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Operational Risk Management in Precast Concrete Manufacturing: Lessons from The Probowangi Plant Indonesia

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ABSTRACT: Precast concrete manufacturing plays a vital role in accelerating infrastructure development, yet its operational phase is often exposed to significant risks that can compromise efficiency, safety, and quality. This study develops and implements a structured risk management framework for the Probowangi Precast Plant in East Java, Indonesia—an industrial facility supplying components for major toll road projects. Using ISO 31000:2018 and ISO 31010:2019 as references and adopting a mixed-method approach, this study identified risks through expert interviews and literature review, then validated and prioritized them using the Probability Impact Matrix (PIM). From an initial list of 32 risks, 18 were confirmed as high-priority based on expert evaluation. These included material shortages, labor skill gaps, equipment failures, and safety violations. Tailored mitigation strategies were formulated in alignment with international standards and operational constraints, covering areas such as supplier diversification, training programs, and enhanced stock management. The study contributes a replicable model for operational risk governance in precast manufacturing, especially relevant for developing countries seeking to improve construction efficiency through prefabrication technologies.

KEYWORDS: precast concrete, operational risk, ISO 31000:2018, ISO 31010:2019, risk management, Probability Impact Matrix (PIM), Indonesia.

I. INTRODUCTION

The rapid advancement of infrastructure development in Indonesia has triggered a paradigm shift in construction methods, moving toward faster, more efficient, and quality-controlled solutions. Precast concrete technology has emerged as a critical component in this transformation. Precast plants, by allowing off-site production of structural components, offer advantages such as accelerated project timelines, reduced on-site labor, and improved safety and consistency in quality. As highlighted by Cheng et al. (2023), precast systems can reduce project duration by up to 30% and labor costs by 20%, contributing significantly to project efficiency.

One such facility, the Probowangi Precast Plant located in East Java, Indonesia, plays a pivotal role in supplying structural components such as girders, u-ditch, and barriers for the Probowangi Toll Road Package II (Figure 1). Managed by PT. SIS, the plant operates under high-volume production demands and tight delivery schedules, posing numerous operational risks. These risks range from technical failures, equipment breakdowns, and labor shortages to supply chain bottlenecks and regulatory compliance issues.

While the benefits of precast operations are evident, risk management in precast plant operations remains a relatively underexplored area, particularly in developing countries. According to the International Organization for Standardization (ISO), effective risk management involves not only identifying and analyzing risks but also implementing treatment strategies to monitor and review risks continuously (ISO 31000:2018). However, in practice, many plants lack formalized frameworks to address operational risks systematically (Zhang, Hammad, & Liu, 2020).

Figure 1. Probowangi precast plant

This study addresses that gap by developing and implementing a risk management framework for the operational phase of the Probowangi Precast Plant. Using a structured methodology combining expert interviews, questionnaires, and a Probability-Impact Matrix (PIM), this research identifies potential risks, assesses their severity, and proposes strategic responses in alignment with ISO 31000:2018 principles. The outcome is a set of prioritized risks and recommended mitigation strategies that are contextually appropriate and operationally feasible.

Ultimately, this paper contributes both theoretically and practically. It enriches academic discourse on operational risk in precast manufacturing, and it provides practitioners with actionable insights to enhance operational resilience. As noted by Kamardeen and Loosemore (2016), risk-informed decision-making in construction enhances not only project outcomes but also long-term organizational sustainability.

II. METHODOLOGY

This research adopted a descriptive, case-based, and semi-quantitative approach to develop a risk management strategy for the operational phase of the Probowangi Precast Plant. The study employed four core stages—risk identification, expert validation, risk analysis and evaluation using the Probability Impact Matrix (PIM), and the formulation of response strategies. All stages refer to ISO 31000:2018 principles and are aligned with methods developed by Kassem and Hamzah (2019), see Figure 2.

1. Risk Identification

The first stage focused on identifying potential operational risks through two sources: (1) literature review and (2) exploratory interviews. The literature covered academic papers, industry reports, and international standards (e.g., ISO 31000:2018; ISO 31010:2019) to define general risks in precast operations. Exploratory interviews were conducted with internal plant personnel—supervisors, HSE officers, and logistics and QC staff—using open-ended, semi-structured formats. The result was a contextualized initial risk inventory comprising technical, procedural, and managerial risks specific to the Probowangi Precast Plant.

