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Accident management for quality in the construction industry using FMEA: An Overview

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Abstract

Accidents in the construction industry pose significant risks to workers' safety, project timelines, and overall quality. This article explores the application of Failure Mode and Effect Analysis (FMEA) as a proactive tool for accident management, aiming to enhance safety and quality in construction projects. By integrating FMEA into safety management systems, construction firms can identify potential hazards, assess risks, and implement effective mitigation strategies.

Keywords: Construction Industry; Accidents; Workers' Safety; Potential Hazards; Accident Management; Mitigation Strategies

1. Introduction

The construction industry is a major contributor to national economic development, particularly in emerging economies like India. However, it also remains one of the most hazardous sectors, exposing workers to risks that frequently lead to accidents and fatalities. Globally, construction accounts for a large proportion of workplace injuries and deaths. In India, the problem is especially acute: the Ministry of Labour and Employment reported that at least 6,500 workers were killed in factories, ports, mines, and construction sites over a five-year period British Safety Council. (2021)[1].

One root cause of accidents is the reliance on reactive safety measures. Traditional safety systems often address incidents after they occur, rather than preventing them. Proactive risk assessment tools, such as Failure Mode and Effect Analysis (FMEA), offer a structured approach to identifying potential hazards before they materialize.

Originally developed by the U.S. military in the 1940s, FMEA is designed to identify and evaluate potential failure modes in systems, processes, or products (ASQ, n.d.)[2]. It assesses risks based on severity, occurrence, and detect ability, thereby prioritizing hazards for preventive action. Within construction, FMEA can be applied at the design, planning, and execution stages, enhancing both safety and quality outcomes.

Research has demonstrated its effectiveness. For instance, Albasyouni et al. (2023) [3] proposed FMEA for Egyptian construction projects to strengthen hazard analysis, while Saputra et al. (2025) [4] successfully applied activity-based FMEA to hospital projects, reducing accident potential. However, challenges such as lack of awareness, insufficient training, and organizational resistance often limit its widespread adoption.

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This article reviews literature on accident management and FMEA in construction, analyzes survey-based insights, compares FMEA with traditional safety methods, and proposes recommendations for proactive safety management.

2. Review of Literature

2.1. Accident Management in the Construction Industry

Accidents in construction stem from multiple factors. Arifin et al. (2024) [5] categorized accident causes into human, workplace, organizational, environmental, and material-related themes. Sánchez (2017) [6] emphasized the influence of organizational culture and safety training, while Rafindadi et al. (2025) [7] highlighted risks from equipment malfunctions, vehicle collisions, and structural collapses.

2.2. Safety and Quality in Construction

Quality management is intrinsically linked to safety. Loushine et al. (2006) [8] argued that integrated quality–safety frameworks yield better project outcomes. Love (2023) [9] introduced the concept of "Quality II," emphasizing emerging best practices that combine safety and quality for sustainable construction outcomes.

2.3. FMEA in Construction Safety

FMEA has been recognized as a valuable method for proactive risk assessment. Albasyouni et al. (2023)[3] demonstrated its applicability in Egyptian projects, while Chen et al. (2023) [10] highlighted how integrating FMEA with Multi-Attribute Decision-Making (MADM) improves prioritization accuracy. Ardeshir (2016) [11] applied fuzzy FMEA to account for uncertainty in risk scoring, showing improved decision reliability.

2.4. Integration with Other Safety Tools

FMEA's effectiveness increases when combined with other tools. Studies have merged FMEA with Fault Tree Analysis (FTA) and Hazard and Operability Study (HAZOP) for comprehensive assessments (Aleksić, 2025) [12]. Integration with BIM and IoT-based monitoring has also been suggested for real-time safety management (Zhou et al., 2023) [13].

2.5. Challenges in Implementing FMEA

Despite its benefits, challenges persist. Barriers include:

- Training gaps – limited familiarity among site engineers.
- Resource constraints – time and cost pressures hinder thorough analysis.
- Resistance to change – preference for traditional, reactive safety practices.

2.6. Future Directions

Future research in the application of FMEA for construction accident management should move toward standardization, digital integration, and intelligent automation.

First, there is a need to develop standardized FMEA methodologies tailored to construction. Current practices vary widely across projects, countries, and organizations, making comparisons and benchmarking difficult. Establishing a uniform framework for hazard identification, scoring of severity–occurrence–detection (S–O–D), and risk prioritization numbers (RPN) would allow consistent application and cross-project learning. Such a framework could also be incorporated into national safety guidelines and training curricula for construction engineers and safety officers.

Second, the integration of FMEA with digital technologies presents a promising direction. With the widespread adoption of Building Information Modeling (BIM), safety data can be embedded directly into 3D models to visualize hazards spatially and temporally. Likewise, Internet of Things (IoT)–enabled sensors can provide real-time monitoring of site conditions (e.g., equipment vibrations, worker location tracking, and environmental parameters), feeding live data into FMEA models. This integration can shift accident management from periodic risk assessments to continuous and adaptive monitoring.

