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Risk Identification and Prioritization in Hospital Construction Projects in Disaster-Prone Areas: A Contractor-Based Probability–Impact Matrix Approach

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ABSTRACT: Hospital construction projects are inherently complex due to strict functional requirements, advanced building systems, and high safety standards. These challenges are further intensified in disaster-prone areas, where environmental uncertainty and external disturbances significantly increase construction risks. Despite the critical role of contractors in managing construction-phase risks, empirical studies focusing on contractor-based risk assessment in hospital projects within hazard-exposed environments remain limited. This study aims to identify and prioritize construction risks in a hospital construction project located in a disaster-prone area using a contractor-based Probability–Impact Matrix (PIM) approach. The research was conducted at the CT Arsa Hospital construction project in Palu City, Central Sulawesi Province, Indonesia, a region with high exposure to seismic and environmental hazards. A qualitative case study design was employed, involving structured interviews with experienced project personnel, expert validation, and semi-quantitative probability–impact assessment. The results indicate that the most critical construction risks are associated with delays in material procurement, shortages of skilled labor, design changes during construction, extreme weather conditions, and site-related technical uncertainties. These risks are clustered in the high to very high-risk categories, highlighting their significant potential impact on construction performance. The findings demonstrate that the Probability–Impact Matrix provides a practical and transparent framework for prioritizing construction risks under conditions of uncertainty and limited data availability.

KEYWORDS: Construction risk management, Hospital construction, Disaster-prone areas, Probability–Impact Matrix, Contractor-based risk assessment, Risk prioritization

I. INTRODUCTION

Hospital construction projects are widely recognized as one of the most complex forms of building development due to their stringent functional requirements, advanced mechanical and electrical systems, and high standards of safety and reliability. Unlike conventional building projects, hospitals must ensure continuous operational readiness and resilience, particularly in emergency and disaster situations. As emphasized by the World Health Organization, the failure of hospital facilities during disasters can lead to severe social and humanitarian consequences, highlighting the critical importance of robust planning and execution throughout the construction phase (World Health Organization [WHO], 2020).

The complexity of hospital projects is further intensified when construction takes place in disaster-prone areas. Regions exposed to earthquakes, extreme weather events, flooding, or other natural hazards face heightened levels of uncertainty that directly affect construction activities. Recent global assessments indicate that climate-related and geophysical hazards are increasingly disrupting construction supply chains, site conditions, and workforce productivity, thereby elevating project risks (Intergovernmental Panel on Climate Change [IPCC], 2022). Within such contexts, construction projects are required not only to meet technical specifications but also to demonstrate resilience against environmental disturbances (Bosher et al., 2019).

From the contractor's perspective, managing risk under these conditions is particularly challenging. Contractors bear direct responsibility for construction methods, material procurement, equipment deployment, labor management, and site safety, all of which are highly sensitive to environmental and logistical disruptions. Inadequate identification and prioritization of construction risks may result in cascading impacts on project performance, including schedule delays, cost overruns, and compromised safety outcomes. Despite the central role of contractors in managing these operational risks, empirical studies that explicitly address contractor-based risk assessment in hospital construction projects—especially within disaster-prone environments—remain relatively limited (Shohet & Lavy-Leibovich, 2017).

Existing construction risk management literature has largely focused on general building or infrastructure projects and often emphasizes quantitative risk modeling techniques that rely on extensive historical data. While such approaches offer analytical rigor, their applicability may be constrained in projects characterized by high uncertainty and limited data availability, as is often the case in disaster-prone regions. In contrast, qualitative and semi-quantitative risk assessment methods provide a more flexible and practical means of supporting decision-making in complex project environments (Aven, 2016).

One of the most widely adopted semi-quantitative tools in construction risk management is the Probability–Impact Matrix (PIM). This method evaluates risks by combining the likelihood of occurrence and the magnitude of potential impact, enabling project stakeholders to prioritize critical risks in a transparent and systematic manner. The Probability–Impact Matrix is formally recognized within established project management standards and has been extensively applied in construction projects to support early-stage risk assessment and prioritization (Project Management Institute [PMI], 2017). Its relative simplicity and adaptability make it particularly suitable for projects operating under uncertain and dynamic conditions.

