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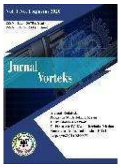

FMEA BASED FRAMEWORK FOR COST RISK MITIGATION IN BUILDING CONSTRUCTION PROJECTS

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Abstract

Infrastructure development in Indonesia, especially building construction projects, often faces cost risk issues, such as budget overruns and delays, that can interfere with project success. In the face of these challenges, the Failure Mode and Effect Analysis (FMEA) method has been known to be an effective tool for identifying and mitigating risks. This research aims to develop an FMEA-based framework to mitigate cost risks in high-rise building construction projects. This study identified, evaluated, and prioritized 30 types of cost risks using quantitative techniques and data collection from 10 respondents directly involved in construction projects in Medan. The gap found in this study is the application of conventional FMEA methods that do not consider uncertainty and interdependence between risks. Therefore, a new approach is needed that integrates FMEA methods with real-time monitoring systems and data-driven technologies. The novelty of this research lies in the development of a more adaptive FMEA model that is integrated with digital technology to manage cost risks more accurately and efficiently. The results showed that most of the cost risks were classified in the medium (43.3%) and low (36.7%) risk categories, with high risks (20%) including material price inflation and logistics disruptions that require immediate handling. The conclusion of the study is that the implementation of a more adaptive and data-driven FMEA can improve cost risk management in construction projects, helping to reduce budget overruns and ensure project success

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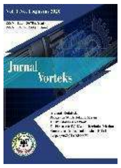

Keywords: *FMEA, Risiko Biaya, Konstruksi*

Abstrak

Pembangunan infrastruktur di Indonesia, khususnya proyek konstruksi bangunan, sering kali menghadapi masalah risiko biaya, seperti pembengkakan anggaran dan keterlambatan, yang dapat mengganggu keberhasilan proyek. Dalam menghadapi tantangan ini, metode Failure Mode and Effect Analysis (FMEA) telah dikenal sebagai alat yang efektif untuk mengidentifikasi dan memitigasi risiko. Penelitian ini bertujuan untuk mengembangkan framework berbasis FMEA guna mitigasi risiko biaya pada proyek konstruksi gedung bertingkat. Penelitian ini mengidentifikasi, mengevaluasi, dan memprioritaskan 30 jenis risiko biaya dengan menggunakan teknik kuantitatif dan pengumpulan data dari 10 responden yang terlibat langsung dalam proyek konstruksi di Medan. Gap yang ditemukan dalam penelitian ini adalah penerapan metode FMEA yang konvensional yang kurang mempertimbangkan ketidakpastian dan interdependensi antar risiko. Oleh karena itu, diperlukan pendekatan baru yang mengintegrasikan metode FMEA dengan sistem monitoring real-time dan teknologi berbasis data. Keterbaruan dari penelitian ini terletak pada pengembangan model FMEA yang lebih adaptif dan terintegrasi dengan teknologi digital untuk mengelola risiko biaya secara lebih akurat dan efisien. Hasil penelitian menunjukkan bahwa sebagian besar risiko biaya terklasifikasi dalam kategori risiko sedang (43,3%) dan rendah (36,7%), dengan risiko tinggi (20%) termasuk inflasi harga material dan gangguan logistik yang memerlukan penanganan segera. Kesimpulan dari penelitian ini adalah bahwa penerapan FMEA yang lebih adaptif dan berbasis data dapat meningkatkan pengelolaan risiko biaya dalam proyek konstruksi, membantu mengurangi pembengkakan anggaran dan memastikan keberhasilan proyek..

INTRODUCTION

Infrastructure development and building construction are top priorities in Indonesia's National Research Master Plan (RIRN) 2025 [1][2][3]. This is in line with the government's efforts to accelerate economic growth, increase connectivity, and support equitable development throughout Indonesia [4][5]. However, the realization of construction projects in Indonesia faces major challenges, especially related to high cost risks, such as cost overruns, delays, and declining building quality [6]. Based on existing data, only about 20% of construction projects in Indonesia are completed within budget, while the rest experience significant cost deviations [7]. The following table shows the percentage of construction projects that experience budget overruns in several countries, including Indonesia:

Table 1 Parameters percentage of construction projects

Country	Percentage of Projects with Budget Strains
Indonesia	80%
Australia	55%
Singapore	45%
United States	60%

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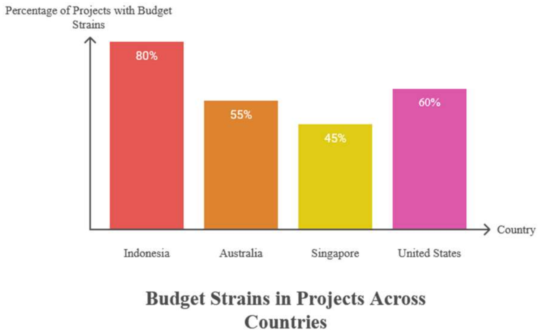


