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Risk Assessment in Construction Using FMEA to Improve Quality: A Multi-Level Analysis

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Abstract: This study employs Failure Mode and Effects Analysis (FMEA) to assess risks across five construction levels (Basement, Lintel, Roof, Casing, and Finishing). Surveying 750 stakeholders (architects, designers, engineers, supervisors, workers), we identify 12 critical failure modes**,** their root causes & severity. Key findings reveal supervisors and workers as most accountable (26–39% responsibility), with "Unsafe working conditions" & "No training" as dominant causes. We propose targeted interventions to mitigate risks and enhance quality.

Keywords: Failure Mode and Effects Analysis, Unsafe working condition, No training, Intervention

I. INTRODUCTION

The construction industry is characterized by complex workflows involving multidisciplinary professionals and laborers. The first step in quality improvement is the realization and identification that something is wrong and that it is needed to change processes and system for improvement to happen (Motwani et al., 1994)[1]. Nowadays, people are anxious with being responsive, flexible and able to adapt instantly to changes in accordance with the changing needs of clients (Jaca et al., 2012)[2]. Ensuring quality and safety at all levels of construction is vital.

Ahmed and Hassan (2003)[3] emphasize that quality management cannot be sustained without the incorporation of appropriate tools and techniques, and implementation of these tools and techniques can lead to better business results. In particular, the failure modes and effect analysis (FMEA) has been one of the most widely used tool in the new product development process (Thia et al., 2005)[4]. The adoption of safety management tools like FMEA enables systematic identification of potential failures and their consequences, guiding effective intervention.

Anik Ratnaningsih, Syamsul Arifin, Hernu Suyoso, Anita Trisiana, and Nizam Azkha Yusuf (2019)[5] Summarize certain key issues of FMEA as follows:

A. Effectiveness of FMEA

Numerous studies have confirmed the effectiveness of FMEA in identifying and prioritizing risks within construction projects. FMEA enables the detection of latent risks that are not simply uncovered through standard safety inspections (O'Brien et al., 2017)[6]. By systematically quantifying and ranking risks based on severity, occurrence, and delectability, FMEA supports more informed resource allocation and facilitates timely risk mitigation strategies.

B. Human Factors

Research has consistently emphasized the critical role of human factors in construction-related accidents. Studies by Akinci et al. (2019)[7] and Goh et al. (2020)[8] have identified variables such as worker competency, safety training, and compliance with safety protocols as common contributors to failures. Within the FMEA framework, these human-related issues frequently emerge as significant failure modes, underlining the need for workforce-focused risk interventions.

C. Impact of Safety Culture

The influence of organizational safety culture on occupational risk levels is also well documented. Kumar et al. (2020)[9] argue that a strong safety culture—characterized by effective supervision, clear communication, and rigorous enforcement of safety protocols—can substantially reduce accident rates. FMEA can be instrumental in evaluating the impact of safety culture by identifying systemic weaknesses that contribute to elevated risk levels, such as inadequate oversight or poor procedural compliance.

D. Mitigation Strategies

FMEA-based mitigation strategies focus on addressing high-priority risks through targeted intervention. In the perspective of structural work in apartment buildings, this may occupy implementing stricter safety protocols, enhancing worker training programs, and improving the maintenance and monitoring of critical equipment (Wang et al., 2017)[10]. Furthermore, integrating advanced technologies such as drones for site monitoring and AI for real-time hazard detection presents additional avenues for improving safety outcomes.

While FMEA is widely adopted, its application across distinct construction phases remains underexplored. This study:

- Analyzes risks at 5 levels (Basement to Finishing).
- Quantifies accountability among stakeholders.
- Recommends phase-specific mitigations.

Research Gap: Prior studies focus on generic FMEA; our links risks to execution phases and stakeholder roles**.**

II. LITERATURE REVIEW

Wahbi Albasyouni, Ibrahim Abotaleb, Khaled Nassar (2023)[11] emphasize that the execution of FMEA can markedly enhance risk analysis procedures by proactively identifying potential failure modes in construction processes before they lead to major safety or performance issues. The study makes a strong case for adopting FMEA within construction projects, with particular relevance to the Egyptian context. FMEA's structured and forward-looking approach provides a comprehensive framework for risk assessment, contributing to increased safety and operational efficiency on construction sites. The authors conclude that integrating FMEA into construction project management can result in more informed decision-making, a reduction in accidents, and overall improved project success. They also highlight the potential for future research to examine FMEA's application in other geographical regions or specialized sectors such as infrastructure, allowing for comparative evaluations of its effectiveness across diverse construction environments.