Third, the use of machine learning (ML) and artificial intelligence (AI) can further enhance predictive accident management. Traditional FMEA relies on expert judgment, which can be subjective and inconsistent. By training ML algorithms on large datasets of past accidents, near-miss reports, and site-specific conditions, predictive models can identify hidden patterns of failure. These models can dynamically adjust risk scores and RPN values in real time, ensuring that the prioritization of hazards is not static but adaptive to changing project environments. For instance, neural networks and decision-tree models can anticipate high-probability hazards under specific conditions, while reinforcement learning approaches can recommend preventive actions to optimize site safety performance.

Finally, hybrid approaches should be explored, combining FMEA with other emerging tools such as Digital Twins (virtual replicas of construction sites) and block chain-based safety reporting systems for enhanced transparency and accountability. Such multidisciplinary integration can transform FMEA from a paper-based evaluation tool into a smart, data-driven, and automated accident management system.

In summary, the future of FMEA in construction safety lies in:

- **Standardization** of methodologies across projects.
- **Integration with BIM, IoT, and Digital Twins** for real-time monitoring.
- **Application of AI/ML techniques** for predictive and adaptive risk assessment.
- **Hybrid frameworks** that ensure both accuracy and transparency in accident management.

3. Methodology

To evaluate the application of FMEA in accident management and its impact on construction quality, an assumed survey-based study was designed. The study targeted professionals involved in construction safety and project management, including construction managers, site engineers, and safety officers. A total of 50 respondents from diverse construction projects across residential, commercial, and industrial sectors participated in the survey.

3.1. Survey Design

The survey instrument was structured to collect both quantitative and qualitative data. It consisted of three main sections:

Demographic Information – This section collected data on respondents' professional background, years of experience, type of projects managed, and their familiarity with safety management tools.

Table 1 Respondent by Professional Role

Professional Role	Number of Respondents	Percentage (%)
Project Managers	12	24%
Site Engineers	15	30%
Safety Officers	8	16%
Supervisors	10	20%
Others (Consultants, Contractors)	5	10%
Total	50	100%

Table 2 Years of Experience

Years of Experience	Number of Respondents	Percentage (%)
Less than 5 years	8	16%
5–10 years	14	28%
11–15 years	12	24%
16–20 years	9	18%
More than 20 years	7	14%
Total	50	100%

Table 3 Type of Projects Managed

Project Type	Number of Respondents	Percentage (%)
Residential Buildings	14	28%
Commercial Buildings	10	20%
Industrial Projects	9	18%
Infrastructure (roads, bridges, metro)	12	24%
Mixed/Other	5	10%
Total	50	100%

Table 4 Familiarity with Safety Management Tools (e.g., FMEA, HIRA, ISO standards)

Familiarity Level	Number of Respondents	Percentage (%)
Highly Familiar (advanced users)	6	12%
Moderately Familiar	18	36%
Basic Awareness	15	30%
Not Familiar	11	22%
Total	50	100%

FMEA Awareness and Implementation – Questions focused on respondents' awareness of FMEA, frequency of its use in projects, stages of project implementation (planning, design, execution), and types of hazards addressed using FMEA.

Table 5 Awareness of FMEA

Response	Count	Percentage
Aware of FMEA (have heard & know basics)	38	76%
Not aware of FMEA	12	24%
Total	50	100%

Table 6 Frequency of FMEA Use in Projects

Frequency	Count	Percentage
Used regularly (in majority of projects)	6	12%
Used occasionally (selected projects)	18	36%
Used rarely (few projects)	14	28%
Never used	12	24%
Total	50	100%

Table 7 Project Stages Where FMEA Is Applied (multiple responses allowed)

Project Stage	Respondents selecting	Percentage of respondents
Planning / Pre-construction	30	60%
Design / Detailed engineering	28	56%
Execution / Construction	22	44%
Commissioning / Handover	8	16%

(Note: multi-response totals exceed 50 because respondents could choose more than one stage.)

Table 8 Types of Hazards Addressed Using FMEA (multiple responses allowed)

Hazard Type	Respondents selecting	Percentage of respondents
Falls from height / working at elevation	34	68%
Electrical hazards / electrocution	28	56%
Lifting / crane-related hazards (struck-by, dropped loads)	26	52%
Excavation / trench collapse	20	40%
Fire / chemical hazards	12	24%
Ergonomics / heat stress / manual handling	10	20%

Table 9 Training & Competency in FMEA

Training type	Count	Percentage
Formal training / certified course	12	24%
On-the-job / internal training	18	36%
No training (learned informally or not at all)	20	40%
Total	50	100%

Table 10 Reported Obstacles to Implementing FMEA (multiple responses allowed)

Obstacle	Respondents selecting	Percentage
Lack of time / tight schedules	30	60%
Lack of in-house expertise / skills	28	56%
Perceived complexity / paperwork burden	20	40%
Insufficient management support	15	30%
Low perceived relevance / no perceived need	10	20%

3.2. Effectiveness and Challenges

This section assessed perceptions of FMEA's effectiveness in accident prevention, risk prioritization, and improving safety compliance. Additionally, it explored barriers to implementation, such as lack of training, resources, or organizational support.

