, equipment, finance, communication, supervision, HSE) on the quality of construction results. The research was conducted cross-sectionally, where data collection was carried out at a specific period of time to capture respondents' perceptions of the actual project conditions.

2.2. Population and Sample

The population in this study was subcontractors involved in large-scale (>100 MW) thermal power plant EPC projects in Indonesia. Given that the exact population size was unknown (infinite population), the sampling technique used purposive sampling with the following strict respondent inclusion criteria:

1) The subcontractor has a direct contract with the main contractor (Tier-1).
2) The subcontractor is a business entity (company), not an individual.
3) Respondents are key personnel with the following positions: Company Management, Project Manager, Site Manager, Engineer, or Field Supervisor.
4) They have work experience on similar projects.

The determination of the minimum sample size (n) is based on the "10-times rule" method for PLS-SEM analysis, which is stated in the following equation:

$$n \geq 10 \times a \qquad (1)$$
$$n \geq 10 \times 7$$
$$n \geq 70$$

Where the a is the number of structural paths leading to the dependent variable or the largest number of formative indicators in the model. Although this method yields a minimum sample size of 70, in this study, the target sample size was set to exceed that value, namely 150.

2.3. Variable Operationalization

Variable operationalization is necessary to translate abstract theoretical concepts (latent variables) into empirical indicators that can be measured in the field. In this study, the variables were grouped into seven exogenous (independent) variables consisting of human resources, materials, equipment, finance, communication, supervision, and environment and HSE factors, and one endogenous (dependent) variable, namely construction quality.

Measurements were conducted using a closed questionnaire with a 5-point Likert scale, where 1 represents 'Strongly Disagree' and 5 represents 'Strongly Agree'. This scale was used to obtain sufficient data intervals to capture the variability of respondents' perceptions of project conditions. All indicators used were validated through a review of previous literature and adjusted to the operational characteristics of current construction projects. Complete details regarding operational definitions, measurement indicators, and supporting references are presented in Table 1.

Table 1. Variables, Indicators, and Statements

Variables	Indicators	Statement	Indicator Reference
Human resources (X1)	Workforce experience	Workers must have work experience relevant to the project requirements	[1–4]
	Technical Competence/Skills of Labor	Workers must have technical competencies/skills	[2–11]

Variables	Indicators	Statement	Indicator Reference
		that are appropriate for the project requirements.	
	Workforce availability	The required workforce must be available in sufficient numbers to meet project needs.	[2–5,10,11]
	Workforce productivity	The workforce must have a level of productivity that meets the project's needs.	[3,11,12]
Construction Materials (X2)	Material quality	Materials used must be of good quality and meet the specified requirements.	[2,3,5,6,10,11,13]
	Material availability	Materials must be delivered and available according to the planned schedule.	[1–5,10,11,13]
	Handling and storage of materials	Material handling and storage must comply with the manufacturer's standard operating procedures (SOP)	[1,13]
	Material procurement process	The material procurement process must be effective and efficient.	[2,3,10,13]
Work equipment (X3)	Work equipment suitability	The work equipment used must be suitable for the specific needs of the project	[2,3,10]
	Availability of work equipment	Work equipment must be delivered and available according to the planned schedule.	[4,10,12]
	Operator capabilities	Operators must have the skills and licenses to operate work equipment	[2,4,12]
Finance (X4)	Financial Capability	The company (subcontractor) must have	[1–3,5,11,13]

Variables	Indicators	Statement	Indicator Reference
		sufficient funds to carry out the project	
	Delay payments	Delay payments from the main contractor will affect the project funding of the company (subcontractor)	[3–5]
	Bank interest rates	Bank loan interest rates will affect the company's project funding (subcontractor)	[4,10]
Communication and collaboration (X5)	Communication	Communication must be effective, clear, and easily understood by all parties	[1–3,5,6,11,14,15]
	Coordination	Coordination must run smoothly with all parties.	[1,2,5,15]
	Teamwork	Good teamwork is needed for the smooth completion of work.	[2,5,16]
Field supervision (X6)	Work supervision	Work supervision in the field must be carried out to ensure that work is performed in accordance with the required work methods.	[1,3,11]
	Availability of supervisors	The number of field supervisors must be sufficient to meet field requirements.	[6]
	Quality control	QA and QC procedures must be carried out correctly in the field.	[6,12]
Environment and occupational safety (X7)	HSE Procedures	There are clear HSE procedures for the project	[7,17]
	HSE Policy	Company management (subcontractors) must have a commitment and policy to implement HSE in the project.	[7,11]