Wang, Feng, and Yang (2019)[12] marks a notable advancement in the application of structured risk evaluation methods within the construction industry through the adaptation of FMEA. By proposing a systematic and proactive framework, the authors contribute to enhancing the reliability, transparency, and consistency of construction project risk management practices. Despite its strengths, the approach faces certain limitations, including a dependence on subjective expert judgments, a static nature of risk assessment, and insufficient consideration of interrelated risk factors. To fully harness the capabilities of FMEA in complex construction settings, upcoming research should aspire to incorporate dynamic, real-time risk monitoring, integrate hybrid analytical models, and explore automation of the evaluation process through emerging technologies such as artificial intelligence and machine learning. The authors provide a clear evaluation of their study's contributions and limitations, summarized as follows:

Table 1 – Contributions & Limitations

Innovation	Strong, through the customization of FMEA for construction applications
Methodological Rigor	Moderate, due to reliance on subjective inputs
Practical Relevance	High, supported by real-world case studies
Limitations	Static risk assessment, limited diversity of case studies, and lack of risk interdependence modeling
Future Directions	Development of dynamic FMEA models, integration with hybrid analytical approaches, AI-based automation, and enhanced modeling of risk interactions

Overall, while the study establishes a solid foundation, it also highlights the need for continued refinement and broader deployment of FMEA-based risk evaluation in increasingly complex and dynamic construction environments.

The study by Liang et al. (2022)[13] introduces an innovative approach to risk evaluation in logistics park construction by integrating traditional FMEA with a hesitation environment framework. Logistics parks, which serve as vital nodes for freight handling, distribution, and storage, involve complex, large-scale construction projects characterized by high levels of uncertainty and diverse risk factors throughout their lifecycle. Conventional methods such as standard FMEA often struggle to accommodate the ambiguity and hesitation inherent in expert judgment—particularly in scenarios where risks are multifaceted and interdependent. By incorporating a hesitation environment, the authors enhance the capacity of risk assessment frameworks to address the nuanced uncertainties typical of large infrastructure projects. The findings specify that this incorporated model offers significant advantages in managing the interplay of technical, financial, and operational risks under uncertain and imprecise information. This approach is particularly well-suited to complex projects like logistics parks, where decision-making requires a more flexible and nuanced evaluation of risk.

Overall, Liang et al.'s work represents a meaningful advancement in construction risk management by bridging the gap between conventional risk evaluation techniques and the reality of hesitant, uncertain expert assessments. It also opens promising pathways for future research, particularly in extending hesitation-based frameworks to other large-scale infrastructure and construction domains.

AmirMohammadi Tehran, Mehdi Tavakolan (2013)[14] highlight ongoing criticism of traditional FMEA, particularly its equal weighting of Severity (S), Occurrence (O), and Detection (D) scores, and its inability to capture the nuances of expert judgment. To tackle these limitations, the study explores the assimilation of Fuzzy Logic with FMEA, allowing for a further realistic evaluation of threat factors that accounts for the inherent ambiguity in expert assessments. Fuzzy-FMEA models utilize fuzzy sets to represent the S, O, and D parameters and apply fuzzy inference mechanisms to generate more accurate and context-sensitive risk prioritizations. Tehran and Tavakolan validate their proposed model through a real-world construction project case study, demonstrating that fuzzy-FMEA often produces different—and arguably more practical—risk rankings compared to conventional FMEA. Their findings are constant with broader research advocating for hybrid and adaptive risk appraisal techniques in construction (e.g., El-Sayegh, 2008)[15]; Dikmen et al., 2007)[16]. The fuzzy-FMEA approach directly addresses key criticisms of traditional FMEA by avoiding rigid equal weighting and discrete scoring systems. By employing linguistic variables and fuzzy sets, the model effectively incorporates varying levels of expert confidence and judgment, enhancing the overall robustness and applicability of the risk analysis process in complex construction environments.

Farah A Wehbe, Farook Hamzeh (2013)[17] contend that conventional risk management practices in construction are predominantly reactive, normally addressing issues only after they have disrupted project performance. In contrast, FMEA introduce a preventive framework by proactively identifying and assessing prospective failures before they occur. The authors argue that construction planning—traditionally driven by Critical Path Method (CPM) schedules and task-focused methodologies—can be significantly enhanced by integrating FMEA, which introduces a risk-aware dimension to project decision-making. Their research demonstrates several key benefits of FMEA implementation: it facilitates earlier detection of potential failures compared to conventional planning methods, improves communication among project stakeholders through its structured approach, and supports the dynamic management of emerging risks when applied iteratively during planning updates. Despite some limitations—such as the time-intensive nature of initial FMEA sessions and the subjectivity involved in scoring severity, occurrence, and detection—the overall advantages are compelling. These challenges can be mitigated by leveraging digital tools and integrating FMEA with Building Information Modeling (BIM) or Lean Construction practices, enhancing both efficiency and effectiveness. Their work underscores the transformative potential of FMEA in fostering a culture of proactive risk mitigation within construction planning. By embedding risk analysis into early-stage decision-making, the study sets the base for safer, more competent, and cost-effective project delivery—marking a meaningful advancement in the field of construction risk management.

Ahmed Mohamed Maged Mahmound Ahmed supervisor Prof. Alessadro Brun (2018)[18] proposes the assimilation of Composite FMEA techniques into a unified risk appraisal framework specifically intended for construction projects. By combining morality from decision theory with stochastic modeling, the Composite FMEA aims to deliver a robust, adaptable, and context-aware tool that better reflects the complexity and dynamic nature of contemporary construction environments. The advancement of traditional FMEA through the incorporation of methods such as Pair wise Comparison and Markov Chains signifies a broader shift in construction risk management toward more analytical, data-driven, and responsive methodologies. The obtainable body of literature provides strong theoretical and empirical support for the potential of a Composite FMEA model to improve the accuracy and efficiency of risk evaluation processes. Accordingly, this study is grounded in a solid academic foundation and holds significant promise for contributing to both scholarly understanding and the practical improvement of risk management practices in the construction industry.