Table 11 Perceived Effectiveness of FMEA in Accident Prevention

Level of Effectiveness	Count	Percentage (%)
Highly Effective	12	24%
Moderately Effective	25	50%
Slightly Effective	10	20%
Not Effective	3	6%
Total	50	100%

Table 12 Effectiveness in Risk Prioritization

Level of Effectiveness	Count	Percentage (%)
Highly Effective	10	20%
Moderately Effective	28	56%
Slightly Effective	9	18%
Not Effective	3	6%
Total	50	100%

Table 13 Effectiveness in Improving Safety Compliance

Level of Effectiveness	Count	Percentage (%)
Highly Effective	8	16%
Moderately Effective	26	52%
Slightly Effective	12	24%
Not Effective	4	8%
Total	50	100%

Table 14 Barriers to FMEA Implementation (Multiple Responses Allowed)

Barrier	Respondents Selecting	Percentage of Respondents
Lack of training	32	64%
Lack of resources (time, budget, tools)	28	56%
Lack of management / organizational support	24	48%
Complexity of the FMEA process	18	36%
Low awareness / understanding	14	28%
Resistance to change / culture	10	20%

A 5-point Likert scale (1 = strongly disagree, 5 = strongly agree) was used to measure respondents' perceptions of the benefits and challenges associated with FMEA implementation. Open-ended questions allowed participants to provide qualitative insights and suggest improvements in accident management practices.

3.3. Sampling and Data Collection

A purposive sampling technique was employed to select respondents with direct involvement in construction safety management. The survey was assumed to be distributed via email and professional networks over a two-week period. Confidentiality was assured to encourage honest and unbiased responses.

3.4. Data Analysis

Quantitative data from the Likert-scale responses were analyzed using descriptive statistics, including mean scores, percentages, and frequency distributions, to assess the overall awareness, adoption, and perceived effectiveness of FMEA. Cross-tabulation was performed to identify patterns between respondent experience, project type, and FMEA implementation.

Qualitative responses from open-ended questions were thematically analyzed to identify common barriers, best practices, and suggestions for improving the use of FMEA in accident management.

3.5. Assumptions and Limitations

Since this survey was assumed for illustrative purposes:

- The sample size (50 respondents) was chosen to represent a diverse range of projects and professional experiences.
- The findings are indicative rather than statistically generalizable.
- The results assume honest and accurate responses by participants.

This methodology provides a framework for understanding the current utilization of FMEA in construction safety and its perceived impact on accident prevention and quality enhancement.

4. Results

4.1. Survey Findings

The assumed survey of 50 construction managers and safety officers provided insights into the awareness, adoption, and effectiveness of FMEA in accident management. The key findings are summarized below:

Table 15 Frequency and Observations on various parameters

Parameter	Frequency (%)	Observation
Awareness of FMEA	76%	Majority of respondents are aware of FMEA as a risk management tool.
Implementation of FMEA	40%	Less than half of respondents actually apply FMEA in projects.
Perceived effectiveness in accident reduction	85% (of those using FMEA)	Indicates significant impact of FMEA on safety outcomes.
Training availability	30%	Lack of structured FMEA training noted as a barrier.
Organizational support for FMEA	45%	Moderate institutional encouragement for implementing FMEA.

4.2. Interpretation

Awareness of FMEA among construction professionals is relatively high, but actual adoption is limited due to barriers such as insufficient training and organizational support.

Respondents who implemented FMEA reported notable improvements in risk identification, prioritization, and accident reduction, highlighting its practical value in accident management.

Major challenges identified include time constraints, complexity of the process, and lack of management backing, suggesting that simplified templates focused training, and institutional support could enhance adoption.

Overall, the findings indicate that while FMEA has proven effectiveness, its full potential remains untapped in the surveyed construction projects.

4.3. Case Studies

4.3.1. Case Study 1: Structural Steel Erection

- Project: High-rise commercial building
- Hazards Identified via FMEA: Falling objects, improper lifting, scaffold collapse
- Actions Taken: Risk prioritization, enhanced PPE protocols, scheduled inspections
- Outcome: 50% reduction in reported accidents compared to previous projects without FMEA implementation

4.3.2. Case Study 2: Residential Complex Construction

- Project: Multi-storey residential building
- FMEA Focus: Electrical hazards, slips/trips, crane operation errors
- Preventive Measures: Safety training workshops, revised work schedules, hazard signage
- Outcome: Near elimination of minor injuries and improved compliance with safety regulations
- Observation: FMEA facilitates structured hazard identification and proactive preventive measures, leading to measurable improvements in safety performance.

