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Risk Barriers and Mitigation Strategies for High-Rise Building Delays in Surabaya Using Fuzzy Logic

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ABSTRACT

Delays in high-rise building projects negatively affect cost, quality, and schedule performance. This study aims to identify the main risk barriers and formulate appropriate mitigation strategies using a fuzzy logic approach. Data were collected from 80 valid respondents occupying strategic and operational roles in construction projects in Surabaya. Linguistic assessments (Low, Medium, High) were converted into Triangular Fuzzy Numbers and defuzzified using the centroid method to obtain crisp severity scores. The results indicate that cost overruns due to design revisions by the project owner (D4) represent the most critical risk barrier, with a defuzzification score of 3.717 (high category), followed by ineffective project control (E1) with a score of 3.483 (upper-medium category). The severity gap between D4 and the overall average of other indicators (≈3.30) shows a dominant external risk influence of approximately 0.40 points on the 1–5 fuzzy scale.Mitigation preferences reveal that risk avoidance is the dominant strategy for D4 (34 respondents), emphasizing design finalization before construction, while risk reduction is dominant for E1 (37 respondents), highlighting intensive monitoring and routine progress evaluation. Practically, prioritizing risks above the 3.50 threshold provides a structured basis for focusing managerial attention on the most critical delay drivers. Theoretically, this study demonstrates that fuzzy logic enhances decision accuracy by transforming subjective expert judgments into measurable and ranked risk severity values for high-rise construction projects.

INTRODUCTION

The demand for high-rise building construction in major cities such as Surabaya continues to increase due to population growth, limited land availability, and economic development (Shirleyana et al., 2018), (Sutantio et al., 2022). However, high-rise construction projects are inherently complex and exposed to significant risks that often lead to project delays (Vahedi Nikbakht et al., 2024), (Santoso et al., 2003). Such delays can generate severe consequences, including financial losses, legal disputes, and reduced trust from investors toward the construction sector (Basari, 2017).

Previous studies have highlighted that construction delays are commonly caused by both internal and external factors, ranging from poor planning and design changes to material supply disruptions, labor issues, and environmental or regulatory challenge (Manea, 2018), (Valente & Nascimento, 2021). Failure to identify and properly manage these risks often escalates project delays and leads to cost overruns (Doloi, 2013).

In the context of high-rise building projects in Surabaya, technical risks are also particularly relevant . A case study on the Grand Sungkono Lagoon project, for example, identified major risks such as adverse weather conditions affecting construction, difficulties in formwork installation at height, frequent design changes, and poor equipment maintenance. These were categorized as high-level risks requiring effective mitigation strategies (Rhosani et al., 2020). Recent international studies have emphasized the increasing adoption of fuzzy-based approaches in assessing construction risks and project delays. Kareem (2020) highlighted that fuzzy inference systems effectively capture subjective expert judgments and transform them into measurable decision parameters. Similarly (Kareem, 2023), Gebrehiwet and Luo (2019) developed a fuzzy comprehensive evaluation combined with the TOPSIS method to assess risk levels throughout the construction project lifecycle, demonstrating the method's accuracy in quantifying uncertainty (Gebrehiwet & Luo, 2019).

Given the high level of uncertainty in construction projects, fuzzy logic–based approaches have been increasingly applied to risk assessment and delay analysis (Abd El Khalek, 2016). Fuzzy logic is particularly effective in handling uncertain, vague, or subjective data, thereby providing more reliable risk evaluation compared to conventional methods (Singh & Trivedi, 2012). Recent studies also confirm the effectiveness of fuzzy inference systems such as Mamdani in identifying and prioritizing construction risks, particularly in areas related to safety, quality, financial management, and technology (Al-Mhdawi et al., 2024).

Therefore, this study focuses on analyzing the main risk barriers and mitigation strategies for project delays in high-rise building projects in Surabaya using a fuzzy logic approach. The findings are expected to provide practical contributions for stakeholders—including contractors, consultants, and project owners—by offering a systematic risk identification framework and more effective strategies for controlling delays.