Figure 1 Parameters percentage of construction projects

In addition, some of the latest issues that have further exacerbated the cost risk in construction projects in Indonesia, include fluctuations in material prices, regulatory uncertainty, limited skilled labor, and the impact of climate change and pandemics [8][9]. Failure to manage these risks can threaten the success of projects, hinder the achievement of national development targets, lower investor confidence, and burden state finances [10].[11] However, the implementation of effective risk management is still a major weakness in the construction sector in Indonesia. Many projects have not implemented a systematic and measurable approach to identifying, assessing, and mitigating cost risks [12][13][14]. In fact, RIRN 2025 emphasizes the importance of innovation and adoption of technology as well as modern management methods to increase efficiency, transparency, and accountability in the management of infrastructure projects [15][16]. One of the internationally proven methods in managing cost risk is Failure Mode and Effect Analysis (FMEA). This method is effective and adaptive in identifying, prioritizing, and mitigating risks systematically, even in an environment of uncertainty [17][18]. The integration of FMEA with multi-criteria approaches and digital technologies is very relevant to answer national research needs and

State Of The Art Research

Research on the application of Failure Mode and Effect Analysis (FMEA) in mitigating the cost of building construction projects has made significant progress in the past decade [19]. This transformation is marked by a shift from conventional FMEA methods to hybrid models that integrate fuzzy logic, multi-criteria decision making (MCDM), and data-driven approaches to improve the accuracy and relevance of risk mitigation [20][21].

Initially, FMEA was traditionally used to identify and prioritize risks based on a Risk Priority Number (RPN) calculated from the severity, likelihood, and detection of 197 risks. However, the limitations of conventional FMEA in dealing with uncertainty and interdependence between risks encourage the birth of innovations in the form of integration with fuzzy, SWARA, ANP, and MCDA 21113 methods. These hybrid models have been shown to provide more accurate and comprehensive results in cost risk assessment and prioritization, even in complex and uncertain project environments 253.

Recent research highlights the application of fuzzy-based and multi-criteria FMEA to a variety of real-life case studies, including construction projects in Indonesia 820 [22]. In addition, recent trends show FMEA's integration with real-time monitoring systems and consensus-based decision-making, which further strengthens its effectiveness in cost risk management 125. This innovation is in line with the needs of the modern construction industry which demands efficiency, transparency, and adaptation to evolving risk dynamics.

Table 2 Development of FMEA Research in Construction (2010–2025)

Year	Main Approaches/Methods	Key & Application Innovation	Quotes
2010	Fuzzy FMEA + AHP	Fuzzy-based risk assessment	[23]
2016	Fuzzy FMEA + MCDA	Multi-criteria integration	[24]
2020	FMEA + FDEMATEL-ANP	Risk interdependence, hybrid model	[25]

2021	FMEA-SWARA-WASPAS (fuzzy)	Integrated model, high accuracy	[26]
2023	FMEA + bibliometric, Indonesian application	Objective analysis, Indonesian case study	[12]
2025	FMEA + real-time monitoring	Digital system integration, wide application	[27][28]

Table 3 FMEA Publication Data in Construction

Year	Number of Publications
2010	1
2011	19
2012	7
2013	4
2014	2
2015	3
2016	4
2017	11
2018	18
2019	14
2020	16
2021	11
2022	13
2023	5
2024	20
2025	6

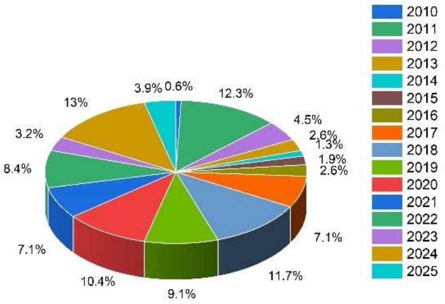


Figure 2 FMEA Publication Data in Construction

Research Gap

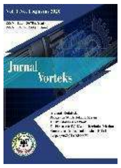
Although the Failure Mode and Effect Analysis (FMEA) method has been widely used to identify and mitigate risks in construction projects, there are still some shortcomings that are research gaps and need to be answered in order to make the implementation of FMEA more effective, especially in Indonesia. First, conventional FMEA still has limitations in dealing with uncertainty and interrelated relationships between risks. Traditional methods rely only on the Risk Priority Number (RPN) which has not been able to consider the interdependencies between risks and often results in inaccurate assessments of complex systems [4][29]. Some studies have developed hybrid models by combining FMEA and other methods such as fuzzy logic, SWARA, ANP, and MAIRCA, but their application is still limited to specific case studies and has not been widely adopted in different types of construction projects [24][20].