Guofeng Ma (Tongji University, Shanghai, China), Ming Wu (Tongji University, Shanghai, China (2019)[19] acknowledges that numerous scholars (e.g., Love et al., 2000[20]; Mills, 2001)[21] have highlighted the detrimental impact of inadequate quality risk management, which results not only in financial losses, it also undermine project safety, damages reputation, and reduces client satisfaction. In efforts to mitigate such risks, traditional evaluation techniques—such as checklists, expert judgment, and statistical analysis—have been widely adopted. However, these conservative methods are often limited by their lack of real-time responsiveness, their inefficiency in processing large-scale data, and their inadequate integration of project scheduling considerations (Hwang & Ng, 2013)[22].

Mohamed Abdelgawad, Aminah Robinson Fayek (2010)[23] observes that traditional risk assessment methods—such as simple probability-impact matrices, deterministic FMEA, and the Analytic Hierarchy Process (AHP)—have been

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extensively utilized in construction project management. Although these techniques present valuable insights, they are often constrained by their reliance on precise numerical inputs and subjective expert judgments, which may not sufficiently reflect the ambiguity and uncertainty inherent in real-world construction scenarios. In answer to these limitations, a growing recognition of the value of incorporating fuzzy logic is there—a mathematical approach designed to handle imprecise and uncertain information—into risk management frameworks. The integration of Fuzzy FMEA and Fuzzy AHP represents a significant step forward, providing more nuanced and flexible tools for evaluating complex project risks. The work of Mohamed Abdelgawad and Aminah Robinson Fayek highlights the critical importance of adopting advanced, uncertainty-sensitive methodologies to address the evolving challenges of modern construction environments. Their research lays the foundation for further research into hybrid fuzzy systems and their broader applications transversely diverse domains of project management.

Jhelison Gabriel Lima Uchoa, Marcos Jean Araujo de Sousa, Luan Silva, André Luís de Oliveira Cavaignac (2019)[24] addresses the ongoing need for hands-on risk management tools capable of systematically reducing workplace incidents in the construction industry. Their theoretical contribution stands out from previous studies in two key ways. First, it advocates for tailoring FMEA parameters to the specific conditions of construction work, rather than applying generic industrial safety models. Second, it proposes integrating FMEA with existing regulatory compliance frameworks, with particular emphasis on Brazil's occupational safety legislation—specifically NR-35, which governs work at height. This approach aligns with earlier calls in the writing (e.g., Chi et al., 2005[25]; Hallowell and Gambatese, 2009)[26] for the early integration of safety-focused design and management techniques during the project planning phase. Uchoa et al.'s model supports this perspective by offering a structured mechanism for identifying and mitigating risks before site work begins. In conclusion, the existing literature underscores the significance of structured, preventive strategies for managing the risks allied with working at height. Uchoa et al.'s model significantly contributes to this body of knowledge by demonstrating how a well-adapted FMEA framework can serve as an effective tool for addressing job-related hazards in construction. Future empirical validation of their model holds the latent to enhance industry safety standards and substantially reduce the incidence of height-related accidents on construction sites.

Saputra, et al. (2025)[26] Mentioned, although a range of methodologies exists for the risk appraisal in construction, FMEA stands out for its structured approach to systematically identifying and prioritizing potential failure modes. This capability makes FMEA a predominantly valuable tool for enhancing safety and reducing accident rates. As evidenced by the reviewed studies, implementing FMEA can significantly strengthen risk management strategies, leading to improved safety, operational efficiency, and overall project success—particularly in the context of underground construction within sensitive environments. Upcoming research should aim to further develop activity-based FMEA frameworks tailored to the specific complexities of military hospital construction, particularly in areas characterized by unstable geotechnical conditions or stringent security demands. Additionally, the combination of real-time data streams and advanced modeling technologies holds enormous promise for increasing the precision of risk assessments and promoting safer, more resilient construction practices in these critical infrastructure projects.

Meylinda Sabrinawati, I Nyoman Dita Pahang Putra (2024)[27] emphasize the application of FMEA in assessing and mitigating risks related to workplace accidents in high-rise building construction has been extensively explored and demonstrated to be effective. It offers a structured tactic for identifying potential failure modes, evaluating their impacts, and prioritizing risks based on severity, likelihood, and detect ability. However, the inherent subjectivity of the method, coupled with the complexity of high-rise construction environments, underscores the need for more sophisticated and integrated risk management approaches. Integrating FMEA with complementary tools and techniques presents a promising pathway to enhance safety management in high-story construction projects. Such hybrid models can improve the accuracy and dependability of risk assessments, thereby presenting to the reduction of accidents and the successful delivery of complex construction initiatives.