RESEARCH METHODS

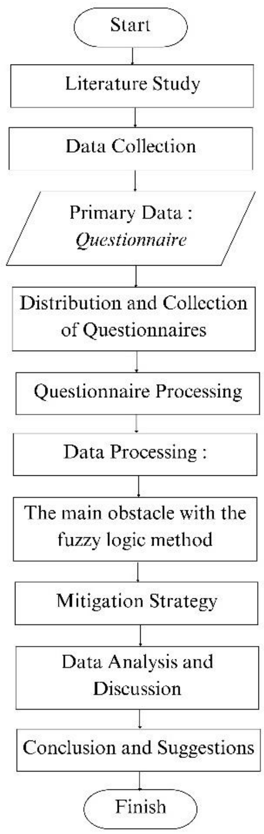

Figure 1. Research flowchart of the study illustrating the sequence of stages from questionnaire design, data collection, fuzzy logic processing, to the formulation of risk mitigation strategies.

This research employed a quantitative survey approach to identify the main barriers contributing to delays in high-rise building projects in Surabaya and to propose appropriate mitigation strategies. The methodology consisted of several interconnected stages, including research design, data collection, data processing using fuzzy logic, and the formulation of risk mitigation strategies.

The research design was developed based on an extensive literature review of previous studies related to construction risk and project delays. From this review, a structured questionnaire was formulated to capture indicators of internal and external risks that could influence the time performance of high-rise building projects.

Primary data were collected through questionnaires distributed to 88 targeted construction companies engaged in multi-storey building projects across Surabaya. The number 88 was determined based on the population of active medium-to-large municipal records to ensure that the survey represented companies with relevant experience in high-rise construction. A total of 80 valid responses were obtained, representing professionals in both managerial and operational positions such as Project Managers, Site Managers, Site Engineers, Estimators, Field Supervisors, General Managers, and Company Directors. This respondent composition ensured that the perspectives reflected a balance between decision-making and field-level implementation, providing a comprehensive overview of project operations.

Before distributing the final questionnaire, content validity was established through expert judgment involving two academics in construction management and one senior practitioner with more than 15 years of experience in high-rise building projects. This validation ensured clarity of wording, contextual relevance, and alignment between indicators and research objectives (Taherdoost, 2016).

To assess internal consistency, reliability testing was conducted using Cronbach's Alpha. Based on the commonly accepted threshold of $\alpha \geq 0.70$ (Nunnally, 1978; Hair et al., 2010), the questionnaire demonstrated acceptable reliability, indicating that the indicators consistently measure delay-related risk barriers and are suitable for further analysis.

The collected data were analyzed using a fuzzy logic approach, a mathematical reasoning framework introduced by Zadeh that allows qualitative linguistic judgments to be expressed quantitatively. Fuzzy logic has been widely applied in construction risk assessment for its capability to handle uncertainty and subjectivity in expert evaluations (Singh & Trivedi, 2012); (Manea, 2018); (Valente & Nascimento, 2021).

The fuzzy logic process in this study consisted of four key stages:

1. Fuzzification – transforming linguistic responses (Low, Medium, High) into Triangular Fuzzy Numbers (TFN) within a defined domain of 1–5. Each linguistic term was represented as a TFN (Low = (1,1,3); Medium = (2,3,4); High = (3,5,5)).
2. Aggregation of TFN Values – combining all respondents' fuzzy ratings into an aggregate TFN (a, b, c) for each delay indicator using the weighted average method.
3. Defuzzification – converting the aggregated TFN into a single crisp score through the centroid method, which produces a precise numerical representation of the risk level.
4. Ranking and Classification – ranking all indicators based on their crisp scores and classifying them into Low (≤2.49), Medium (2.50–3.49), and High (≥3.50) categories to identify the main risk barriers contributing to project delays.

This structured approach enables fuzzy logic to combine qualitative expert judgment and quantitative evaluation, providing a more objective prioritization of delay-related risks (Rhosani et al., 2020); (Valente & Nascimento, 2021).

The 1–5 domain was selected because it corresponds to the widely used five-point Likert scale, which provides sufficient sensitivity to distinguish levels of risk perception without generating excessive ambiguity (Likert, 1932; Boone & Boone, 2012). The five-level structure facilitates respondents' understanding and ensures methodological consistency with previous construction risk studies employing fuzzy approaches (Singh & Trivedi, 2012; Manea, 2018).

Triangular Fuzzy Numbers were chosen due to their mathematical simplicity and efficiency in representing linguistic uncertainty through three parameters (a, b, c), reflecting minimum, most probable, and maximum values (Zadeh, 1965; Buckley, 1985). Compared with other fuzzy representations, TFN provides a practical balance between analytical flexibility and interpretability, particularly in risk aggregation and defuzzification processes (Abd El Khalek, 2016; Valente & Nascimento, 2021).

