Implementation of Failure Mode Effect Analysis and Multi-Criteria Analysis in Construction Project

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Abstract - Construction projects often encounter various risks that can affect their timelines, costs, and overall quality. This study presents a systematic method that combines Failure Mode and Effect Analysis (FMEA) with Multi-Criteria Analysis (MCA) to enhance risk management practices in the construction industry. FMEA is employed to identify and prioritize the most significant risks by analyzing their severity, probability, and detectability, while MCA evaluates different criteria to identify and choose the most effective risk mitigation strategies. By integrating these methodologies, the framework facilitates accurate identification of critical risks and a comprehensive evaluation of mitigation strategies, leading to improved decision-making and better project results. This combined approach underscores the necessity of aligning risk prioritization with solution evaluations, thus fostering strong and strategic risk management within the construction sector.

***Key Words*:** FMEA (Failure Mode and Effects Analysis), MCA (Multi-Criteria Analysis), construction risks, safety considerations in projects, risk prioritization, and assessments in engineering.

1. INTRODUCTION

The construction industry plays a vital role in the advancement of infrastructure and the promotion of economic growth; nevertheless, it is inherently intricate and laden with risks that can adversely affect project outcomes. Effective risk management and well-informed decision-making are crucial for addressing these challenges and achieving project objectives within the constraints of time, budget, and quality standards. Given the ever-changing nature of construction projects, it is essential to adopt sophisticated methods for the systematic assessment, prioritization, and mitigation of risks.

This research investigates the comparison between two prominent methodologies—Failure Mode and Effects Analysis (FMEA) and Multi-Criteria Analysis (MCA)—to improve risk management in construction projects. FMEA identifies possible failure modes and categorizes them based on factors such as severity, likelihood, and detectability, providing a structured approach for proactive risk management. In contrast, MCA evaluates multiple criteria simultaneously, which is advantageous for navigating complex decision-making situations that involve competing interests.

By acknowledging and leveraging the benefits of these methodologies, this study aims to develop a comprehensive framework for enhancing risk management practices in construction project failure Mode and Effects Analysis (FMEA):
Originating in the 1950s, the Failure Mode and Effects Analysis (FMEA) methodically identifies potential risks, evaluates their impact, likelihood, and detectability, and ranks these risks using the Risk Priority Number (RPN). Research conducted by Ji-Won Song and colleagues (2007) demonstrated its effectiveness in improving safety, while Gain1 and Mishra (2021) implemented it to mitigate hazards in road construction during the pandemic.

Multi-Criteria Analysis (MCA):
MCA evaluates options based on various criteria, including cost, time, safety, and sustainability, thereby providing a comprehensive framework for decision-making. Zavadskas1 et al. (2013) highlighted its use in assessing project performance, while Belay et al. (2022) applied it to prioritize essential success factors for infrastructure projects.

2. METHODS

This strategy incorporates FMEA to recognize and rank risks in construction by examining their impact, probability, and detectability. At the same time, it utilizes MCA to evaluate and prioritize risk mitigation approaches based on weighted criteria. This integrated methodology provides a systematic framework for choosing effective risk management strategies, as evidenced by case studies.

CASE STUDY OF RESIDENTIAL BUILDING: SENTOSA PRIDE

Data Collection

This study examines the Sentosa Pride residential construction initiative located in Pune, following established project management standards. The project began in January 2023, with a projected completion date of December 2025.

To ensure precision and incorporate diverse viewpoints, data collection started six months before the official project launch. The techniques used for gathering information included interviews, surveys, and site observations, employing purposive sampling methods. The participants comprised professionals and stakeholders engaged in the project, specifically:

Project Managers: Accountable for the overall oversight of the construction process and risk management.
Project Supervisors: Responsible for the daily management and coordination of construction activities.
Foremen: Tasked with supervising on-site teams and ensuring adherence to safety regulations. Additionally, the research gathered feedback from 100 workers, including both laborers and technical staff, to understand their experiences and the challenges faced at the operational level. This methodology led to a comprehensive understanding of potential risks, mitigation strategies, and project-specific factors, thereby laying the groundwork for the application of FMEA and MCA methodologies.

Execution of FMEA and MCA

The selected methodology includes two main components: Failure Mode and Effects Analysis (FMEA) for identifying and prioritizing risks, and Multi-Criteria Analysis (MCA) employing the Analytic Hierarchy Process (AHP) to ascertain the most effective mitigation strategies. This approach was implemented in the Sentosa Pride residential construction project situated in Pune.

1. Implementation of FMEA

FMEA was employed to systematically identify risks, evaluate their severity, and prioritize them for mitigation. The following steps were undertaken:

1) Risk Identification:

Risks were identified across various stages of the project, focusing on critical areas such as:
Delays in material supply.
Equipment failures.
Weather-related disruptions.
Safety hazards during the construction phase.