Variables	Indicators	Statement	Indicator Reference
	HSE Implementation	HSE must be strictly implemented and monitored during project execution.	[7]
	Work environment	Working conditions on the project must be safe and conducive.	[4,6,17]
Construction Quality (Y1)	Compliance of construction results with specifications	Construction results comply with the specified technical specifications	[18,19]
	User satisfaction level	Users (project owners/main contractors) are satisfied with the construction results	[20,21]
	Timeliness of project completion	Construction projects are completed on time according to the agreed schedule.	[21,22]
	No work accidents occurred	No work accidents occurred during the project implementation period.	[23–25]

Based on the operationalization of the above variables, the relationship between these variables was then mapped into a path model. This model hypothesizes that the seven exogenous variables (X1-X7) have a direct influence on the endogenous variable of Construction Quality (Y1). The visualization of the causal relationships between the variables to be tested in this study is illustrated in the Structural Model Concept in Figure 1.

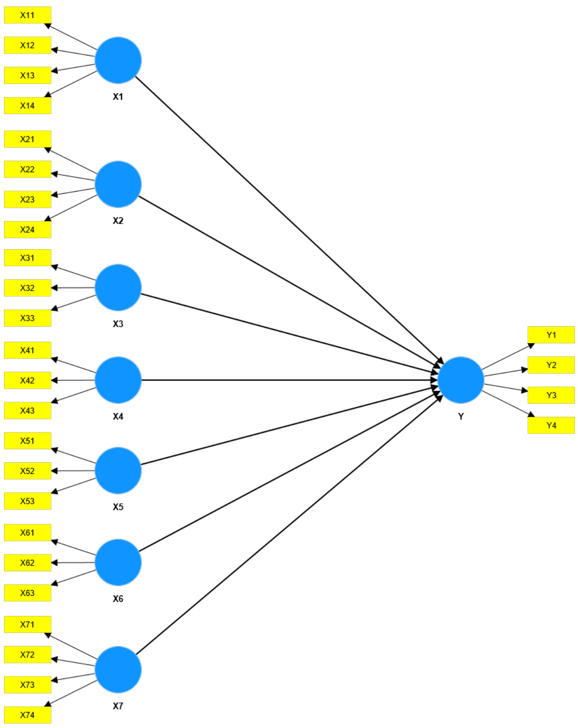

Figure 1. Conceptual Structural Model

2.4. Data Analysis

Data analysis in this study was conducted using the Partial Least Squares Structural Equation Modeling (PLS-SEM) approach with the help of SmartPLS software. This method was chosen because of its flexibility in managing complex structural models with abnormal data distributions. Given that all variables were conceptualized as reflective models, the measurement model (outer model) evaluation was conducted comprehensively through four main testing stages. The first stage was Indicator Reliability testing to assess how much of the indicator variance could be explained by its latent construct, where indicators were considered reliable if they had an Outer Loading value of $\lambda \geq 0.7$. The second stage focuses on evaluating Internal Consistency Reliability to ensure the consistency of measurement results. In this case, the study uses Composite- Reliability ρ_c, which is considered more accurate than Cronbach's Alpha, with an acceptance threshold of $\rho_c \geq 0.7$ calculated using the equation:

$$\rho_c = \frac{(\sum \lambda_i)^2}{(\sum \lambda_i)^2 + \sum Var(\epsilon_i)} \quad (2)$$

Furthermore, the validity of the measurement model is strengthened through two validity tests. Convergent validity was evaluated using the Average Variance Extracted (AVE) value to measure the extent to which indicators in a construct are positively correlated. A construct is considered convergent valid if the value of the $AVE \geq 0.5$, implying that the construct is able to explain more than 50% of the variance of its constituent indicators, according to the following equation:

$$AVE = \frac{\sum \lambda_i^2}{\sum \lambda_i^2 + \sum Var(\epsilon_i)} \quad (3)$$

Finally, discriminant validity is tested to ensure empirical uniqueness between constructs using the Heterotrait-Monotrait Ratio (HTMT) criterion. Discriminant validity is fulfilled if the HTMT ratio is below 0.90, which indicates no overlap between latent variables.