Following the identification of major risk barriers, mitigation strategies were formulated based on four fundamental risk management principles: avoidance, reduction, transfer, and acceptance. Each mitigation measure was tailored to the characteristics of the identified risks. For instance, risks caused by design revisions were addressed using avoidance strategies, while risks resulting from weak project control were mitigated through reduction strategies involving tighter monitoring and progress evaluations.

Finally, the overall research process was summarized through a flow diagram to illustrate the logical connection between data collection, fuzzy logic analysis, and the formulation of mitigation strategies. This framework ensures that each analytical stage contributes systematically to achieving the research objectives.

RESULTS AND DISCUSSION

This section presents the findings of the study, which are structured into four main parts. The first part describes the distribution of respondents who participated in the survey, providing an overview of their professional roles in high-rise construction projects in Surabaya. The second part summarizes the delay effect indicators that were used as the basis for the fuzzy logic analysis. The third part discusses the identification of the main risk barriers using the fuzzy logic approach, which converts linguistic assessments into quantitative scores to objectively rank the delay factors. Finally, the fourth part outlines the risk mitigation strategies proposed to address the most significant internal and external risks identified in the study.

Respondent Distribution

The data for this study were obtained through a questionnaire survey distributed to professionals involved in high-rise building construction projects in Surabaya. A total of 88 questionnaires were distributed, of which 80 valid responses were returned and used for further analysis, resulting in a response rate of 90.9%. This response rate is considered sufficient for quantitative analysis.

The respondents consisted of individuals occupying both strategic and operational positions within construction projects, including Company Directors, Project Managers, Site Managers, Site Engineers, General Managers, Field Executors (Pelaksana), and Estimators. Among the respondents, Site Engineers constituted the largest proportion at 25% (20 respondents), followed by Field Executors at 23% (18 respondents). Project Managers accounted for 19% (15 respondents), while Site Managers represented 16% (13 respondents). Estimators comprised 10% (8 respondents), and Company Directors accounted for 6% (5 respondents). General Managers formed the smallest group, representing only 1% (1 respondent).

Overall, this distribution demonstrates that the respondents adequately represent various hierarchical levels within construction organizations, encompassing both managerial decision-making and field-level execution. Such a composition strengthens the reliability and comprehensiveness of the data collected for analyzing construction project performance.

Delay Effect Indicators

Before conducting the fuzzy logic analysis, it is important to present the set of delay effect indicators that served as the foundation of this study. These indicators were developed based on a comprehensive literature review and refined through expert validation to ensure their relevance to high-rise building projects in Surabaya. The indicators were then incorporated into the questionnaire survey and grouped into six major categories: Labor, Materials, Equipment, Cost, Construction Management, and Project Conditions.

The complete list of delay effect indicators is shown in Table 2. These indicators represent the potential barriers that contribute to project delays and were later evaluated using the fuzzy logic approach to identify the most critical risk factors.

Table 1. Delay Effect Indicators

Code	Delay Effect Indicator	Source
	Labor (Workforce)	
A1	Low labor productivity due to external and technical factors	(Noviyarsi et al., 2023)
A2	Mismatch between the number of workers and project requirements	(Noviyarsi et al., 2023)
A3	Lack of project management training for new workers	(Sandi et al., 2022)
A4	Ineffectiveness of overtime work that reduces productivity	(Kurniawan & Nursin, 2021)
A5	Limited availability of skilled local workers	(Gea, 2016)
A6	Low work motivation and communication barriers between supervisors and workers	(Gea, 2016)
A7	High accident rates due to insufficient use of personal protective equipment (PPE)	(Yuswantoro & Indarjo, 2023)
	Materials	
B1	Delays in material delivery from suppliers	(Yuswantoro & Indarjo, 2023)
B2	Non-conformity of materials with project technical specifications	(Harsoyo & Arkan, 2020)
B3	Material damage at storage areas due to weather or poor handling	(Kurniawan & Nursin, 2021)
B4	Limited stock of materials causing procurement delays	(Harsoyo & Arkan, 2020)
B5	Design changes during execution impacting material requirements	(Kurniawan & Nursin, 2021)
B6	Poor coordination between procurement teams and field executors causing supply delays	(Sandi et al., 2022)
	Equipment	
C1	Equipment breakdowns during project execution	(Yuswantoro & Indarjo, 2023)
C2	Limited availability of heavy equipment	(Harsoyo & Arkan, 2020)
C3	Equipment not meeting project specifications	(Kurniawan & Nursin, 2021)
C4	Long waiting times for equipment use due to poor scheduling	(Harsoyo & Arkan, 2020)
C5	Lack of skilled operators for heavy equipment	(Gea, 2016)
C6	High costs of equipment maintenance and rental	(Harsoyo & Arkan, 2020)
	Cost	
D1	Cost overruns due to schedule changes and workforce adjustments	(Harsoyo & Arkan, 2020)
D2	Inefficient use of acceleration methods (crashing) that increase direct project costs	(Harsoyo & Arkan, 2020)
D3	Lack of integration between cost control systems and project scheduling	(Gea, 2016)
D4	Cost overruns due to design revisions by the project owner during execution	(Harsoyo & Arkan, 2020)
D5	Inadequate budget planning for appropriate execution methods	(Kurniawan & Nursin, 2021)
	Construction Management	
E1	Ineffective project control leading to schedule non-compliance	(Harsoyo & Arkan, 2020)
E2	Insufficient use of efficient project management technology	(Kurniawan & Nursin, 2021)
E3	Project managers' limited ability to manage risks and resources adaptively	(Harsoyo & Arkan, 2020)
E4	Weak coordination among project stakeholders (owner, (Kurniawan & Nursin, 2021) contractor, consultant)	
	Project Conditions	
F1	Irregular project monitoring resulting in schedule deviations	(Harsoyo & Arkan, 2020)
F2	Extreme weather conditions affecting field operations	(Gea, 2016)