2) Parameter Evaluation:

Each risk was assessed based on three criteria:

Severity (S): The impact of the failure on project outcomes.
Occurrence (O): The likelihood of the failure occurring.
Detection (D): The ease of identifying the failure prior to its effect on the project.

3) Scoring and RPN Calculation:

Each criterion was scored on a scale from 1 to 10.
The Risk Priority Number (RPN) was calculated using the formula:
$RPN = S \times O \times D$
Example:
Time:
$S = 7, O = 6, D = 5$
$RPN = 7 \times 6 \times 5 = 210$

4) Risk Prioritization:

The risks with the highest RPN values were chosen for mitigation. Significant risks included time (RPN = 210) and cost (RPN = 160).

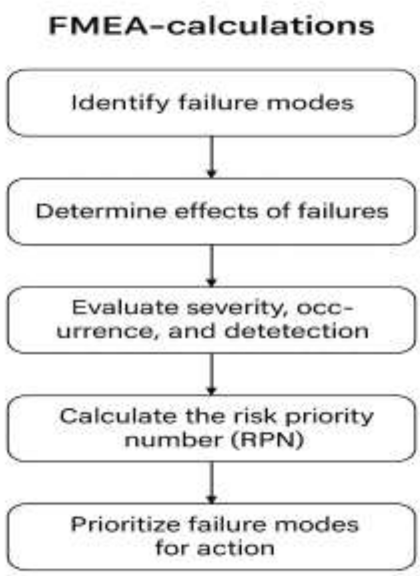


Fig -1: FMEA flowchart

2. Implementation of MCA Using AHP

MCA was employed to assess various mitigation strategies for the high-priority risks identified through FMEA. The AHP method was utilized to ensure a systematic evaluation process:

1) Criteria Selection:

Five critical criteria were defined to assess mitigation strategies:

Cost: The financial feasibility of the option.
Time: The impact on the project timeline.
Environmental Impact: Factors related to sustainability and ecology.
Technical Risk: Potential technical challenges in execution.
Feasibility: The practicality and simplicity of implementation.

2) Pairwise Comparison:

Pairwise comparisons were conducted to assign weights to each criterion, reflecting their relative importance to the project.

3) Alternative Scoring:

Each mitigation strategy was assessed against the criteria on a scale from 1 to 5, with higher scores indicating better performance.

4) Composite Score Calculation:

The weighted scores were aggregated to calculate a composite score for each alternative:
Composite Score = Σ (Criterion Weight × Alternative Score)

5) Ranking and Selection: Alternatives were ranked based on their composite scores, with the strategy that has the highest score selected.

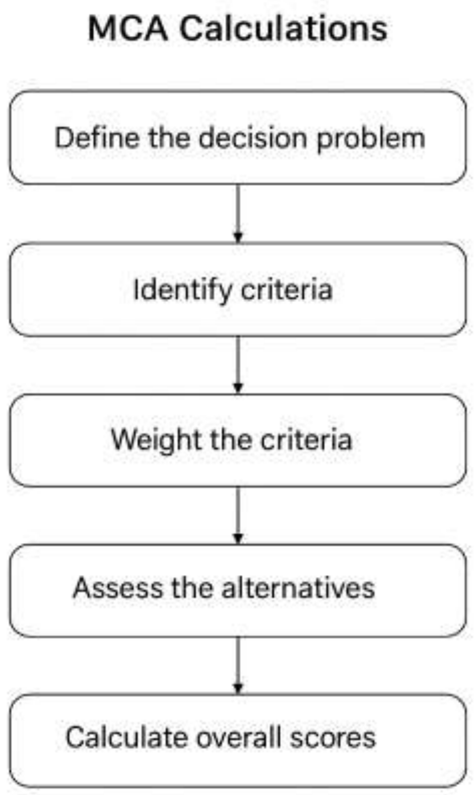
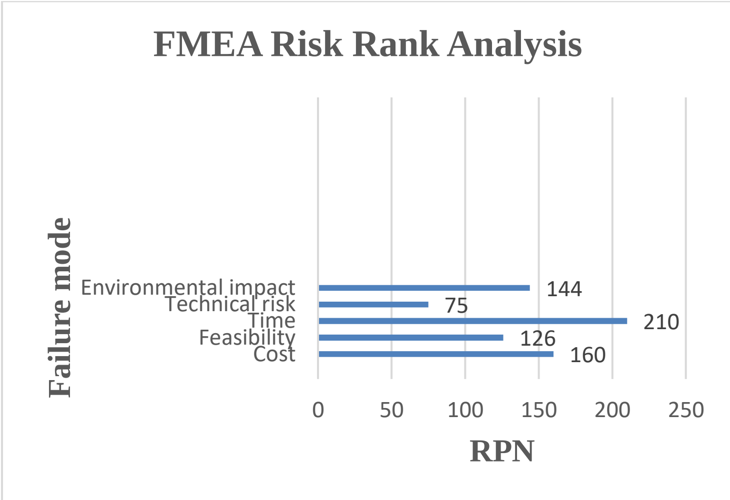