After confirming the validity and reliability of the measurement model, the analysis continued with the evaluation of the structural model (inner model) to test the causal relationship. This stage began with a multicollinearity test using the Variance Inflation Factor (VIF) with a requirement of a value of $AVE \leq 5$ to avoid bias between independent variables. Hypothesis significance testing was conducted through a bootstrapping procedure to generate values and P-values, where the hypothesis was accepted if $P-value \leq 0.05$. The strength of the structural model was then assessed based on the Coefficient of Determination R^2, for explanatory power, and Predictive Relevance Q^2, for predictive power [26]. As a concluding analysis, this study applied Importance-Performance Map Analysis (IPMA), which maps the dimensions of importance and performance to identify priority variables that require strategic managerial improvement.

3. Results and Discussion

3.1. Respondent Characteristics

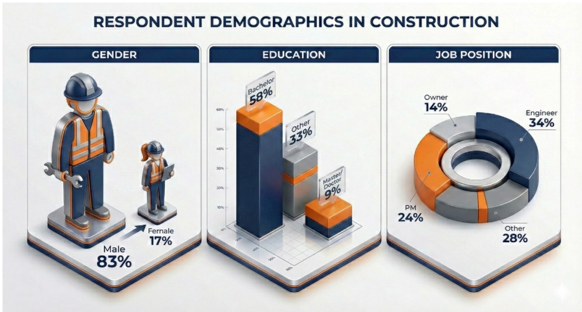

Figure 3. Respondent Characteristics

The majority of respondents were in the productive age range of 38–48 years, reflecting a level of maturity and experience. Based on gender, respondents were predominantly male (83%), while the remaining 17% were female. Almost all respondents were Indonesian citizens (97%), while the remaining 3% were foreign citizens. The educational level was dominated by bachelor degree graduates (58%), indicating that the respondents had adequate academic backgrounds. In terms of position, most respondents were Engineers/Field Supervisors (34%) and Project Managers/Site Managers (24%), which means that the data was obtained from key technical implementers.

3.2. PLS-SEM

3.2.1. Evaluation of the Measurement Model (Outer Model)

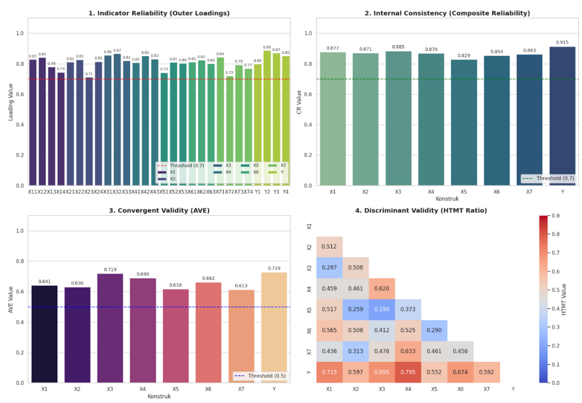

Figure 4. Evaluation of the Reflective Measurement Model

All indicators were found to be valid and reliable. The Outer Loadings values for all indicators were above 0.70 or within acceptable limits. The Average Variance Extracted (AVE) values for all constructs were above

0.50, with the lowest value for the HSE variable (0.613) and the highest for Construction Quality (0.729), indicating good convergent validity. The reliability test using Composite Reliability shows that all variables have values above 0.80, far exceeding the threshold of 0.70, which indicates excellent internal consistency. Discriminant validity through the HTMT (Heterotrait-Monotrait Ratio) criteria shows that all values are below 0.90, ensuring that each construct is empirically different.