2. Expert Validation

The initial risk list was validated using structured expert judgment. Five practitioners with extensive experience in precast plant operations evaluated each risk's relevance using a 5-point Likert scale (1 = Not Important, 5 = Extremely Important). Only risks with an average score ≥3.0 were retained. This validation method was adapted from Kassem & Hamzah (2019) and Ibironke et al. (2013), ensuring the list's contextual accuracy and analytical reliability.

3. Risk Analysis and Evaluation Using PIM

Validated risks were assessed using the Probability Impact Matrix (PIM). Each respondent assigned a score of 1 to 5 for two dimensions:

- ➢ Probability (P) – likelihood of risk occurrence
- ➢ Impact (I) – severity of consequences if the risk occurs

Mean scores were calculated across respondents, and each risk was plotted on a 5×5 matrix using the following axes (Figure 3).

The methodological approach described above provided a clear and structured pathway for assessing operational risks at the Probowangi Precast Plant. By combining expert insights, contextual validation, and a risk prioritization tool in the form of the Probability Impact Matrix (PIM), the study was able to identify and evaluate risks in a way that reflects both real-world operational challenges and internationally recognized best practices.

Using the matrix-based model proposed by Kassem and Hamzah allowed for a more intuitive visualization of which risks required urgent attention. This helped the management team focus their mitigation efforts on the most critical issues—particularly important in environments where resources and time are limited. The subsequent formulation of response strategies, guided by ISO 31000:2018 and ISO 31010:2019 principles, offered practical and adaptable solutions tailored to the plant's specific conditions.

With this methodological foundation in place, the next section of the paper presents the key findings. It includes the list of validated risks, their classification within the PIM framework, and the specific response strategies developed. These results are discussed by drawing on both qualitative insights from field interviews and semi-quantitative analysis derived from the risk matrix.

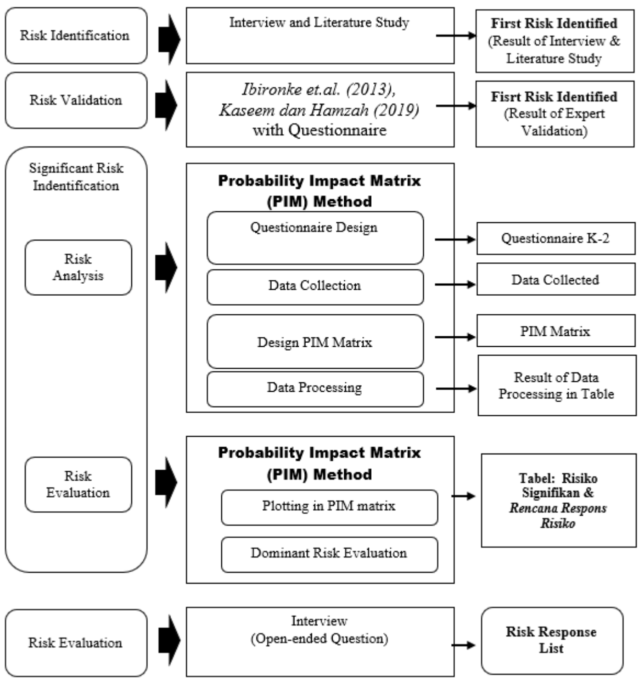

Figure 2. Methodology diagram

The integration of these methodological stages, as illustrated in Figure 2, enabled the research to transition systematically from broad risk exploration to focused prioritization and strategy formulation. By leveraging expert input alongside literature-based identification, the process ensured that only contextually relevant risks were retained for further analysis. The application of the Probability

Impact Matrix (PIM), adapted from Kassem et al. (2019), provided a visual and analytical framework to evaluate each risk based on its likelihood and severity. This approach not only facilitated clearer decision-making for plant management but also ensured consistency with international standards such as ISO 31000:2018 and ISO 31010:2019. Figure 3 presents the 5×5 PIM grid used to map and classify the validated risks accordingly.

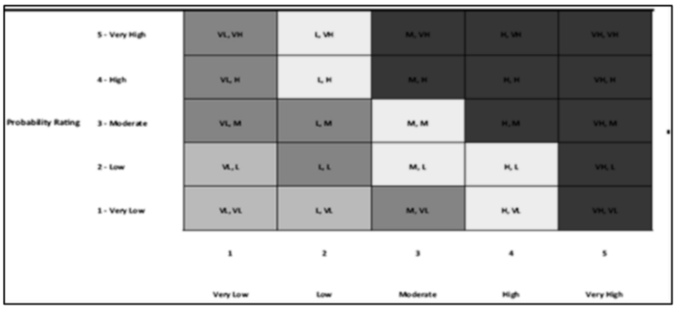

Figure 3. PIM Matrix (source: Kaseem et al., 2019)

III. RESULT AND DISCUSSION

The findings of this study demonstrate a structured and systematic implementation of risk management during the operational phase of the Probowangi Precast Plant. The process was carried out through several key stages, including initial risk identification, expert validation, risk analysis and evaluation using the Probability Impact Matrix (PIM), and the formulation of targeted response strategies for significant risks. This approach combined both qualitative insights and quantitative assessments to ensure accuracy and relevance to actual operational conditions.