Second, most FMEA research still focuses on static risk assessment and has not integrated much of FMEA with real-time monitoring systems or data-driven approaches. In fact, this integration is essential to improve the speed and accuracy of responses to changes in risks in the field [21][29][23].

Third, empirical research that tests the effectiveness of FMEA models, especially hybrid or fuzzy-based models, on construction projects in Indonesia is still very limited. Most studies in Indonesia are still conceptual or only on a specific project scope, so they have not been able to provide a comprehensive picture of the effectiveness of FMEA in the local context [28].

Fourth, the decision-making process in FMEA often involves many experts, but consensus models and multi-expert collaboration are still rarely systematically integrated. This causes the potential for bias and differences in perception between assessors to be high, so that the results of the risk assessment are less than optimal [17].

Fifth, there is still a lack of research linking the results of FMEA to the needs of national standardization, development policies, and the Indonesian National Research agenda 2025. In fact, this integration is important so that research results can be implemented widely and sustainably [6].



Thus, research that develops FMEA models that are more adaptive, data-based, integrated with digital systems, empirically tested in Indonesia, and aligned with national policies are needed to answer real challenges in the field and support the progress of Indonesia's construction industry [4].

Research Novelty

This research introduces an innovative approach to creating water-efficient sewer systems using Monte Carlo simulations and the Empirical Method of Deconstruction Equipment Units. The fixed coefficients associated with the unit's equipment are replaced with a probabilistic distribution that captures observed variations in facility utilization, thereby improving the accuracy of the wastewater demand representation and making it more detailed and less susceptible to uncertainty. The proposed Monte Carlo-based design framework integrates technical factors (pressure, flow, pipeline size), financial considerations (life-cycle costs, return on investment), and environmental issues (carbon emissions, water efficiency) into a comprehensive design assessment system to improve pipeline sizing, network layout, and maintenance strategies. This approach seeks to offer a more flexible solution to clean water supply system requirements, especially regarding fluctuations in demand and operational challenges.

RESEARCH METHODS

Research Location and Time

This research was carried out on the construction project of the Product Testing and Animal Disease Inspection Laboratory located on Jalan Jenderal Gatot Subroto No. 255 A, Medan, North Sumatra. The selection of this location is based on its relevance to the purpose of the study, in particular in analyzing the cost risk of high-rise building construction projects. The research was carried out during the project implementation period in 2025.

Research Type and Design

This study uses a quantitative approach with *the Failure Mode and Effect Analysis* (FMEA) method to identify, evaluate, and prioritize cost risks in high-rise building construction projects. The research design is descriptive-analytical using primary data obtained through structured questionnaire instruments.

Population and Sample

Population

The population in this study is all personnel who are directly involved in the management and implementation of the construction project of the Product Testing and Animal Disease Inspection Laboratory in Medan, including the project management team, field supervisors, and support staff.

Sample

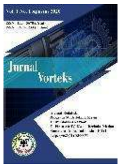
Sampling technique using *purposive sampling* with the criteria of respondents who have experience, competence, and active involvement in the technical and cost aspects of the project. The total sample used was 10 respondents representing various strategic positions in the project, namely: *Project Manager*, *Site Manager*, *Technical Manager*, logistics staff, HSE staff (*Health, Safety, and Environment*Field Supervisor, *MEP Manager*, documentation staff, and administrative staff. This number of respondents was considered adequate for FMEA-based research given the depth of analysis and diverse representation of expertise [17].

Research Materials and Tools

Research Materials

The materials used in this study include:

1. **Project Documents**
    - Project Cost Budget Plan (RAB)
    - Working drawings and technical specifications
    - Employment contracts and procurement documents
    - Historical data of similar projects (if available)
    - *Project progress report*
2. **Literature and References**



  - Scientific journal on construction risk management
  - FMEA standards and their application guidelines in the construction industry
  - Previous research related to *cost overrun* in Indonesia
  - Construction project management textbook
3. **Primary Data**
   - FMEA questionnaire that has been filled out by 10 respondents
   - Severity *(S),* Occurrence *(O), and* Detection (D) *assessment data* for each identified cost risk

Research Tools

The tools used in this study consisted of:

1. **FMEA Questionnaire Instrument**
      - The structured questionnaire contains 30 construction cost risk items
      - Rating scale of 1-10 for parameters S, O, and D
   - Digital and print formats for easy filling
2. **Data Analysis Software**
   - **Microsoft Excel 2019**: for data processing, calculation of S, O, D, and RPN mean values, and creation of tables and graphs
   - **IBM SPSS Statistics 26**: for instrument reliability tests using *Cronbach's Alpha*
   - **Data visualization software**: for risk distribution diagramming
3. **Supporting Devices**
   - Laptop/computer for data processing
   - *Smartphones* for documentation and communication with respondents
   - Stationery for field recording
   - Cameras for research site documentation
4. **Documentation Tools**
   - Google Maps for project location mapping
   - Document management application (*cloud storage*) for data storage

