

Designing and Applying an FMEA-Based Framework for Cost Risk Mitigation in Building Construction Projects

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KEYWORDS	ABSTRACT
FMEA Framework Cost Risk Risk Mitigation Risk Priority Number (RPN). High Rise Projects	Cost overruns remain a persistent challenge in building construction, especially in high-rise projects where uncertainties in material prices, logistics, and cost estimation are prevalent. This study proposes an FMEA-based framework to systematically identify, evaluate, and prioritize cost risks using the Risk Priority Number (RPN). A case study in Medan demonstrates how risks can be classified into high, medium, and low categories, with high-risk factors such as material price escalation and delivery delays requiring immediate attention. The results highlight that integrating FMEA into the budgeting process improves cost allocation while enabling proactive risk mitigation. The study contributes theoretically by adapting FMEA to focus on construction cost risks, and practically by providing project managers and contractors with a structured tool to minimize budget overruns and enhance financial efficiency.

1. INTRODUCTION

High rise building construction projects are highly complex because they require the integration of labour, materials, equipment, financing, and time under dynamic conditions. This complexity increases susceptibility to uncertainties, especially in cost management. Cost deviations often lead to budget overruns, delays, and reduced construction quality. In Indonesia, these risks are particularly acute due to volatile material prices, logistical inefficiencies, and institutional financing constraints.

Empirical studies consistently report persistent cost overruns. Susanti and Nurdiana [1] identified inaccurate estimates, inflation, late deliveries, and delayed owner payments as major factors. Turkyilmaz [2] emphasized material price escalation and project complexity in high-rise contexts. Recent studies show that rework, design errors, scope changes, and weak cost evaluation systems remain critical drivers of inefficiency [3], [5]. These findings highlight the need for structured cost risk assessment frameworks.

Failure Mode and Effect Analysis (FMEA) offers a systematic approach to identifying and prioritizing risks through the Risk Priority Number (RPN). Although FMEA has been widely applied in quality, safety, and procurement contexts, its direct use for cost risk management in Indonesian high-rise projects remains limited. This presents an opportunity to adapt FMEA into a cost-focused framework.

Recent advances demonstrate its potential. Paydar et al. [6] used neuro-fuzzy inference to improve cost overrun forecasting, while Juan et al. [7] showed that statistical integration enhances risk prioritization. Lim et al. [8] combined FMEA with FTA and Delphi methods in high

rise residential projects, while Mahdi [9] and Al-Nahhas [10] developed fuzzy and ANFIS-based modifications. Collectively, these studies confirm the relevance of modernized FMEA in addressing complex construction risks.

This study contributes by designing and applying an FMEAbased framework for cost risk mitigation, with a case study in a high-rise building project in Medan. The framework systematically classifies risks into priority levels, offering both theoretical value to construction risk research and practical guidance for contractors and project managers in improving cost control and financial efficiency.

2. EXPERIMENTAL PROCEDURE

This study was carried out through several stages designed to develop and test an FMEA-based framework for cost risk mitigation in building construction projects.

A case study approach was adopted to ensure that the proposed framework could be tested in a real project context. The selected case was the construction of a Type-48 house, chosen because of its standardized design, well-defined cost structure, and frequent exposure to common risks such as material price escalation and delays in delivery.

Data for this research were obtained from both primary and secondary sources. Primary data were collected through interviews and questionnaires administered to project managers, site engineers, and procurement staff. Secondary data were drawn from budget documents, project progress reports, and material procurement records. This combination ensured that both planned costs

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and actual uncertainties encountered on site were captured. The Failure Mode and Effect Analysis (FMEA) method was applied to identify potential failure modes that could trigger cost overruns. Each risk was evaluated using three parameters: severity (S), occurrence (O), and detection (D). Scores were assigned on a scale of 1–10 based on expert judgment and historical project data. Risk levels were then quantified using the formula:

$$RPN=S \times O \times D$$

The Risk Priority Number (RPN) was used to rank risks according to their level of urgency.

Based on the RPN values, risks were classified into three categories: high, medium, and low. High-priority risks required immediate intervention, while medium- and low-level risks were managed through preventive actions and continuous monitoring. The framework was then integrated into the budget planning process, allowing cost allocations to be aligned with risk prioritization.

This procedure not only demonstrates the effectiveness of FMEA in analyzing cost risks but also provides practical guidance for project managers in linking budget planning with risk mitigation strategies.