In the initial stage, potential risks were identified through in-depth interviews with key personnel directly involved in daily activities related to production, quality control, logistics, and occupational health and safety (OHS). A total of 32 risks were recorded, covering a wide range of operational concerns such as delays in material delivery, inadequate workforce skills, equipment breakdown, flawed communication, and client-related financial uncertainties. To strengthen the robustness of this initial identification, a literature review was also conducted. It confirmed that the risks identified in previous studies—such as those by Surve and Biswas (2019), Hatmoko et al. (2019), and Al-Gahtani et al. (2024)—aligned with those found in the interviews.

To ensure the relevance and severity of each identified risk, a validation process was conducted involving five expert practitioners with more than 10 years of experience in precast operations and infrastructure project management. Each expert rated the importance of every risk using a five-point Likert scale, from "Not Important" to "Extremely Important." Only risks with an average score greater than 3.0 were retained for further analysis. As a result, 18 risks were validated as significant, representing both technical and managerial concerns directly relevant to the plant's operations.

These 18 validated risks were subsequently analyzed using the Probability Impact Matrix (PIM) adapted from the framework proposed by Kassem and Hamzah (2019). Experts were asked to assess each risk based on two parameters—probability of occurrence and impact on operations—using a five-point scale. The results were averaged and plotted on a 5×5 matrix that categorized risks into three zones: green (low), yellow (moderate), and red (high). The analysis revealed that all 18 risks fell into the red zone, indicating their high criticality and the need for immediate risk treatment.

Table 1. Identified significant risks

No.	Risk Description	Impact (I)	Probability (P)	Category
1	Delay in material delivery	4.1	3.9	High
2	Material runs out during production	3.8	4.4	High
3	Unskilled labor	3.7	3.8	High
4	Incorrect concrete mix ratio	3.7	4.2	High
5	Inaccurate moulding	3.8	4.0	High
6	Production delays	3.7	3.9	High
7	Delay in primary raw material supply	3.9	4.2	High
8	Accidents due to unskilled equipment operators	3.4	3.9	High
9	Worker accidents due to neglecting OHS protocols	3.5	4.1	High
10	Wrong concrete composition during mixing	3.6	4.2	High
11	Overproduction due to inaccurate demand forecasting	3.4	3.5	High
12	Environmental pollution (air and water)	3.5	4.1	High
13	Delay in client installment payments	3.7	3.9	High
14	Customer complaints	3.8	3.9	High
15	Uncomfortable working	3.5	3.9	High

	environment			
16	Precast elements damaged during transportation	3.5	3.8	High
17	Precast elements damaged during field installation	3.4	4.1	High
18	Delay of truck-mixer arrival during production	3.9	4.1	High

Following the prioritization process, response strategies were developed through another round of expert consultation. These experts, each with deep experience in the precast and infrastructure construction sectors, proposed mitigation strategies grounded in real-world constraints and operational realities. The responses were consistent with ISO 31000:2018 principles and included techniques such as supplier diversification, minimum stock level control, structured worker training and certification, strict adherence to standard.

CONCLUSION

This study developed and applied a structured risk management framework for the operational phase of the Probowangi Precast Plant in Indonesia, using ISO 31000:2018 and the Probability Impact Matrix (PIM) approach. Out of 32 initially identified risks, 18 were validated as significant and categorized as high-priority, requiring immediate attention.

The integration of expert judgment and semi-quantitative analysis ensured that risk identification, evaluation, and treatment were both contextually relevant and operationally feasible. The resulting mitigation strategies—such as supplier diversification, training programs, and enhanced safety protocols—offer practical guidance for improving operational resilience in precast manufacturing.

This research underscores the importance of formalized risk management in industrial precast settings and provides a replicable model for similar facilities in developing contexts. Future work may focus on tracking the effectiveness of these strategies and incorporating digital tools for real-time risk monitoring.

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