III. METHODOLOGY

A. Data Collection

- **Survey**: 750 respondents (150/level × 5 levels) across roles:

- **Mode of accidents**: Falling from heights, Electrocutions, Construction vehicles & machineries, Power / Manual tools, Stairs / Ladder / Scaffolding, Slip and fall down, Shuttering and De-shuttering, Struck by objects / Machineries, Quality Construction materials, Gas leaks, fires and explosions, Caught between & Exposure to dangerous chemicals & toxins

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- **5 Levels:**
  - Basement, Lintel, Roof, Casing, Finishing

- **Who - Responsible person:**
  - Architects, Designers, Construction Engineers, Supervisors, Workers.

- **Why - Reasons:**
  - Unsafe working condition, No Training / Experience, Non / Semi skilled, No awareness.

- **What – The impact:**
  - Mild injury, Moderate injury, Loss of parts, Causality.

- **Tool**: FMEA-based questionnaire

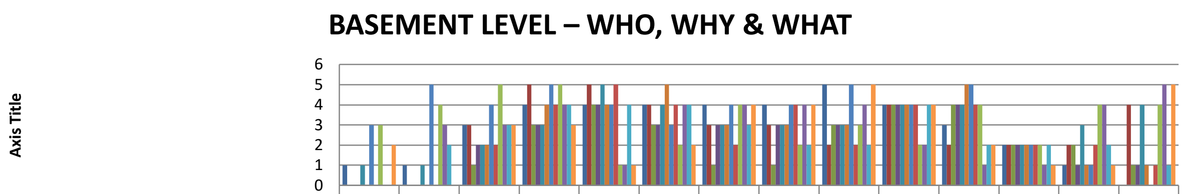
- **Scoring:**
  - Likelihood (1–5), Severity (Mild Injury to Casualty).

B. Analysis

- Risk Priority Number (RPN)**:** = Likelihood × Severity.

Who, why & what (from graph).

Table 2 – Basement level – Who, Why & What



	Architect	Designer	Cons. Engineer	Superrvisor	Workers	Unsafe working condition	No Training / Experience	Non / Semi skilled	No awareness	Negligence	Mild Injury	Moderate Injury	Lose of parts	Casuality
Falling from height	1	1	3	4	4	4	4	4	5	4	3	2	1	0
Electrocusions	0	0	3	5	5	4	3	3	2	4	2	2	2	4
Construction Vehicles & Machineries	0	0	1	3	4	3	1	1	3	4	4	2	2	1
Power / Manual Tools	0	0	2	3	4	3	3	3	3	4	4	2	1	1
Stairs / Ladder / Scaffolding	1	1	2	3	5	4	3	3	3	4	4	2	3	4
Slip & fall down	0	0	2	4	4	5	3	3	3	4	5	2	1	1
Shuttering & Deshuttering	3	5	4	5	4	3	4	4	5	4	5	2	1	0
Struck by moving objects / Machineries	0	0	2	4	5	4	2	4	2	4	4	2	2	1
Quality Construction materials	3	4	5	5	1	2	4	2	3	2	4	2	4	4
Gas leaks, fires and explosions	0	3	3	4	1	4	4	4	4	2	1	1	4	5
Caught-between	0	2	3	4	4	4	3	2	2	4	2	2	2	1
Exposure to dangerous chemicals or toxins	2	0	3	3	1	2	4	4	5	4	2	1	1	5

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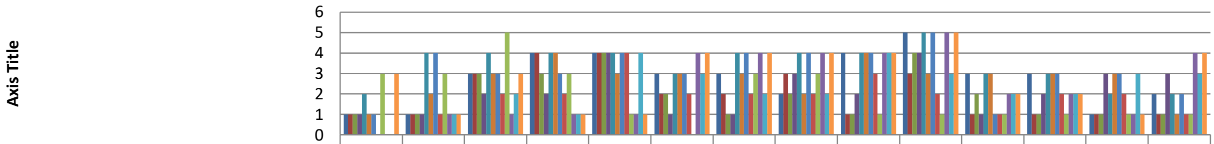
Table 3 – Lintel level – Who, Why & What

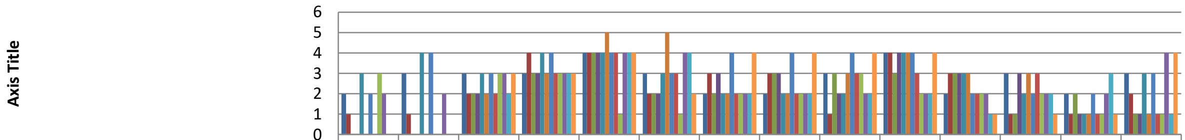
LINTEL LEVEL – WHO, WHY & WHAT



	Architect	Designer	Cons. Engineer	Superrvisor	Workers	Unsafe working condition	No Training / Experience	Non / Semi skilled	No awareness	Negligence	Mild Injury	Moderate Injury	Lose of parts	Casuality
Falling from height	1	1	3	4	4	3	3	2	4	5	3	3	1	2
Electrocusions	1	1	3	4	4	2	2	3	1	3	1	1	1	1
Construction Vehicles & Machineries	1	1	3	3	4	2	1	2	1	4	2	1	1	1
Power / Manual Tools	1	1	2	2	4	1	1	3	2	4	1	2	3	3
Stairs / Ladder / Scaffolding	2	4	4	4	4	3	4	4	4	5	3	3	2	2
Slip & fall down	1	2	3	4	3	3	3	2	4	3	3	3	3	1
Shuttering & Deshuttering	1	4	3	3	4	3	4	4	4	5	1	3	3	2
Struck by moving objects / Machineries	0	1	2	2	4	2	2	2	3	2	1	2	2	1
Quality Construction materials	3	3	5	3	1	0	3	3	1	1	1	1	1	1
Gas leaks, fires and explosions	0	1	1	1	1	4	4	4	4	5	2	2	1	4
Caught-between ….	0	1	2	1	4	3	2	2	4	3	2	2	3	3
Exposure to dangerous chemicals or toxins	3	1	3	1	1	4	4	4	4	5	2	2	1	4