Research Variables

Variables in this study include:

Independent Variables

- **Severity (S):** The severity of the impact if risk occurs (scale 1-10)
- **Occurrence (O):** The frequency or probability of occurrence of risk (scale 1-10)
- **Detection (D):** Ability to detect risks before they make an impact (scale 1-10)

Dependent Variable

- **Risk Priority Number (RPN):** The risk priority index calculated by multiplying S × O × D

Cost Risk Variables

There are 30 types of cost risks identified, including: unit price inflation, material logistics disruptions, material delivery delays, initial cost misestimates, late payments, licensing issues, design changes, extreme weather, and others.

Data Collection Procedure

Data collection is carried out through the following stages:

1. **Early Risk Identification**
      - Conduct a literature review to identify common cost risks in high-rise building construction projects
      - Conducting initial observations at the project site
      - Consult with *a project manager* to validate the risk list
2. **Instrument Arrangement**
      - Design FMEA questionnaires based on theory and literature studies
      - Validating instruments through *expert judgment*
      - Conduct *a pilot test* to ensure the clarity of the instrument
3. **Primary Data Collection**
   - Explain the purpose of the research and the questionnaire procedure to the respondents
   - Distribute questionnaires to 10 selected respondents
   - Conduct *follow-up* to ensure complete filling
   - Recollect completed questionnaires
4. **Data Verification**
   - Check the completeness and consistency of data
   - Reconfirm if there is any suspicious data

Data Analysis Techniques

1. Instrument Reliability Test

Before conducting the main analysis, a reliability test was carried out using *Cronbach's Alpha* through IBM SPSS Statistics 26. The instrument is considered reliable if *Cronbach's Alpha* value ≥ 0.70 (Sugiyono, 2020). The results of the reliability test in this study showed a *value of Cronbach's Alpha* = 0.960, which indicates very high reliability.

2. Calculation of Average Values of S, O, and D

For each risk, the *Severity* (S), *Occurrence* (O), and *Detection* (D) values of the 10 respondents were summed and then divided by the number of respondents:

$$rata - rata = \frac{\sum_{i=1}^{n} X_i}{n}$$

where:

X_I = value from the first respondent

n = number of respondents (n = 10)

3. Risk Priority Number (RPN) Calculation

RPN is calculated by multiplying the average values of *Severity*, *Occurrence*, and *Detection*:

$$RPN = S_{avg}\ x\ O_{avg}\ xD_{avg}$$

where:

S_{avg} = average *Severity value*

O_{avg} = *average Occurrence value*

D_{avg} = *average Detection value*

4. Risk Priority Classification

Based on the RPN values obtained, risks are classified into three categories (Sugiyono, 2020; Juan, Sheu, & Chen, 2023)

Table 4 Risk priority

RPN range	Risk Categories	Action
RPN ≥ 200	High Risk	Requires immediate treatment and priority mitigation strategies
100 ≤ RPN < 200	Medium *Risk*	Requires monitoring and corrective action

ANALYSIS AND EVALUATION

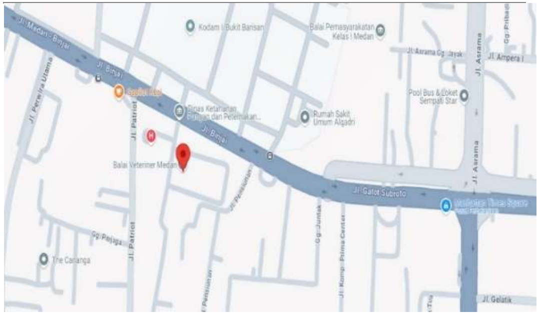


Figure 3 GPS Map of the Project Location (Google Map, 2025)

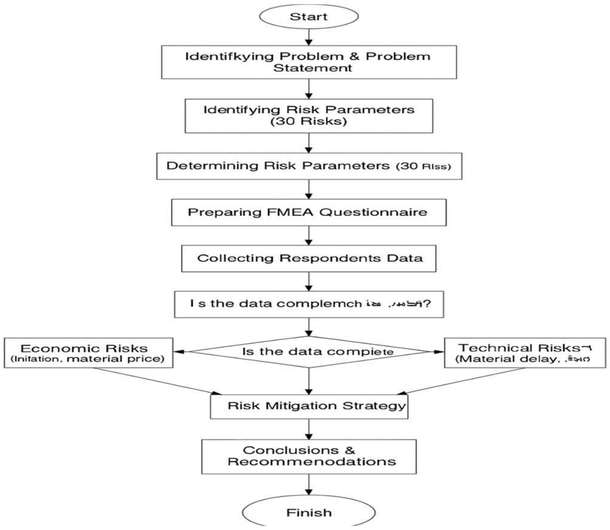
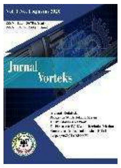


Figure 4 Research Method Flowchart

Results and Discussion

General Overview of Respondents

The respondents in this study are professionals who play important roles in the implementation



process of multi-storey building construction projects. The respondents were selected using purposive sampling, based on their experience, competence, and active involvement in managing projects from both technical and cost perspectives.