Code	Delay Effect Indicator	Source
F3	Lack of supporting infrastructure such as access roads to the project site	(Harsoyo & Arkan, 2020)
F4	Social disturbances around the project site (e.g., community protests, permit disruptions)	(Kurniawan & Nursin, 2021)

This set of indicators formed the input variables for the fuzzy logic analysis, where each was evaluated according to linguistic judgments (Low, Medium, High) provided by the respondents.

Main Risk Barriers Using a Fuzzy Logic Approach

The identification of main risk barriers was carried out using the fuzzy logic approach, which allows linguistic judgments to be expressed in quantitative form. Respondents assessed each indicator using three linguistic categories: Low, Medium, and High.

These responses were then converted into Triangular Fuzzy Numbers (TFN) with a domain of 1–5, defined as follows: Low = (1,1,3), Medium = (2,3,4), and High = (3,5,5).

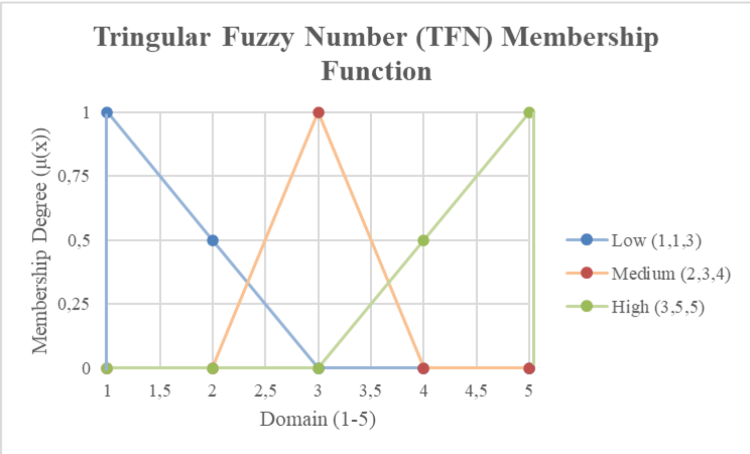

Figure.2 Triangular membership functions representing the linguistic variables "Low," "Medium," and "High" used in the fuzzification process. Each function illustrates the overlapping boundaries that allow smooth transitions between categories in the fuzzy logic analysis.

In the figure, it can be seen that each linguistic category has an overlapping membership region, allowing the transition between categories to occur gradually rather than rigidly. The intersection point at the value of 2.5 represents the boundary between the Low and Medium categories, while the intersection point at the value of 3.5 represents the boundary between the Medium and High categories. Thus, this membership function enables the linguistic data of respondents to be processed into quantitative values through fuzzification and defuzzification.