3.2.2. Structural Model Evaluation (Inner Model)

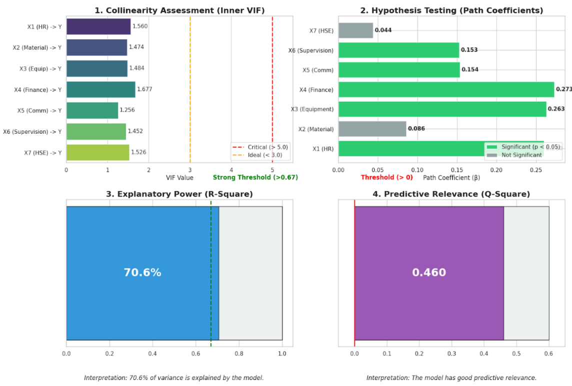

Figure 4. Structural Model Evaluation

The evaluation of the structural model (inner model) in this study was conducted through a series of systematic tests to assess the causal relationships between latent variables, the predictive power of the model, and the relevance of the model to the phenomenon under study. The first step in this evaluation was to examine the issue of lateral collinearity using the Inner Variance Inflation Factor (VIF) value. Based on the data processing results, the VIF value for all relationships between exogenous variables (Human Resources, Construction Materials, Work Equipment, Finance, Communication and Collaboration, Field Supervision, and HSE) and endogenous variables (Construction Quality) ranged from 1.256 to 1.6771. This value is well below the critical threshold of 5.0, and even meets the conservative criterion of below 3.0, indicating that there is no multicollinearity problem in the structural model. This confirms that each independent variable provides unique and unbiased information in predicting the dependent variable.

After the assumption of collinearity was met, hypothesis testing was conducted through path coefficient analysis using the bootstrapping procedure. The test results show that five of the seven independent variables have a positive and significant effect on construction quality ($P - value \leq 0.05$). The Financial Factor (X4) was identified as the variable with the most dominant effect ($\beta = 0.273$), followed in succession by Work Equipment (X3) ($\beta = 0.263$) and Human Resources (X1) ($\beta = 0.260$). These findings confirm that managerial aspects and internal resource readiness have a greater impact than other aspects. Conversely, the Construction Materials (X2) and Environment and Work Safety (X7) factors were found to have values of $P - value \leq 0.05$, meaning they did not have a significant effect on construction quality in this model.

Next, the strength of the model in explaining the phenomenon is evaluated using the coefficient of determination (R^2). The R^2 value for the endogenous variable Construction Quality is 0.7064. This figure indicates that the research model falls into the substantial category, where 70.6% of the variance or diversity of construction quality can be explained simultaneously by the seven independent variables tested. The remaining 29.4% is explained by variables or factors outside this research model. The high value of the R^2 indicates that the structural model constructed has high accuracy in representing the factors that determine construction quality in EPC power plant projects.

Finally, to measure the model's predictive capability against observational data, a predictive relevance test was conducted using Stone-Geisser's Q^2 through a blindfolding procedure. The calculation results produced a value of 0.460 for the Q^2. Considering that the Q^2 value is much greater than zero ($Q^2 > 0$), this model is declared to have good predictive relevance (medium to strong predictive relevance). This implies that the model is not only capable of explaining the current sample data, but is also valid and reliable for use in predicting the quality of construction results in similar cases or observational data in the future.

3.3. IPMA

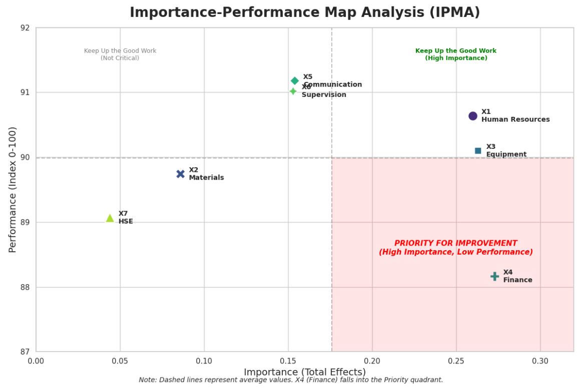

Figure 4. Importance Performance Map Analysis

As a follow-up analysis to strengthen the managerial implications of this study, an Importance-Performance Map Analysis (IPMA) was conducted. This analysis aims to map strategic improvement priorities by juxtaposing the "importance" dimension, derived from the total effects of exogenous variables on endogenous variables, with the "performance" dimension, measured from the average score of latent variables on a scale of 0 to 100. This map provides a visual guide for decision makers to identify which areas require urgent attention and which areas need to maintain their performance.