A total of 10 respondents participated in this study, representing various strategic positions in the project, including project manager, technical manager, site manager, field supervisor, HSE (Health, Safety, and Environment) staff, logistics staff, and foreman. With their diverse backgrounds and experiences, the data obtained are expected to reflect the actual conditions as well as the potential cost risks in multi-storey building construction projects in an objective and comprehensive manner. The following table presents the details of the respondents' names and positions:

Table 5 Respondents Names and Positions

Yes	Respondent's Name	Position
1	Abdul Jaelani, S.T.	Project Manager
2	Ragil Trio, S.Ars.	Site Manager
3	Alexander Manurung, S.T.	Technical Manager
4	Salmon Sinaga	Logistics Staff
5	Yuven Wedo, S.Ars.	HSE Staff
6	Davit Aritonang	Field Supervisor 1
7	Lusben Ompusunggu	Field Supervisor 2
8	Romillo Tanahitumess, S.T.	MEP Manager
9	Boby Dunant Panjaitan	Documentation Staff
10	Dika Saputra, S.T.	Administrative Staff

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 ParameterThe 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:

$$S_{avg}=\frac{\sum_{i=1}^{10} s_i}{10}, O_{avg}=\frac{\sum_{I=1}^{10} 0_I}{10}, \frac{\sum_{i=1}^{10} D_I}{10}$$

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×O avg×D avg

3. Example Calculation for Risk 1 (Delay in Delivery of Main Materials):

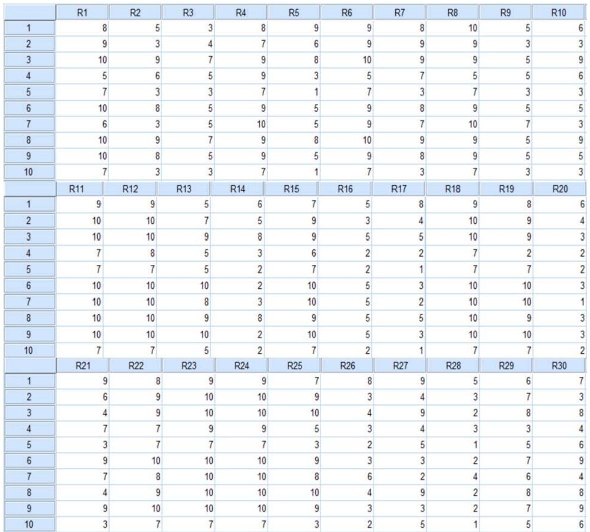
- The S value from 10 respondents = 82 → Savg
= 82/10 = 8.2
- The O value from 10 respondents = 63 → avg = 63/10 = 6.3
- The D value from 10 respondents = 46 → Davg
= 46/10 = 4.6

Thus:
RPN = 8.2 × 6.3 × 4.6 = 237.64

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:

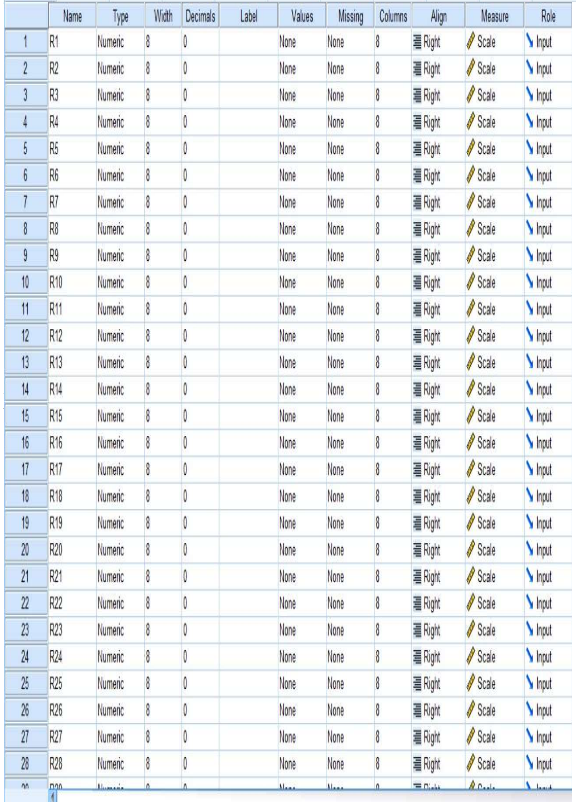
Table 6 Recapitulation of Average Values of S, O, D, and RPN