After obtaining the number of responses for each linguistic category (nR, nS, nT), the next step was to calculate the aggregate Triangular Fuzzy Number (TFN) for each indicator. The aggregate TFN is expressed as three components: a (left endpoint), b (mode), and c (right endpoint). These values were derived using a weighted average based on the proportion of respondents in each category, with the following equations:

$$a = \frac{\mathrm{nR}\,.\,1 + \mathrm{nS}\,.2 + \mathrm{nT}.\,3}{\mathrm{N}}$$

$$b = \frac{\mathrm{nR}\,.\,1 + \mathrm{nS}\,.3 + \mathrm{nT}.\,5}{\mathrm{N}}$$

$$c = \frac{\mathrm{nR}\,.\,3 + \mathrm{nS}\,.4 + \mathrm{nT}.\,5}{\mathrm{N}}$$

where:

- a, b, c = left, mode, and right values of the aggregate TFN,
- nR, nS, nT = number of respondents selecting Low, Medium, and High, respectively,

- N = total number of respondents.

For example, for Indicator D4 – Cost overruns due to design revisions by the project owner during execution with nR = 6, nS = 25, and nT = 49 (N = 80), the calculations are:

$$a = \frac{6.1 + 25.2 + 49.3}{80} = 2{,}538$$
$$b = \frac{6.1 + 25.3 + 49.\ 5}{80} = 4{,}075$$
$$c = \frac{6.3 + 25.4 + 49.5}{80}\ 4{,}538$$

Once the aggregate Triangular Fuzzy Number (TFN) (a,b,c) was obtained for each indicator, the next step was defuzzification, which converts fuzzy values into a single crisp score. In this study, the centroid method (mean of maximum).

For example, for Indicator D4 – Cost overruns due to design revisions by the project owner during execution, the aggregate TFN was (2.538, 4.075, 4.538). Applying the centroid formula:

$$\text{Skor Crisp} = \frac{2{,}538 + 4{,}075 + 4{,}538}{3} = 3{,}717$$

This crisp score indicates the relative severity of the indicator. In accordance with the classification thresholds adopted in this study:

- Low = ≤ 2.49
- Medium = 2.50 – 3.49
- High = ≥ 3.50

The crisp score of 3.717 places Indicator D4 in the **High** category.

This process was repeated for all indicators, and the results were compiled into a ranking of risk barriers based on their crisp scores, as presented in the subsequent table.

The defuzzification process was carried out for all indicators, resulting in a crisp score that reflects the relative severity of each delay effect factor. These scores were then classified into Low, Medium, and High categories based on the defined thresholds. A complete summary of the results, including the crisp scores and their classifications, is presented in **Table 5**. This table serves as the basis for further interpretation and discussion in the subsequent section.

Table 2. Recapitulation of Fuzzy Logic Values for Risk Indicators

	A.1	**A.2**	**A.3**	**A.4**	**A.5**	**A.6**	**A.7**	**B.1**
Defuzzifikasi (centroid)	3,383	3,550	3,317	3,217	3,150	3,183	2,983	3,350
Category	Medium	High	Medium	Medium	Medium	Medium	Medium	Medium
	B.2	**B.3**	**B.4**	**B.5**	**B.6**	**C.1**	**C.2**	**C.3**
Defuzzifikasi (centroid)	3,300	2,950	3,167	3,533	3,167	3,433	3,233	3,000
Category	Medium	Medium	Medium	High	Medium	Medium	Medium	Medium
	C.4	**C.5**	**C.6**	**D.1**	**D.2**	**D.3**	**D.4**	**D.5**
Defuzzifikasi (centroid)	3,183	3,367	3,167	3,550	3,233	3,217	3,717	3,367
Category	Medium	Medium	Medium	High	Medium	Medium	High	Medium
	E.1	**E.2**	**E.3**	**E.4**	**F.1**	**F.2**	**F.3**	**F.4**
Defuzzifikasi (centroid)	3,483	3,050	3,517	3,367	3,300	3,383	3,367	3,133
Category	Medium	Medium	High	Medium	Medium	Medium	Medium	Medium

Risk Mitigation Strategies

Following the identification of delay risk barriers using the fuzzy logic approach, the next stage of analysis was to formulate appropriate risk mitigation strategies. The purpose of this step is to propose preventive and corrective actions that can minimize the impact of both external and internal risks identified in high-rise building projects.

The mitigation strategies were developed with reference to four fundamental approaches in risk management:

1. Risk Avoidance – eliminating the risk by modifying project plans or conditions so that the risk no longer occurs.
2. Risk Reduction – minimizing the probability or impact of the risk through proactive measures.
3. Risk Transfer – shifting the responsibility of risk consequences to third parties, typically through contractual agreements or insurance.
4. Risk Acceptance – acknowledging the risk and preparing contingency measures if it materializes.