However, the application of the Probability–Impact Matrix to hospital construction projects located in disaster-prone areas, specifically from the contractor's operational perspective, has not been sufficiently explored in the existing body of knowledge. This gap limits the availability of empirically grounded insights that could assist contractors in identifying and prioritizing the most critical construction risks in high-hazard environments (Wang et al., 2020).

Accordingly, this study aims to identify and prioritize construction risks in a hospital construction project situated in a disaster-prone area using a contractor-based Probability–Impact Matrix approach. The empirical investigation was conducted at the CT Arsa Hospital construction project located in Palu City, Central Sulawesi Province, Indonesia, an area with a history of seismic activity and environmental hazards. By eliciting expert judgment from experienced project personnel and applying a structured semi-quantitative risk assessment framework, this research provides empirical evidence on the most significant risks affecting hospital construction under hazardous environmental conditions. The findings are expected to contribute to the construction risk management literature and offer practical insights for contractors involved in hospital projects within disaster-prone regions

II. METHODOLOGY

2.1 Research Design and Approach

This study adopts a qualitative research design using a case study approach to identify and prioritize construction risks in a hospital construction project located in a disaster-prone area. A qualitative and semi-quantitative approach is considered appropriate for examining construction risks under conditions of high uncertainty and limited availability of historical data, where expert judgment plays a central role in the assessment process (Aven, 2016).

The study focuses specifically on risk identification and prioritization using the Probability–Impact Matrix (PIM) method. Consistent with the exploratory nature of the research, the analysis is deliberately limited to assessing the relative significance of construction risks and does not extend to quantitative risk modeling or risk response evaluation, which typically require more extensive datasets and predictive assumptions (PMI, 2017).

2.2 Case Study Description

The empirical investigation was conducted on the CT Arsa Hospital construction project located in Palu City, Central Sulawesi Province, Indonesia, a disaster-prone region characterized by exposure to natural hazards such as seismic activity and extreme weather conditions. The project was selected as a representative case due to the inherent complexity of hospital facilities and the heightened level of environmental uncertainty affecting construction activities.

The unit of analysis in this study is the construction phase of the project. Focusing on the construction phase enables the identification of operational risks directly experienced by contractors, including risks related to site conditions, material procurement, construction methods, labor productivity, and safety management. This focus aligns with previous construction risk studies that emphasize contractor-level operational risks as a critical determinant of project performance (Wang et al., 2020).

2.3 Expert Selection and Data Collection

Data were collected through expert judgment obtained from key personnel involved in the construction phase of the project. A purposive sampling technique was employed to select respondents based on their professional experience, technical expertise, and direct involvement in the project. The selected experts included project managers, site engineers, and construction supervisors representing the contractor's perspective.

The use of expert judgment as a primary data source is widely recognized in construction risk research, particularly in contexts where empirical data are limited or project-specific (Kassem & Hamzah, 2019). Data collection was conducted using structured and semi-structured questionnaires to capture expert insights systematically.

2.4 Risk Identification and Expert Validation

An initial list of construction risks was generated using open-ended questions that allowed experts to identify potential risks based on their practical experience. This exploratory step enabled the capture of context-specific risks relevant to the hospital construction project.

To enhance the credibility and reliability of the identified risks, an expert validation process was conducted. Experts were asked to review, refine, and confirm the relevance of the identified risks to the project context. The use of expert judgment and validation has been widely recognized as an effective approach for improving the reliability of construction risk identification, particularly from the contractor's perspective in developing country contexts (Ibironke et al., 2013). Only risks confirmed through expert consensus were retained for subsequent analysis.

2.5 Probability–Impact Assessment

Following expert validation, the identified risks were assessed using the Probability–Impact Matrix approach. Each expert evaluated the risks based on two dimensions: the likelihood of occurrence (probability) and the severity of impact on the construction phase. A five-point ordinal scale was applied for both probability and impact, ranging from very low (1) to very high (5), consistent with established risk assessment practices (PMI, 2017).

The Probability–Impact Matrix method enables semi-quantitative prioritization of risks by combining probability and impact scores, providing a structured and transparent framework for ranking construction risks (Kassem & Hamzah, 2019). The risk score for each risk was calculated by multiplying the probability and impact values, allowing risks to be categorized according to their relative criticality.

2.6 Data Analysis and Risk Prioritization

Risk prioritization was conducted by ranking risks based on their calculated Probability–Impact scores. Risks with higher scores were interpreted as having a greater potential influence on construction performance and were therefore classified as critical risks. Descriptive analysis was employed to examine the distribution of risks across different categories.