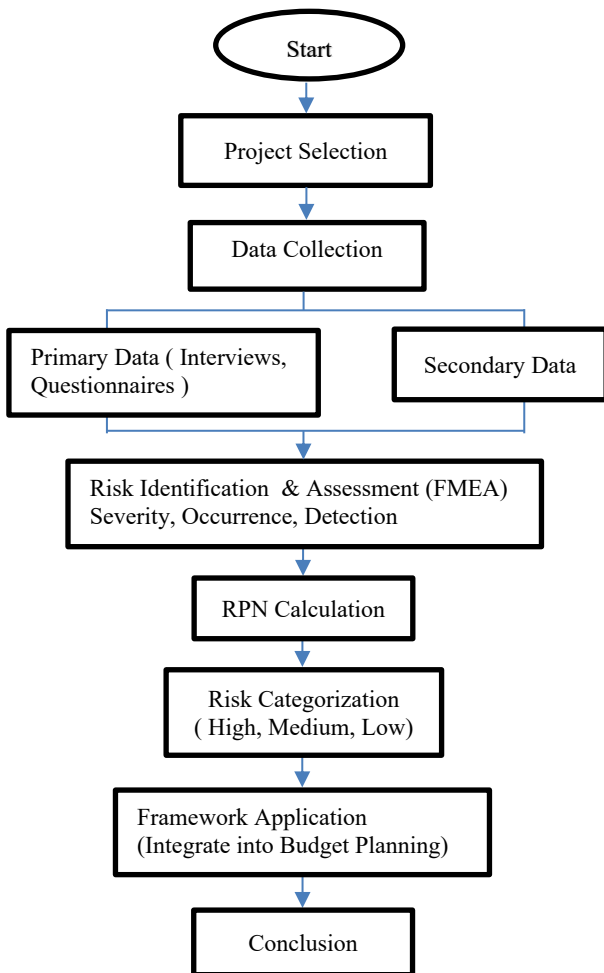


Figure 1. Research methodology flowchart.

3. RESULTS AND DISCUSSION

3.1 Recapitulation of Average Values of S, O, D, and RPN

Based on the results of processing the FMEA questionnaire data from 10 respondents, the average values of Severity (S), Occurrence (O), and Detection (D) were obtained for each identified risk. These average values were then used to calculate the Risk Priority Number (RPN), which serves as an indicator of the level of risk priority. The calculation steps are undertaken as follows:

1. Calculating the Average Value of Each Parameter
The values of Severity (S), Occurrence (O), and Detection (D) from the 10 respondents are summed, then divided by the number of respondents (n = 10). The formula is as follows:

$$S_{avg} = \frac{\sum_{i=1}^{10} S_i}{10}, \quad O_{avg} = \frac{\sum_{i=1}^{10} O_i}{10}, \quad D_{avg} = \frac{\sum_{i=1}^{10} D_i}{10}$$

2. Calculating the Average RPN
After obtaining the average values, the RPN is calculated by multiplying the average S, O, and D values:

$$RPN_{avg} = S_{avg} \times O_{avg} \times D_{avg}$$

3. Example Calculation for Risk 1 (Delay in Delivery of Main Materials):
4.
 - The S value from 10 respondents = 82 → $S_{avg} = 82/10 = 8.2$
 - The O value from 10 respondents = 63 → $O_{avg} = 63/10 = 6.3$
 - The D value from 10 respondents = 46 → $D_{avg} = 46/10 = 4.6$

Thus:

$$RPN = 8.2 \times 6.3 \times 4.6 = 237.64$$

4.2 Results of the Calculation

Table 1 Risk Distribution Chart Based on RPN Categories

No.	Risk Description	S	O	D	Average RPN
1	Delay in the delivery of main materials	8.2	6.3	4.6	237.64
2	Design changes during construction	5.7	6.0	6.4	218.88
3	Fluctuation in construction material prices	4.7	4.7	6.4	141.38
4	Lack of supervision in material usage	8.4	6.5	3.2	174.72