Table 4 – Roof level – Who, Why & What

ROOF LEVEL – WHO, WHY & WHAT



	Architect	Designer	Cons. Engineer	Supervisor	Workers	Unsafe working condition	No Training / Experience	Non / Semi skilled	No awareness	Negligence	Mild Injury	Moderate Injury	Lose of parts	Casuality
Falling from height	2	3	3	3	4	3	2	2	3	4	2	3	2	3
Electrocusions	1	1	2	4	4	2	3	3	1	4	3	1	1	2
Construction Vehicles & Machineries	0	0	2	3	4	2	2	3	3	3	3	1	2	1
Power / Manual Tools	0	0	2	3	4	2	3	3	2	4	3	3	1	1
Stairs / Ladder / Scaffolding	3	4	3	4	4	3	2	2	2	4	3	2	1	3
Slip & fall down	0	0	2	3	5	5	2	2	3	4	3	3	1	1
Shuttering & Deshuttering	2	4	3	4	4	3	4	4	4	4	2	2	2	3
Struck by moving objects / Machineries	0	0	2	3	4	3	2	2	3	3	2	3	1	1
Quality Construction materials	3	0	3	3	1	1	2	2	3	2	2	2	1	1
Gas leaks, fires and explosions	2	2	3	3	4	4	2	2	2	2	2	2	2	4
Caught-between ….	0	0	2	3	4	4	2	2	2	2	1	2	3	1
Exposure to dangerous chemicals or toxins	0	0	3	3	4	2	4	4	4	4	1	1	1	4

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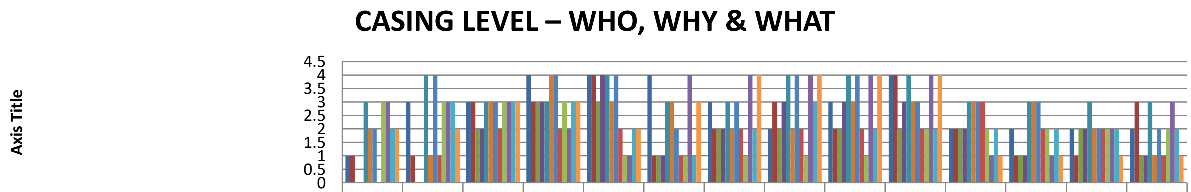
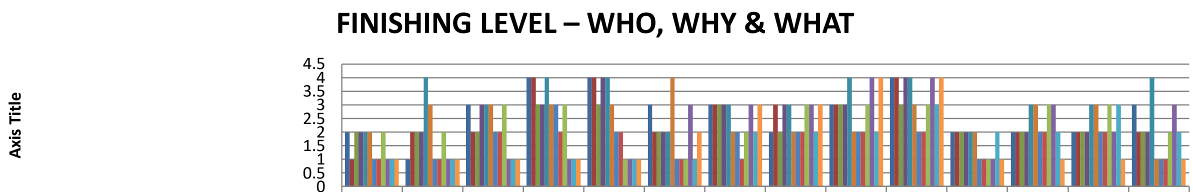
Table 5 – Casing level – Who, Why & What



	Architect	Designer	Cons. Engineer	Superrvisor	Workers	Unsafe working condition	No Training / Experience	Non / Semi skilled	No awareness	Negligence	Mild Injury	Moderate Injury	Lose of parts	Casuality
Falling from height	1	3	3	4	4	4	3	2	3	4	2	2	2	2
Electrocusions	1	1	3	3	4	1	2	3	2	4	2	1	1	3
Construction Vehicles & Machineries	0	0	2	3	3	1	2	2	2	2	2	1	2	1
Power / Manual Tools	0	0	2	3	4	1	2	3	3	3	2	1	2	1
Stairs / Ladder / Scaffolding	3	4	3	3	4	3	3	4	4	4	3	3	3	3
Slip & fall down	2	1	3	4	3	3	2	2	3	3	3	3	2	1
Shuttering & Deshuttering	2	4	3	4	4	2	3	4	4	3	3	3	2	2
Struck by moving objects / Machineries	0	1	2	2	2	1	2	2	2	2	3	2	2	1
Quality Construction materials	3	3	3	3	1	1	1	1	1	2	2	2	2	2
Gas leaks, fires and explosions	3	3	3	2	1	4	4	4	4	4	1	1	2	3
Caught-between	2	3	3	3	2	1	2	3	2	2	2	2	2	2
Exposure to dangerous chemicals or toxins	2	2	3	3	2	3	4	4	4	4	1	1	1	1