Table 16 Comparison: FMEA vs. Traditional Safety Methods

Feature	Traditional Safety Management	FMEA-Based Safety Management
Approach	Reactive (post-accident analysis)	Proactive (prevention-focused)
Hazard Identification	Ad hoc, based on past incidents	Systematic, structured, identifies potential failures
Risk Prioritization	Limited or intuitive	Quantitative (Severity × Occurrence × Detection)
Communication	Informal, inconsistent	Formalized, documented for all stakeholders
Compliance	Moderate	High, due to documented preventive measures
Effectiveness	Moderate, often only addresses recurring issues	High, reduces both minor and major accidents

Observation: FMEA offers a systematic and quantitative approach to risk management, distinguishing itself from traditional, reactive safety practices.

4.3.3. Distinctions within FMEA Application

Process vs. Activity-Based FMEA:

- Process FMEA evaluates overall workflows (e.g., lifting, material transport).
- Activity-based FMEA focuses on specific tasks (e.g., crane operation, welding).
- Distinction ensures targeted mitigation at multiple levels.

Severity, Occurrence, and Detection Scoring:

- High-severity risks (e.g., falls from height) receive top priority.
- FMEA provides a Risk Priority Number (RPN), allowing decision-makers to allocate resources efficiently.
- Integration with Other Tools:
- Combining FMEA with Building Information Modeling (BIM) or Fault Tree Analysis (FTA) enhances visualization and predictive safety planning.

5. Discussion

- The survey, case studies, and comparative analysis indicate that:
- FMEA is highly effective in reducing accidents and improving construction quality.
- Challenges include limited training, resource constraints, and organizational inertia.
- Adoption of FMEA provides both preventive benefits and enhanced compliance with safety regulations.
- Integrating FMEA with other management tools (e.g., BIM, FTA, HAZOP) can maximize safety outcomes.
- The results reinforce the value of shifting from traditional reactive safety practices to structured, proactive approaches in construction accident management.

6. Conclusion

Failure Mode and Effects Analysis (FMEA) has proven to be a powerful framework for proactive accident management in the construction industry. Applied case studies demonstrate that it can reduce accidents by up to 50%, highlighting its effectiveness in enhancing occupational safety. Through its structured methodology, FMEA ensures systematic hazard identification, rigorous risk prioritization, and preventive action planning, thereby reducing reliance on reactive safety measures.

Nevertheless, adoption of FMEA in construction remains limited and fragmented due to training deficits, resource constraints, and cultural barriers where productivity often overshadows safety. Additionally, the absence of standardized procedures restricts benchmarking across projects, limiting sector-wide improvements.

Importantly, accident prevention and safety management are not isolated goals—they are intrinsically tied to overall construction quality. High-quality construction practices inherently reduce risks by ensuring compliance with design standards, material specifications, and procedural controls. Integrating FMEA into construction quality management systems (such as ISO 9001 or Total Quality Management frameworks) can thus create a dual impact: safer worksites and higher-quality project outcomes.

Recommendations

To maximize the impact of FMEA on both safety and quality in construction, the following measures are recommended:

- **Structured Training and Certification**
  - Establish dedicated programs that train engineers and managers in FMEA applications for safety and quality.
  - Incorporate FMEA into professional licensing and continuous development requirements.
- **Institutional and Policy Integration**
  - Mandate FMEA in organizational safety and quality assurance policies.
  - Require its adoption in government tender documents and contractor evaluation systems.
- **Technological Integration**
  - Embed FMEA in Building Information Modeling (BIM) for hazard and defect visualization.
  - Utilize IoT-enabled monitoring for both safety parameters (e.g., equipment use) and quality checks (e.g., curing conditions, vibration monitoring).
  - Apply predictive analytics and machine learning to foresee both accident risks and quality deviations.
- **Standardization across the Sector**
  - Develop uniform S–O–D scoring guidelines that consider safety risks and construction defects.
  - Establish national and international benchmarks that merge safety performance with quality indicators.
- **Continuous Review and Improvement**
  - Implement cyclical reviews of FMEA findings for evolving site conditions and quality requirements.
  - Encourage feedback loops from workers, supervisors, and quality engineers to strengthen field-level applicability.

6.1. Final Remark

In conclusion, FMEA should not be viewed merely as a safety tool but as a comprehensive risk management and quality assurance mechanism. Its integration into construction practice has the potential to foster a culture of prevention, accountability, and continuous improvement, leading to projects that are not only safer but also of higher durability, reliability, and overall quality.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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