Based on the IPMA mapping results, the most crucial finding places the Finance variable (X4) as the top priority for improvement. This variable was identified as having the highest importance with a total effect value of 0.273, which means that financial factors are the strongest determinants in influencing the quality of construction results. However, contradictorily, this variable recorded the lowest performance index among all the factors studied, with a score of only 88.162. This significant gap between high influence and low performance indicates serious problems in the financial management of subcontractors (such as cash flow stability or funding accuracy) that hinder the achievement of optimal quality. Therefore, improvement strategies focused on financial aspects are predicted to have the greatest positive impact on improving overall construction quality.

In the other quadrants, the variables of Work Equipment (X3) and Human Resources (X1) show a very strategic position. These two variables have relatively high levels of importance (0.263 and 0.260, respectively), which have been offset by satisfactory performance achievements, namely a score of 90.099 for equipment and 90.634 for human resources. This position places these two factors in the "Keep Up the Good Work" category. These findings imply that subcontractors in thermal power plant EPC projects generally have mature operational readiness, both in terms of equipment reliability and workforce competence. The managerial strategy for these two variables does not require major overhauls, but rather maintenance of performance standards to remain consistent and avoid decline.

Meanwhile, other variables show different characteristics. The Communication and Collaboration (X5) and Field Supervision (X6) variables recorded very high performance (above 91.00) with a moderate level of importance, indicating that resources in this sector are already allocated very efficiently. Conversely, the Construction Materials (X2) and Environment and Occupational Safety (X7) variables are in the low priority zone because they have very low importance values (0.086 and 0.044, respectively). Although their performance is quite good, excessive improvement in these two aspects will not provide significant leverage for improving construction quality compared to focusing resources on improving the financial sector.

3.4. Discussion

This study found that finance is the most significant factor affecting the quality of construction results. The financial stability of subcontractors, including smooth cash flow and independent funding capabilities, is the foundation of operations. In the event of delay payments or high interest rates, subcontractors may become distracted by survival mode, potentially sacrificing quality standards. These findings are in line with studies [4,5] that emphasize the crucial importance of financial management.

Work equipment has a significant effect (0.263), confirming that in power plant projects involving heavy and complex components, the reliability of technology and precision tools are crucial to the outcome. Similarly, human resources have a significant effect (0.260), indicating that the competence and experience of the workforce are fundamental assets. This supports the findings [1] regarding the importance of worker expertise.

Communication and field supervision proved to have a significant effect, although the magnitude of the effect was lower than that of financial and resource factors. Effective collaboration minimizes the risk of misinterpretation (rework), while strict supervision ensures that work methods comply with SOPs. This is consistent with study [16] on the importance of interpersonal communication.

An interesting finding is the insignificant effect of construction materials. This is interpreted as meaning that in large-scale EPC projects, material specifications are determined very rigidly by the project owner through a layered approval procedure. Compliance with material specifications is a baseline requirement, so that variability in quality due to materials is minimal at the subcontractor level. This is in contrast to housing projects where subcontractors may have flexibility in choosing materials. Similar to materials, HSE did not have a statistically significant effect on the physical quality of the building. Although the implementation of HSE was considered good, it was seen more as regulatory compliance for safety, which does not necessarily correlate directly with the technical precision or aesthetics of the construction results.

4. Conclusion

This study concludes that the quality of construction results in large-scale thermal power plant EPC projects is largely determined by the managerial readiness and internal resources of subcontractors. Five factors were found to have a positive and significant effect: Finance, Work Equipment, Human Resources, Communication and Collaboration, and Field Supervision. Conversely, Construction Materials and HSE have no significant influence due to the rigid nature of specifications and the regulatory compliance nature of HSE. IPMA analysis confirms that Finance is the factor with the highest priority for improvement because it has the greatest impact but the lowest performance.

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