The strategies were derived from the questionnaire responses and expert validation, ensuring that they are practical and applicable to construction projects in Surabaya. A summary of the proposed mitigation measures for the most significant risk indicators is presented in Table 6.

Comparative Analysis with Previous Studies

The finding that design revisions by project owners (D4) represent the most dominant risk barrier is consistent with several previous studies that identify design changes as a primary cause of construction delays and cost overruns. Doloi (2013) emphasized that stakeholder-driven changes significantly contribute to time and cost escalation in building projects. Similarly, Santoso et al. (2003) found that design modifications in high-rise construction projects in Indonesia often generate cascading impacts on scheduling and resource allocation.

However, unlike studies that highlight material supply or labor productivity as the dominant delay factors (Noviyarsi et al., 2023; Harsoyo & Arkan, 2020), the present research indicates that managerial and owner-related factors are more critical in the Surabaya context. This suggests that delay risks in high-rise projects may shift from operational issues toward decision-making and governance-related uncertainties.

Regarding ineffective project control (E1), the results align with Manea (2018) and Valente & Nascimento (2021), who identified weak monitoring systems as a significant contributor to project delays. The fuzzy severity score obtained in this study (3.483) confirms that internal managerial capability remains a crucial determinant of schedule performance.

Interpretative Discussion: Context of Surabaya

The dominance of D4 (design revisions) can be interpreted within the context of rapid urban development in Surabaya. High-rise building projects are often initiated under dynamic market conditions, where investors adjust functional requirements or design specifications in response to commercial considerations. Such late-stage design changes inevitably affect procurement planning, cost estimation, and scheduling, thereby amplifying delay risks.

Furthermore, contractual arrangements in many local construction projects still allow flexibility for owner-initiated revisions during execution, which increases uncertainty. This structural condition explains why D4 obtained the highest defuzzification score (3.717), placing it in the high-risk category.

Meanwhile, the prominence of E1 (ineffective project control) reflects internal management challenges. Despite technological advancements, not all contractors consistently implement integrated monitoring systems. Weekly evaluations and daily reporting, as preferred by respondents, indicate that project control practices remain partially manual and reactive rather than predictive.

These findings suggest that delay risks in Surabaya's high-rise projects are driven by a combination of governance-related external uncertainty and managerial capability limitations. Therefore, mitigation strategies must address both contractual discipline and internal control system strengthening.

Table 3. Recapitulation of Proposed Mitigation Strategies Against Two Main Obstacle Indicators

Code	Variable	Mitigation			
		Accepting Risk	Reducing Risk	Transferring Risk	Avoiding Risk
Z.D4	Cost overrun due to design revisions by the project owner during implementation	Agreeing on tolerance limits for design changes with the owner	Reviewing the design periodically with the technical team and the owner	Including design change clauses in the contract	Ensuring the design is finalized and fully approved before construction begins
Respondents' Answers		8	32	6	34
Z.E1	Ineffective project control leading to schedule deviations	Adjusting the project schedule according to actual field conditions	Conducting weekly evaluations and daily progress reports	Involving a third party as an independent supervisor (external supervision)	Implementing a technology-based monitoring system from the beginning of the project
Respondents' Answers		4	37	6	33

CONCLUSION

This study analyzed the main risk barriers and corresponding mitigation strategies for delays in high-rise building projects in Surabaya using a fuzzy logic approach. The findings identified cost overruns due to design revisions by project owners (D4) as the most dominant external risk (defuzzification score = 3.717, high category) and ineffective project control (E1) as the most significant internal risk (score = 3.483, upper-medium category). These results indicate that both governance-related uncertainties and internal managerial limitations significantly influence schedule performance.

The fuzzy logic method proved effective in transforming subjective expert judgments into measurable and ranked severity values, thereby supporting more objective risk prioritization. Practically, the study highlights the importance of early design finalization and strengthened monitoring systems to enhance schedule reliability and cost control in high-rise construction projects.

For future research, methodological development can be expanded by integrating Fuzzy Logic with multi-criteria decision-making approaches such as Fuzzy-AHP to obtain more structured weighting among risk factors. In addition, the incorporation of digital technologies, including Building Information Modeling (BIM) and real-time digital monitoring systems, may provide more predictive and data-driven delay management frameworks. Further studies may also involve larger samples across multiple cities to improve generalizability and enable comparative regional risk analysis.

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