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5	Errors in initial project cost estimation	5.1	8.0	3.7	150.96
6	Issues in project licensing	8.4	4.5	3.7	139.86
7	Insufficient labor skills	7.1	5.2	3.1	114.45
8	Delay in payment from project owner	8.4	5.5	4.1	189.42
9	Workplace accidents causing additional costs	4.6	4.5	6.1	126.27
10	Changes in fuel and energy prices	5.2	3.4	6.6	116.69
11	Rework due to poor quality	9.0	3.4	2.3	70.38
12	Delays caused by subcontractors	9.1	4.6	2.3	96.28
13	Extreme weather disruptions hindering work	7.3	4.2	6.5	199.29
14	Mismatch between drawings and site conditions	4.1	7.2	3.4	100.37
15	Limited construction equipment	8.4	3.5	2.1	61.74
16	Changes in work methods during the project	3.9	5.5	3.1	66.50
17	Administrative errors in procurement	3.4	5.8	5.4	106.49
18	Inflation affecting unit prices of work	9.0	5.8	7.8	407.16
19	Material damage due to poor storage	8.6	3.4	2.1	61.40
20	Conflicts among project teams	2.9	5.2	2.7	40.72
21	Disruptions from external parties (e.g., local community)	6.1	5.9	2.8	100.77
22	Additional costs due to excessive overtime	8.4	3.2	2.4	64.51
23	Incorrect material orders (wrong specifications)	9.2	2.8	2.0	51.52
24	Project subject to late penalties	9.2	3.3	1.9	57.68
25	Disruptions in logistics and material distribution	7.3	6.9	4.5	226.67
26	Discrepancies between budget plan and realization	3.8	8.3	3.2	100.93
27	Absence of contingency funds	5.3	6.0	2.6	82.68
28	Cost adjustments due to owner's requests	2.5	8.3	2.8	58.10

29	Lack of project documentation	6.2	4.5	2.5	69.75
30	Delays due to shortage of specialized experts	6.4	4.1	3.3	86.59

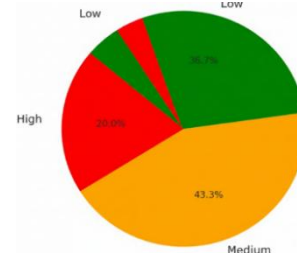


Figure 2. Risk Classification Chart Based on RPN.

Table 2 Mitigation Strategy Table Based on RPN

No.	Risk	RPN & Category	Handling Strategy
1	Inflation affecting unit prices of work	374.63 (High)	Use a price escalation clause in the main work contract. Involve the procurement team to project commodity price trends and make bulk purchases early when prices are still stable. Build long-term partnerships with trusted suppliers.
2	Disruptions in material logistics and distribution	295.58 (High)	Map out the material supply chain from the start of the project. Use logistics software with real-time tracking. Prepare alternative distribution routes and backup vendors for emergencies.
3	Delays in key material delivery	258.20 (High)	Implement a buffer stock system for crucial materials. Create delivery contracts with time penalties. Monitor delivery schedules and logistical preparations digitally and integrated with the project schedule.
4	Errors in initial project cost estimation	237.80 (High)	Update the cost estimation system using actual data from previous projects. Involve the Quantity Surveyor (QS) team and an independent auditor during the

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			preparation of the budget plan. Conduct a more detailed feasibility study before the project begins.
5	Payment delays from the project owner	219.98 (High)	Include a penalty clause in the contract for payment delays. Create a legally binding, phased payment schedule. Build open communication with the project owner to mitigate cash flow risks.
6	Slow permit and licensing issues	205.72 (High)	Establish early relationships with the relevant licensing agencies. Prepare administrative documents from the outset. Use the services of a legal consultant to oversee the permitting process.
7	Design changes during construction	190.45 (Medium)	Implement a "Design Freeze" system, where all designs must be approved before construction. If revisions are needed, they must be approved by risk management. Save all revision documentation digitally.
8	Extreme weather	189.14 (Medium)	Use long-range weather forecasts as the basis for scheduling. Provide protection for outdoor work (tarps, work tents). Add contingency duration to the project's Critical Path Method (CPM).
9	Lack of supervision in material usage	178.33 (Medium)	Create an internal logistics system based on barcodes and daily inspection forms. Use CCTV in material storage areas. Conduct weekly audits by an independent oversight team.
10	Material price fluctuations	151.04 (Medium)	Use fixed-price contracts for key materials. Diversify

			suppliers. Prepare an escalation fund within the project budget.
11	Discrepancy between budget plan (RAB) and actual costs	136.87 (Medium)	Use real-time budget software that syncs with on-site execution. Conduct a weekly review of the budget plan and actual costs with the project management team.
12	Lack of skilled labour	133.77 (Medium)	Hold regular technical training at the start of the project and when critical work is about to begin. Implement a mentoring system from senior to junior workers.
13	Work accidents resulting in additional costs	126.13 (Medium)	Mandate safety and health (K3) induction for all workers. Implement high K3 standards (Personal Protective Equipment/PPE, signs, hazard zones). Conduct weekly K3 audits by a special team.
14	Rising fuel prices	121.75 (Medium)	Rent heavy equipment with a fuel-inclusive system. Plan equipment operations efficiently. Provide manual tool alternatives for light work.
15	Procurement administration errors	119.45 (Medium)	Digitize all procurement documents. Use an administrative checklist before submitting a purchase request. Conduct documentation training for procurement staff.
16	Discrepancy between work drawings and field conditions	117.77 (Medium)	Conduct a joint site visit between the design and implementation teams before execution. Implement a fast Request for Information (RFI) system for technical questions from the field.