	R1	R2	R3	R4	R5	R6	R7	R8	R9	R10
1	8	5	3	8	9	9	8	10	5	6
2	9	3	4	7	6	9	9	9	3	3
3	10	9	7	9	8	10	9	9	5	9
4	5	6	5	9	3	5	7	5	5	6
5	7	3	3	7	1	7	3	7	3	3
6	10	8	5	9	5	9	8	9	5	5
7	6	3	5	10	5	9	7	10	7	3
8	10	9	7	9	8	10	9	9	5	9
9	10	8	5	9	5	9	8	9	5	5
10	7	3	3	7	1	7	3	7	3	3

	R11	R12	R13	R14	R15	R16	R17	R18	R19	R20
1	9	9	5	6	7	5	8	9	8	6
2	10	10	7	5	9	3	4	10	9	4
3	10	10	9	8	9	5	5	10	9	3
4	7	8	5	3	6	2	2	7	2	2
5	7	7	5	2	7	2	1	7	7	2
6	10	10	10	2	10	5	3	10	10	3
7	10	10	8	3	10	5	2	10	10	1
8	10	10	9	8	9	5	5	10	9	3
9	10	10	10	2	10	5	3	10	10	3
10	7	7	5	2	7	2	1	7	7	2

	R21	R22	R23	R24	R25	R26	R27	R28	R29	R30
1	9	8	9	9	7	8	9	5	6	7
2	6	9	10	10	9	3	4	3	7	3
3	4	9	10	10	10	4	9	2	8	8
4	7	7	9	9	5	3	4	3	3	4
5	3	7	7	7	3	2	5	1	5	6
6	9	10	10	10	9	3	3	2	7	9
7	7	8	10	10	8	6	2	4	6	4
8	4	9	10	10	10	4	9	2	8	8
9	9	10	10	10	9	3	3	2	7	9
10	3	7	7	7	3	2	5	1	5	6



	Name	Type	Width	Decimals	Label	Values	Missing	Columns	Align	Measure	Role
1	R1	Numeric	8	0		None	None	8	Right	Scale	Input
2	R2	Numeric	8	0		None	None	8	Right	Scale	Input
3	R3	Numeric	8	0		None	None	8	Right	Scale	Input
4	R4	Numeric	8	0		None	None	8	Right	Scale	Input
5	R5	Numeric	8	0		None	None	8	Right	Scale	Input
6	R6	Numeric	8	0		None	None	8	Right	Scale	Input
7	R7	Numeric	8	0		None	None	8	Right	Scale	Input
8	R8	Numeric	8	0		None	None	8	Right	Scale	Input
9	R9	Numeric	8	0		None	None	8	Right	Scale	Input
10	R10	Numeric	8	0		None	None	8	Right	Scale	Input
11	R11	Numeric	8	0		None	None	8	Right	Scale	Input
12	R12	Numeric	8	0		None	None	8	Right	Scale	Input
13	R13	Numeric	8	0		None	None	8	Right	Scale	Input
14	R14	Numeric	8	0		None	None	8	Right	Scale	Input
15	R15	Numeric	8	0		None	None	8	Right	Scale	Input
16	R16	Numeric	8	0		None	None	8	Right	Scale	Input
17	R17	Numeric	8	0		None	None	8	Right	Scale	Input
18	R18	Numeric	8	0		None	None	8	Right	Scale	Input
19	R19	Numeric	8	0		None	None	8	Right	Scale	Input
20	R20	Numeric	8	0		None	None	8	Right	Scale	Input
21	R21	Numeric	8	0		None	None	8	Right	Scale	Input
22	R22	Numeric	8	0		None	None	8	Right	Scale	Input
23	R23	Numeric	8	0		None	None	8	Right	Scale	Input
24	R24	Numeric	8	0		None	None	8	Right	Scale	Input
25	R25	Numeric	8	0		None	None	8	Right	Scale	Input
26	R26	Numeric	8	0		None	None	8	Right	Scale	Input
27	R27	Numeric	8	0		None	None	8	Right	Scale	Input
28	R28	Numeric	8	0		None	None	8	Right	Scale	Input

Table 7 SPSS Output (Variable View)