Fig -1: MCA flowchart

Table -1: FMEA analysis

Failure Mode	**Severity (S)**	**Occurrence (O)**	**Detection (D)**	**RPN**	**Risk Rank**
Cost	8	5	4	160	2
Feasibility	7	3	6	126	4
Time	7	6	5	210	1
Technical risk	5	3	5	75	5
Environmental impact	6	4	6	144	3

Bar Chart

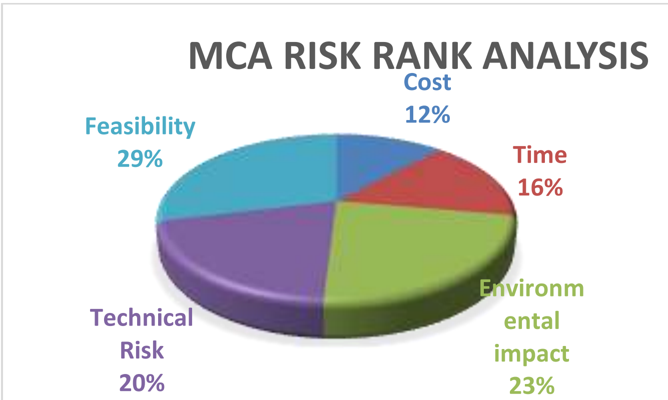


The FMEA chart shows the Risk Priority Numbers (RPNs) related to five detected failure modes: Feasibility, Cost, Environmental Impact, Technical Risk, and Time. Time exhibits the highest RPN of 210, stressing an urgent need to resolve possible delays, but Cost is remarked at 160, noting significant financial risks. With a score of 144, Environmental Impact and Feasibility at 126 highlight moderate risk levels; Technical Risk, at 75, is considered the least important issue. This assessment emphasizes how critical it is to give Time and Cost first priority so as to enable successful execution of the project and enable efficient risk management.

Table -2: MCA analysis

Parameters	**% Score**	**Risk Rank**
Cost	44%	5
Time	60%	4
Environmental impact	86%	2
Technical Risk	75%	3
Feasibility	100%	1

Pie Chart



The findings from the MCA reveal that Feasibility (29%) is perceived as the top priority, underscoring the importance of practicality and ease of implementation.
Following closely is Environmental Impact (23%), which highlights the significance of sustainability and the reduction of ecological harm.
In third position is Technical Risk (20%), which pertains to potential technical obstacles, while Time (16%) and Cost (12%) are viewed as less critical.
This prioritization guarantees a focus on viable, sustainable, and technically sound solutions, effectively aligning development goals with project constraints.

3. RESULT

The FMEA-MCA methodology effectively identified and addressed significant risks related to the Sentosa Pride project. The FMEA underscored critical risks, including time (RPN=210) and cost (RPN=160). The MCA evaluated mitigation strategies while taking into account factors such as costs, timelines, environmental impacts, technical challenges, and feasibility. Notably, high feasibility ratings were observed to correlate with increased associated risks, which influenced the selection of effective mitigation strategies such as proactive procurement and advanced scheduling tools. This strategy enhanced the project's safety, quality, and efficiency by aligning risk-driven decisions with the project's overall objectives.

4. DISCUSSION

This study covers the application and analysis of MCA and FMEA for construction project risk management. By assessing and prioritizing risks depending on their severity, likelihood, and detectability, FMEA produces risk priority numbers (RPN). MCA assesses and prioritizes risk reduction techniques using a range of factors including schedules, costs, and results. It synthesizes both methods, examines their relative benefits, drawbacks, and relevance, then provides useful advice on how each one manages building risks and assists in wise decision about the ideal course of action for a given project.

5. CONCLUSION

The study shows that FMEA and MCA provide a complete framework for risk management in construction projects. While MCA helps to assess mitigation plans depending on several standards including cost, time, and feasibility, FMEA accurately finds and prioritizes risks using measurable variables like severity, frequency, and detectability. This approach helped informed decision-making when applied in the Sentosa Pride project and greatly aided in the choice of the most efficient techniques, therefore improving project execution, reducing delays, and matching sustainability objectives. This approach connects risk analysis with strategic planning, therefore giving construction managers a workable, data-driven instrument to better project results.

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