Table 6 – Finishing level – Who, Why & What



	Architect	Designer	Cons. Engineer	Superrvisor	Workers	Unsafe working condition	No Training / Experience	Non / Semi skilled	No awareness	Negligence	Mild Injury	Moderate Injury	Lose of parts	Casuality
Falling from height	2	1	3	4	4	3	3	2	3	4	2	2	2	3
Electrocusions	1	2	2	4	4	2	3	3	3	4	2	2	2	2
Construction Vehicles & Machineries	2	2	2	3	3	2	3	2	3	3	2	2	2	2
Power / Manual Tools	2	2	3	3	4	2	3	3	3	4	2	2	2	2
Stairs / Ladder / Scaffolding	2	4	3	4	4	2	3	3	4	4	2	3	3	4
Slip & fall down	2	3	3	3	3	4	2	2	2	3	2	3	3	1
Shuttering & Deshuttering	1	1	2	3	2	1	2	2	2	2	1	2	2	1
Struck by moving objects / Machineries	1	1	2	2	2	1	1	2	2	2	1	2	2	1
Quality Construction materials	2	2	3	3	1	1	2	3	3	3	1	3	3	2
Gas leaks, fires and explosions	1	1	1	1	1	3	3	3	4	4	1	3	2	3
Caught-between	1	1	1	1	1	1	2	2	2	3	2	2	3	2
Exposure to dangerous chemicals or toxins	1	1	1	1	1	2	3	3	4	4	1	1	1	1

Table 7 – All levels in total– Who, Why & What

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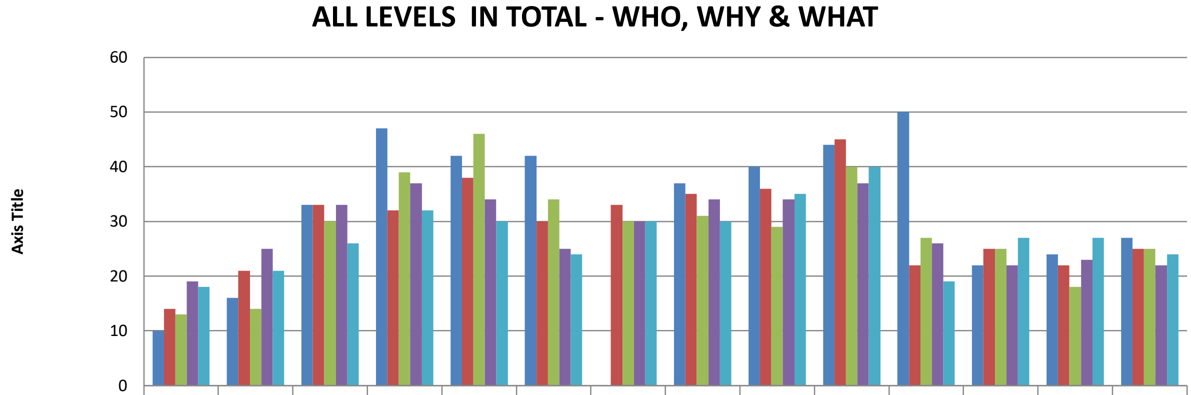


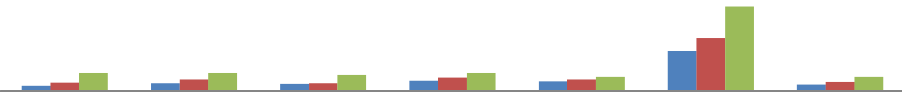
	Architect	Designer	Cons. Engineer	Superrvisor	Workers	Unsafe working condition	No Training / Experience	Non / Semi skilled	No awareness	Negligence	Mild Injury	Moderate Injury	Lose of parts	Casuality
Baement Level	10	16	33	47	42	42	0	37	40	44	50	22	24	27
Lintel Level	14	21	33	32	38	30	33	35	36	45	22	25	22	25
Roof Level	13	14	30	39	46	34	30	31	29	40	27	25	18	25
Caseing Level	19	25	33	37	34	25	30	34	34	37	26	22	23	22
Finishing Level	18	21	26	32	30	24	30	30	35	40	19	27	27	24

C. Results

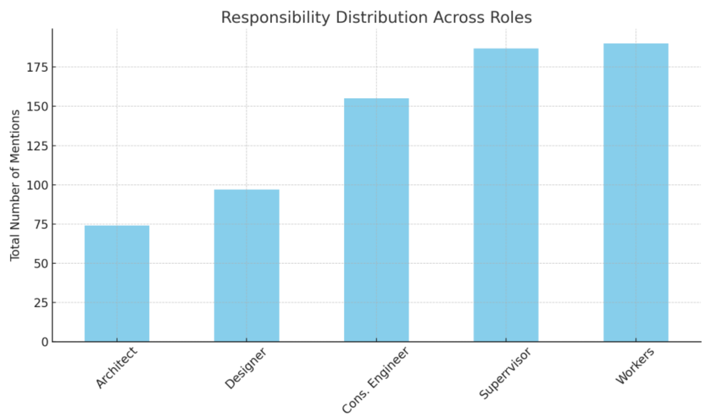
1. Stakeholder Accountability (Comparative Analysis)

Table 8 – Role-wise accountability across various levels (date from "full in %.xlsx").