The use of the Probability–Impact Matrix facilitates comparative analysis of risks and supports decision-making in complex construction environments where uncertainty is high (Aven, 2016; Wang et al., 2020). In accordance with the research scope, the analysis was confined to risk identification and prioritization without extending to predictive or optimization-based techniques.

2.7 Ethical Considerations

Participation in the study was voluntary, and all respondents were informed of the research objectives prior to data collection. The anonymity and confidentiality of participants were maintained throughout the research process. The study adhered to standard ethical principles for qualitative research involving human participants.

III. RESULT AND DISCUSSION

3.1 Initial Risk Identification Based on Interviews

The initial stage of the analysis focused on identifying construction risks based on in-depth interviews with key project personnel involved in the hospital construction project. This process resulted in a comprehensive list of potential risks reflecting practical challenges encountered during the construction phase from the contractor's perspective.

A total of 25 initial construction risks were identified and categorized according to their primary sources, including material procurement, financial, human resources, technical, managerial, operational, environmental, regulatory, and health and safety factors. The complete list of risks identified from the interviews is presented in Table 1.

Table 1. Initial Construction Risks

Risk Code	Risk Description	Risk Category
R1	Delay in delivery of main construction materials to the project site	Material Procurement
R2	Fluctuation in construction material prices (cement, steel, and reinforcing bars)	Financial
R3	Shortage of skilled labor on site	Human Resources
R4	Low labor productivity due to fatigue or lack of work motivation	Human Resources
R5	Disruption caused by extreme weather conditions (heavy rainfall, strong winds) affecting on-site activities	Environmental
R6	Breakdown of heavy equipment during construction activities	Technical
R7	Delay in progress payment from the project owner	Financial
R8	Design errors or design changes during project execution	Technical / Managerial
R9	Ineffective coordination among project stakeholders (contractor, consultant, and owner)	Managerial
R10	Errors in interpreting construction drawings by site personnel	Technical
R11	Delay in obtaining on-site permits from local authorities	Regulatory / Administrative
R12	Inadequate quality control supervision during construction works	Technical
R13	Delay in procurement of finishing materials due to supplier distribution issues	Material Procurement
R14	Logistics and transportation disruptions to the project site	Operational

R15	Errors in work schedule planning (unrealistic project time schedule)	Managerial
R16	Non-compliance of material specifications with site requirements	Technical
R17	Changes in government policies related to taxation or construction regulations	Regulatory / External
R18	Lack of coordination among subcontractors	Managerial
R19	Work-related accidents at the construction site	Health and Safety
R20	Limited working space in congested construction areas	Technical / Operational
R21	Internal communication problems among project teams	Managerial
R22	Actual soil conditions differing from initial geotechnical investigation results	Technical / Geotechnical
R23	Disruption of electricity and water supply at the project site	Operational
R24	Work delays due to late decision-making by the project owner	Managerial / External
R25	Delay in delivery of specialized equipment from outside the region	Procurement / Logistics

This initial risk list served as the basis for further refinement through expert validation.

3.2 Expert Validation of Construction Risks

Following the initial identification stage, an expert validation process was conducted to ensure the relevance and significance of the identified risks within the specific project context. Experts reviewed the initial risk list and confirmed which risks were considered significant and applicable to the hospital construction project.

As a result of this validation process, all 25 risks were confirmed as relevant, although their perceived significance varied. The validated risks were retained for probability and impact assessment using the Probability–Impact Matrix method. The list of expert-validated risks is summarized in Table 2.

Table 2. Expert-Validated Construction Risks

Risk Code	Risk Description (Short)
R1	Delay in delivery of main construction materials
R3	Shortage of skilled labor
R8	Design changes during construction
R5	Disruption due to extreme weather conditions
R25	Delay in delivery of specialized equipment
R2	Fluctuation in construction material prices
R13	Delay in procurement of finishing materials
R16	Non-compliance of material specifications
R14	Logistics disruption to the project site
R22	Actual soil conditions differing from investigation results
R12	Inadequate supervision of work quality
R24	Delay in decision-making by the project owner
R18	Lack of coordination among subcontractors
R4	Low labor productivity
R7	Delay in progress payment
R9	Ineffective coordination among project stakeholders
R15	Errors in work schedule planning
R19	Work-related accidents at the construction site
R21	Internal communication problems
R6	Breakdown of heavy equipment
R20	Limited working space in the construction area
R10	Errors in interpreting construction drawings
R23	Disruption of electricity and water supply
R11	Delay in obtaining site permits
R17	Changes in government policies

This validation step enhanced the credibility of the risk assessment by ensuring that subsequent analysis was based on shared expert judgment rather than individual perceptions.