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17	Untidy project documentation	110.69 (Medium)	Use a cloud-based document management system like Google Drive or OneDrive. Appoint a Person-In-Charge (PIC) for documentation in each division. Conduct weekly project file audits.
18	Disruptions from external parties	107.76 (Medium)	Build communication with local residents. Involve village officials in the early stages of the project. Install information boards and work schedules at the project site.
19	Subcontractor delays	101.72 (Medium)	Include a delay penalty clause in subcontractor contracts. Hold weekly progress meetings. Prepare backup subcontractors for critical work.
20	Lack of expert personnel	98.78 (Low)	Involve experts from the tender or initial planning stage. Use a system of rotating expert teams between projects within the same company.
21	Material damage due to stacking	96.84 (Low)	Use the FIFO (First In, First Out) storage method. Provide storage areas for heavy materials that are protected from the weather.
22	Rework due to execution errors	90.54 (Low)	Implement a system for material testing and feasibility checks before installation. Provide intensive supervision during structural and finishing work.
23	Inefficient work methods	78.68 (Low)	Conduct daily toolbox meetings. Evaluate work methods weekly and change them if they prove to be ineffective.
24	Swelling overtime costs	76.28 (Low)	Reorganize the normal work schedule and involve additional shifts. Avoid overtime work

			unless it is absolutely essential.
25	Fines due to project delays	69.83 (Low)	Monitor weekly progress with time-tracking software. Identify the critical path and perform crashing if necessary.
26	Unavailable contingency funds	68.83 (Low)	Create a contingency fund of at least 5-10% of the total project cost. Discuss this risk during the initial budgeting stage.
27	Additional requests from the project owner	65.69 (Low)	Use an official variation order document for every change. Recalculate the volume and duration resulting from the changes.
28	Unavailable work equipment when needed	63.33 (Low)	Conduct a weekly equipment inventory. Create a list of critical tools and plan for backup rentals from outside vendors.
29	Technical specification errors	53.38 (Low)	Review technical specifications in contract documents and work plan and budget (RKS). Conduct a technical verification before purchasing and installation.
30	Conflict among project teams	44.08 (Low)	Hold regular discussion forums and create a shared work ethic code. Involve the project manager as a facilitator if conflicts arise.

The results are obtained as follows:

1. High Risk (20.0%)
There are 6 risks categorized as high. These are the top-priority risks that must be addressed immediately because they have RPN values above the average and potentially bring significant impacts to construction costs. Examples of risks in this category include inflation, logistics, and material delays.
2. Medium Risk (43.3%)
There are 13 risks categorized as medium. This proportion is the largest compared to other categories. Medium level risks still require consistent control; however, their urgency is lower

than that of high level risks. Examples include permitting, extreme weather, and material supervision.

3. Low Risk (36.7%)

There are 11 risks categorized as low. These risks are relatively more manageable and their impact on project costs is not highly significant. Nevertheless, low-level risks should still be monitored to prevent them from escalating into bigger issues. Examples include team conflicts, incorrect material specifications, and owner requests.

This distribution shows that the majority of building construction cost risks fall under the medium category (43.3%), followed by the low category (36.7%), and the high category (20.0%). Therefore, risk mitigation strategies should be focused on high priority risks, while maintaining proper supervision of medium-level risks to prevent them from escalating into more critical issues.

4. CONCLUSION

This study develops and applies an FMEA-based framework to address cost risks in building construction projects, particularly in the context of a typical type 48 house. The framework integrates risk identification, quantification, and prioritization directly into the budgeting process, ensuring that cost allocation is systematically aligned with risk mitigation. Using FMEA, each potential cost risk is assessed through severity, occurrence, and detection, producing Risk Priority Numbers (RPN) that allow for transparent classification into high, medium, and low categories. This structured approach enables project managers to distinguish between risks that require immediate intervention and those that can be managed through continuous monitoring.

The novelty of this framework lies in its integration of FMEA based risk prioritization directly into cost budgeting, linking RPN outcomes with profit margin sustainability. Unlike previous studies that tend to treat budgeting and risk analysis separately, this research demonstrates how risk-informed budgeting can safeguard contractor profitability under conditions of uncertainty. The application shows that inflation, material logistics disruption, and delayed material delivery are among the most critical risks, with RPN values significantly above the average. By embedding mitigation strategies into the cost plan such as contract clauses, supply chain mapping, and digital logistics monitoring the framework not only enhances financial efficiency but also strengthens decision-making in managing construction cost volatility.

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