Rolewise Accountability



	Baement Level	Lintel Level	Roof Level	Caseing Level	Finishing Level	Total	out of 600 - Percentage
Architect	8	12	11	16	15	62	10
Designer	13	18	12	21	18	82	14
Cons. Engineer	28	28	25	28	22	131	22



Graph 1 – Responsibility distribution

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Table 9 – Phase-wise accountability and critical risks

Level	Top 2	Dominant Failure Mode	Highest Severity
Basement	Supervisors (39%) Workers	Falling from height (RPN:	Moderate Injury
Lintel	Workers (32%), Designers (28%)	Electrocutions (RPN: 18)	Mild Injury (38%)
Roof	Workers (37%) Supervisors	Slip & fall (RPN: 25)	Moderate Injury
Casing	Supervisors (31%) Workers	Shuttering defects (RPN: 22)	Lose of parts (31%)
Finishing	Workers (33%) Negligence	Gas leaks (RPN: 24)	**Casualty (33%)**

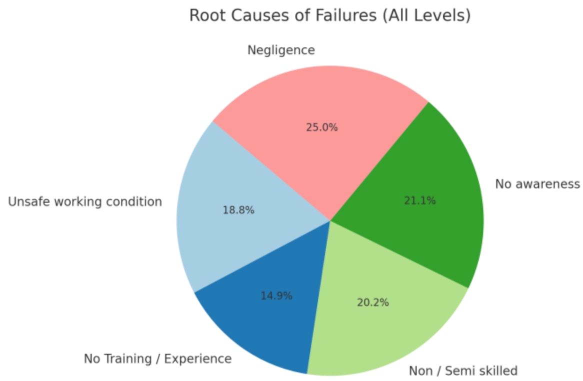


Figure 1 – Root cause of Failures (All levels)

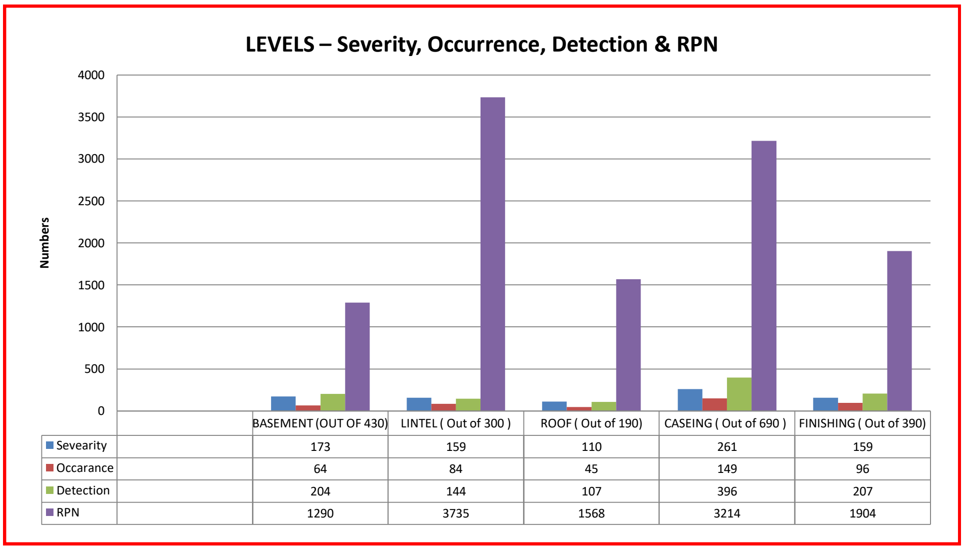
2. Root Causes ("Why")

Basement	Poor supervision (39%)	→ un safe scaffolding
Roof	Lack of training (25%)	→ Slip hazards
Finishing	Negligence (33%)	→ Gas leak explosions

3. Outcome Severity ("What")

- **Casualties highest in**: Finishing (gas leaks) and Basement (falls).
- **Material defects peak at**: Casing (28% accountability).

Table 10 – Levels – Severity, Occurrence, and Detection & RPN



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IV. DISCUSSION

A. Key Findings

- Responsibility Distribution: Workers and supervisors were most frequently cited as responsible parties, especially due to unsafe practices & lack of awareness.
- Variation across Levels: Roof level showed the highest concentration of failure modes, while basement had the most critical ones (e.g., electrocution, falling from heights).
- Severity Prediction: Casualties were mostly observed during basement and roof-level failures, while finishing stage saw higher mild/moderate injuries.
- Supervisors & workers are pivotal in 80% of failures
- Training gaps (25-32%) and unsafe conditions (35-42%) are systemic.
- Severity escalates from basement (moderate) to finishing (casualty).

B. Recommendations

1. Mandatory Safety Training for all workers before site induction.

Purpose: Ensure all workers are aware of site hazards, safety rules, and emergency procedures.

Procedure / Steps:

1. Prepare a training schedule before worker on boarding.
2. Cover topics such as: PPE usage, emergency evacuation, hazard recognition, machinery safety, and first aid basics.
3. Conduct classroom/theory sessions followed by practical demonstrations.
4. Test understanding through a short assessment.
5. Provide certification of completion before site entry.