3.3 Probability and Impact Assessment Results

Each expert-validated risk was assessed using a five-point Likert scale to evaluate its probability of occurrence and potential impact on the construction phase. The average probability (P) and impact (I) scores were calculated to represent collective expert judgment for each risk.

The results of the Probability–Impact assessment are presented in Table 3, which shows the average probability, average impact, calculated risk score ($R = P \times I$), and corresponding risk level for each validated risk.

Table 3. Probability and Impact Scores of Expert-Validated Risks

Risk Code	Risk Description (Short)	Risk Score ($R = P \times I$)	Risk Level
R1	Delay in delivery of main construction materials	21.6	Very High
R3	Shortage of skilled labor	19.8	High
R8	Design changes during	19.8	High

	construction		
R5	Disruption due to extreme weather conditions	18.9	High
R25	Delay in delivery of specialized equipment	18.5	High
R2	Fluctuation in construction material prices	18.1	High
R13	Delay in procurement of finishing materials	17.6	High
R16	Non-compliance of material specifications	16.8	High
R14	Logistics disruption to the project site	16.4	High
R22	Actual soil conditions differing from investigation results	16.0	High
R12	Inadequate supervision of work quality	15.6	Medium
R24	Delay in decision-making by the project owner	15.6	Medium
R18	Lack of coordination among subcontractors	15.2	Medium
R4	Low labor productivity	14.8	Medium
R7	Delay in progress payment	14.8	Medium
R9	Ineffective coordination among project stakeholders	14.8	Medium
R15	Errors in work schedule planning	14.8	Medium
R19	Work-related accidents at the construction site	14.7	Medium
R21	Internal communication problems	14.4	Medium
R6	Breakdown of heavy equipment	14.0	Medium
R20	Limited working space in the construction area	13.7	Medium
R10	Errors in interpreting construction drawings	13.0	Medium
R23	Disruption of electricity and water supply	12.6	Medium
R11	Delay in obtaining site permits	11.2	Medium
R17	Changes in government policies	11.2	Medium

The results indicate that several risks exhibit both high probability and high impact, suggesting a strong potential to disrupt construction performance if not adequately managed.

3.4 Risk Prioritization and Ranking

Risk prioritization was performed based on the calculated risk scores derived from the Probability–Impact Matrix. Risks were ranked from highest to lowest according to their R values, allowing the identification of critical risks requiring greater managerial attention.

The analysis reveals that material procurement delays, labor shortages, design changes, extreme weather conditions, and site-related technical issues dominate the upper ranks of the risk hierarchy. A summary of the Top 10 critical construction risks is presented in Table 4.

Table 4. Risk Ranking Summary of Top 10 Critical Construction Risks

Rank	Risk Code	Risk Description (Short)	Risk Level
1	R1	Delay in delivery of main construction materials	Very High
2	R3	Shortage of skilled labor	High
3	R8	Design changes during construction	High
4	R5	Disruption due to extreme weather conditions	High
5	R25	Delay in delivery of specialized equipment	High
6	R2	Fluctuation in construction material prices	High
7	R13	Delay in procurement of finishing materials	High
8	R16	Non-compliance of material specifications	High
9	R14	Logistics disruption to the project site	High
10	R22	Actual soil conditions differing from investigation results	High

All risks included in the Top 10 fall within the High to Very High risk levels, indicating their critical influence on the construction phase of the hospital project.

3.5 Distribution of Risks Based on the Probability–Impact Matrix Results

The distribution of risks across the Probability–Impact Matrix demonstrates a concentration of risks in the high-probability and high-impact zone. This clustering reflects the vulnerability of hospital construction projects in disaster-prone areas to operational disruptions arising from external environmental factors and internal project management challenges.

The Probability–Impact Matrix proved effective in providing a clear and transparent framework for comparing risks and identifying priority areas for managerial focus during the construction phase.