No	Risk	S	O	D	RPN (Average)
1	Delay in 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	Fluctuations in construction material prices	4.7	4.7	6.4	141.38
4	Lack of supervision over material usage	8.4	6.5	3.2	174.72
5	Errors in initial project cost estimation	5.1	8.0	3.7	150.96
6	Project permit issues	8.4	4.5	3.7	139.86
7	Lack of worker 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	Work 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	Delay in subcontractor work	9.1	4.6	2.3	96.28
13	Extreme weather disruptions hindering work	7.3	4.2	6.5	199.29
14	Discrepancy between working 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	Change of work methods during the project	3.9	5.5	3.1	66.5
17	Administrative errors in procurement	3.4	5.8	5.4	106.49
18	Inflation affecting unit work prices	9.0	5.8	7.8	407.16
19	Material damage due to poor storage	8.6	3.4	2.1	61.4
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	Ordering errors (wrong material specifications)	9.2	2.8	2.0	51.52
24	Penalties for project delays	9.2	3.3	1.9	57.68
25	Logistic and material distribution disruptions	7.3	6.9	4.5	226.67
26	Discrepancy between budget plan and realization	3.8	8.3	3.2	100.93
27	Unavailability of contingency funds	5.3	6.0	2.6	82.68
28	Cost adjustments due to project owner requests	2.5	8.3	2.8	58.1
29	Lack of project documentation	6.2	4.5	2.5	69.75
30	Delays due to limited specialized experts	6.4	4.1	3.3	86.59

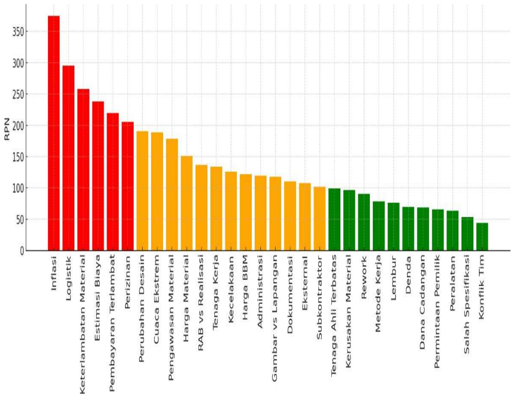
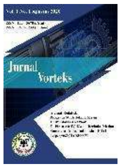


Figure 5 Risk Distribution Chart Based on RPN Categories

Based on the table above, the number of respondents used in the reliability test was 10 people (100%), with no excluded data (Excluded = 0). The total number of items tested was 30 questions representing the variables of construction cost risks in multi-story building projects. The Cronbach's Alpha value obtained was 0.960**,** which indicates that the reliability of the instrument falls into the very high category (≥ 0.90). **level approach. By integrating statistical data into the calculation of severity, occurrence, and detection, their model reduces subjectivity and allows for more precise risk prioritization.**

The classification of risk priority levels is based on the average RPN values, as proposed by



Sugiyono (2020). According to his methodology, risks can be categorized into three priority levels:

- **RPN > 200 :** High-Priority Risk
- **100 < RPN ≤ 200** : Medium-Priority Risk
- **RPN ≤ 100** : Low-Priority Risk

This structured approach allows project managers to systematically identify and address risks, ensuring that critical risks are managed promptly while avoiding unnecessary effort on low priority risks. The classification also provides a quantitative basis for risk assessment, supporting evidence-based decision making in construction project management (Sugiyono, 2020).

This structured approach allows project managers to systematically identify and address risks, ensuring that critical risks are managed promptly while avoiding unnecessary effort on low-priority risks. Moreover, the 10 level RPN classification provides a more quantitative basis for risk assessment, thereby supporting evidence based decision-making and enhancing the reliability of construction project management (Juan, Sheu, & Chen, 2023).

Based on the above criteria, the following classification results were obtained:

High-Priority Risks (RPN > 200):

1. Inflation affecting unit prices = (RPN 374.63)
2. Logistical and material distribution disruptions = (RPN 295.58)
3. Delay in delivery of main materials = (RPN 258.20)
4. Error in initial project cost estimation = (RPN 237.80)
5. Delay in payment from project owner = (RPN 219.98)
6. Project permitting issues = (RPN 205.72)

Medium-Priority Risks (100 < RPN ≤ 200):

1. **Design changes during construction** = **(**RPN 190.45)
2. **Extreme weather disruptions hindering work** = **(**RPN 189.14)
3. **Lack of supervision over material usage** = (RPN 178.33)
4. **Fluctuations in construction material prices** = **(**RPN 151.04)
5. **Mismatch between budget plans and actual implementation** = (RPN 136.87)
6. **Insufficient workforce skills** = (RPN 133.77)
7. **Work accidents causing additional costs** = (RPN 126.13)
8. **Changes in fuel and energy prices** = (RPN 121.75)
9. **Administrative errors in procurement** = (RPN 119.45)
10. **Mismatch between working drawings and field conditions** = (RPN 117.77)
11. **Inadequate work documentation** = (RPN 110.69)
12. **External disturbances (e.g. local community)** = (RPN 107.76)
13. **Delays in subcontractor works** = (RPN 101.72)

Low-Priority Risks (RPN ≤ 100):