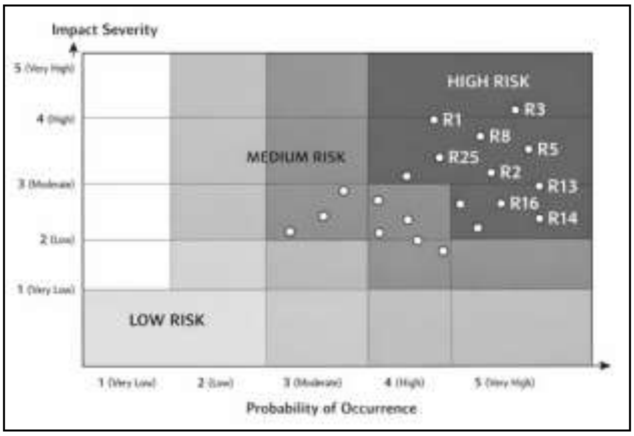

Figure 1. Probability Impact Matrix construction risks

The Figure 1 illustrates the distribution of expert-validated construction risks based on their average probability and impact scores. The majority of critical risks are clustered in the high-probability and high-impact zone, indicating significant vulnerability of the construction phase, particularly to material procurement delays, labor shortages, design changes, and extreme weather conditions.

3.6 Summary of Key Findings

Overall, the results indicate that construction risks in the studied hospital project are predominantly driven by material procurement, human resources, technical/site conditions, and environmental factors. The Probability–Impact Matrix approach enabled systematic identification and prioritization of risks under conditions of uncertainty and limited historical data.

These findings provide a solid empirical basis for further discussion on the characteristics of construction risks in hospital projects located in disaster-prone environments. However, the development of specific risk response strategies is beyond the scope of this study.

3.7 Discussion

The results of the Probability–Impact Matrix analysis indicate that construction risks in the hospital project are predominantly concentrated in the high and very high-risk categories, particularly those related to material procurement delays, labor shortages, design changes, and extreme weather conditions. The clustering of these risks in the high-probability and high-impact zone highlights their critical influence on construction performance in disaster-prone environments.

The prominence of procurement- and weather-related risks reflects the vulnerability of hospital construction projects to supply chain disruptions and environmental uncertainty. This finding is consistent with previous studies emphasizing that complex healthcare facilities are highly sensitive to external disruptions, especially in hazard-exposed regions (Shohet & Lavy-Leibovich, 2017; Bosher et al., 2019).

From the contractor's perspective, operational and coordination-related risks—such as design changes during construction and ineffective stakeholder coordination—also emerged as critical. These risks underline the importance of effective communication and decision-making processes during the construction phase, particularly in projects involving multiple stakeholders and complex technical requirements.

The application of the Probability–Impact Matrix proved effective in structuring expert judgment and prioritizing construction risks under conditions of uncertainty and limited data availability. Consistent with prior research, the findings confirm the suitability of semi-quantitative risk assessment methods for complex construction projects in disaster-prone areas (Kassem & Hamzah, 2019; PMI, 2017).

Overall, this study provides empirical evidence that a contractor-based Probability–Impact Matrix approach offers a practical and transparent framework for identifying and prioritizing critical construction risks in hospital projects located in disaster-prone environments. While the development of risk response strategies is beyond the scope of this study, the results establish a foundation for further research and informed risk management planning.

CONCLUSIONS

This study investigated construction risks in a hospital construction project located in a disaster-prone area using a contractor-based Probability–Impact Matrix approach. Through structured interviews, expert validation, and semi-quantitative risk assessment, the study identified and prioritized critical construction risks affecting the project during the construction phase.

The results indicate that the most critical risks are primarily associated with material procurement delays, shortages of skilled labor, design changes during construction, extreme weather conditions, and site-related technical uncertainties. The concentration of these risks in the high to very high risk categories highlights the vulnerability of hospital construction projects to operational and environmental disruptions in hazard-exposed regions.

The findings demonstrate that the Probability–Impact Matrix provides a practical and transparent framework for prioritizing construction risks under conditions of uncertainty and limited data availability. By adopting a contractor-based perspective, this study contributes empirical evidence to the construction risk management literature and enhances understanding of risk characteristics specific to hospital projects in disaster-prone environments.

While this study is limited to a single case and focuses on risk identification and prioritization, the results establish a foundation for further research. Future studies may extend this work by examining multiple projects or integrating semi-quantitative approaches with quantitative risk analysis methods to support more comprehensive construction risk management.

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