1. **Delays due to limited availability of certain experts =** (RPN 98.78)
2. **Material damage due to poor storage =** (RPN 96.84)
3. **Rework caused by poor quality =** (RPN 90.54)
4. **Changes in working methods during the project** = (RPN 78.68)
5. **Additional costs due to excessive overtime =** (RPN 76.28)
6. **Project subject to delay penalties** = (RPN 69.83)
7. **Unavailability of contingency funds =** (RPN 68.83)
8. **Cost adjustments due to project owner's requests** = (RPN 65.69)
9. **Limited availability of construction equipment =** (RPN 63.33)
10. **Errors in material orders (wrong specifications) =** (RPN 53.38)
11. **Conflicts among project teams** = (RPN 44.08)

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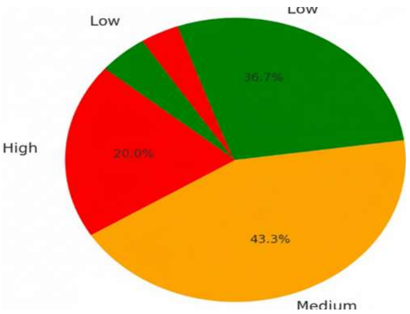
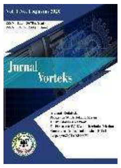


Figure 6 Risk Classification Chart Based on RPN

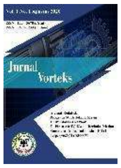
Medium makes up the largest portion at 43.3%.
Low is the second largest category, representing 36.7%.
High is the smallest category at 20.0%.

Table 4. 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 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



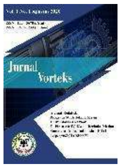
			by an independent oversight team.
10	Material price fluctuations	151.04 (Medium)	Use fixed-price contracts for key materials. Diversify suppliers. Prepare an escalation fund within the project budget.
11	Discrepancy between budget plan (RAB) and actual costs	136.87 (Medium)	Use real-time budget software 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.
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 between 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

CONCLUSION

Based on the research conducted on the cost risk management analysis of high-rise building construction projects using the Failure Mode and Effect Analysis (FMEA) method, the following conclusions can be drawn:

1. The implementation budget plan for a typical type-48 house shows that the contractor's profit margin is closely tied to the management of cost risks. Based on FMEA analysis, most of the 30 identified risks such as material price inflation, rework, and payment delays have high severity and occurrence, which can erode the expected profit margin if left uncontrolled. In general, contractors in similar residential projects aim for a profit margin of around 8–12%, but this margin may decrease substantially when risks are not mitigated effectively. Therefore, the budget plan serves not only to allocate costs but also to safeguard the contractor's profitability under uncertainty.
2. The implementation budget plan for the construction of a typical type 48 house is structured through a systematic identification and evaluation of potential cost risks using the Failure Mode and Effect Analysis (FMEA) method. This approach ensures that each potential source of cost deviation is quantified and categorized based on its level of urgency. The analysis results indicate that construction cost risks are distributed into three categories:
   high risk (20.0% with 6 risks), medium risk (43.3% with 13 risks), and low risk (36.7% with 11 risks). The high risk category represents the primary priority that must be addressed immediately, including material price inflation, logistical disruptions, and delays in material delivery, as these risks hold above average RPN values and exert the greatest potential impact on project costs. Medium level risks, although less urgent, constitute the largest proportion and therefore require consistent monitoring and preventive measures to avoid escalation. Meanwhile, low level risks are relatively manageable and exert a limited impact, but they still demand attention to ensure they do not develop into more severe problems. These findings demonstrate that the budget plan for a type 48 house construction project must not only allocate costs but also integrate risk prioritization, thereby enhancing financial efficiency and minimizing the probability of budget overruns.
3. The data processing results show that the risks with the highest RPN (Risk Priority Number) values are:
   - Inflation affecting unit prices of work (RPN: 374.63)
   - Disruption of material logistics and distribution (RPN: 295.58)
   - Delay in the delivery of key materials (RPN: 258.20)

These fall into the high priority category and must be addressed immediately, as they pose the greatest potential impact on project costs and schedules.

These risks fall into the high priority category and must be addressed immediately, as they represent critical vulnerabilities in the project's cost structure. Their potential to cause significant cost overruns and schedule delays makes them the most urgent risks for mitigation.

4. Mitigation strategies were developed based on the RPN levels, as follows:
    - **For Inflation**: Implementing price escalation clauses in contracts, making early bulk purchases, and forming partnerships with fixed suppliers.
    - **For Logistics**: Conducting supply chain mapping, utilizing logistics software, and appointing alternative vendors to minimize disruptions.
    - **For Material Delivery**: Establishing a buffer stock system, creating delivery contracts with penalties for delays, and implementing
    Digital logistics control to track and manage deliveries effectively.

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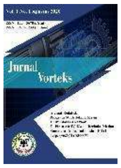

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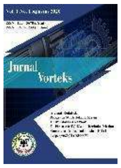

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