Example:

- A new laborer attends a 2-hour induction covering PPE, scaffolding safety, and fall hazards. Passes a short quiz and receives a “Site Safety Induction Certificate.”

SOP:

- Documented in a Safety Induction Manual, updated annually. Include sign-off sheets for all participants.

2. Daily Safety Briefings conducted by site supervisors.

Purpose: Keep safety top-of-mind, communicate daily risks, and address ongoing issues.

Procedure / Steps:

1. Conduct a 10–15 minute briefing at the start of each shift.
2. Discuss planned work, hazards, control measures, and emergency contacts.
3. Encourage workers to raise concerns or near-miss incidents.
4. Record the briefing in a logbook.

Example:

- Site supervisor briefs team about working near live electrical wires and the precautions required.

SOP (detailed, written instructions that describe exactly how to perform a specific task or activity safely and efficiently)**:**

- Maintain a Daily Safety Briefing Template: Date, attendees, hazards, mitigation measures, supervisor signature.

3. Use of Checklists and SOPs for all critical construction activities.

Purpose: Standardize tasks, ensure safety, and reduce errors.

Procedure / Steps:

1. Identify critical activities (e.g., lifting operations, scaffold erection, crane operation).
2. Develop a step-by-step SOP for each activity.
3. Create a checklist to verify each step before work begins.
4. Ensure supervisors sign off each completed checklist.

Example:

- **Crane Operation SOP:** Inspect crane, check load limits, clear area, confirm communication signals, lift, and position load.
- **Checklist:** Crane inspection done ✅, load weight confirmed ✅, area cleared ✅.

4. Enhanced Supervision & Monitoring using real-time digital tools.

Purpose: Detect unsafe behavior and enforce safety standards effectively.

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Procedure / Steps:

1. Use wearable devices, cameras, or apps to monitor worker activity.
2. Track PPE compliance, risky behaviors, and site conditions.
3. Supervisors review reports daily and address safety deviations.

Example:

- Smart helmets alert supervisors if a worker enters a hazardous zone without PPE.

SOP:

- Create a **Digital Safety Monitoring SOP**: tool usage, data collection, and action protocols.

5. Improved Communication Channels among design and execution teams.

Purpose: Prevent accidents caused by miscommunication or design-execution gaps.

Procedure / Steps:

1. Establish regular meetings between engineers, supervisors, and workers.
2. Use collaborative platforms for design updates, site drawings, and instructions.
3. Ensure critical safety changes are highlighted and acknowledged.

Example:

- Digital platform shares an updated scaffold layout; supervisors confirm receipt and discuss risks with workers.

SOP:

- **Communication SOP:** frequency of meetings, platform usage, and confirmation protocol for design changes.

6. Regular Risk Audits to identify potential hazards early.

Purpose: Proactively detect and mitigate safety risks before accidents occur.

Procedure / Steps:

1. Schedule audits weekly/monthly.
2. Inspect high-risk zones (heights, excavation, electrical areas).
3. Record findings and assign corrective actions with deadlines.
4. Follow up to ensure implementation.

Example:

- Audit identifies uneven floor slabs. Immediate corrective action: barricade and level the surface.

SOP:

- **Risk Audit SOP:** checklist for site areas, risk scoring, reporting format, and follow-up procedure.

7. Skill Upgrade Programs for non/semi-skilled laborers.

Purpose: Improve worker competency, reduce errors, and increase safety awareness.

Procedure / Steps:

1. Assess skill gaps in non/semi-skilled laborers.
2. Organize short courses: equipment handling, scaffold erection, hazard recognition.
3. Include hands-on demonstrations and assessments.
4. Maintain skill records and issue completion certificates.

Example:

- Laborer completes 3-day training on safe welding and receives a competency certificate.

SOP:

- **Skill Development SOP:** training frequency, course content, assessment method, certification, and record-keeping.

Summary Table

Recommendation	Example	SOP / Checklist
Safety Training	Site induction certificate	Safety Induction Manual
Daily Briefings	Discuss live wire hazards	Daily Safety Briefing Template
Checklists/SOPs	Crane operation checklist	Activity-specific SOPs
Digital Monitoring	Smart helmet alerts	Digital Safety Monitoring SOP
Communication	Design update platform	Communication SOP
Risk Audits	Uneven floor corrected	Risk Audit SOP
Skill Upgrade	Welding training	Skill Development SOP

Key examples – Risk, intervention & expected impact:

Table 11 – Risk, Intervention & Expected Impact

Risk / Hazard	Intervention	Expected Impact
Falling from height	Mandatory harness use + supervisor audits	↓ 50% injuries (Basement/High-rise works)
Electrocutions	Lockout-tagout training	↓ 30% incidents (Lintel/electrical works)
Gas leaks	Automated detectors + worker drills	↓ 60% explosions (Finishing works)
Unsafe practices due to lack of awareness	Mandatory safety training for all workers before site induction	↓ 40% near-misses & minor accidents across site
Miscommunication / design-execution gaps	Improved communication channels among design and execution teams	↓ 25% planning errors and rework
Unidentified site hazards	Regular risk audits	Early detection & mitigation of 70% potential hazards
Skill deficiencies in non-skilled labor	Skill upgrade programs for non/semi-skilled laborers	↑ 50% productivity & ↓ 35% operational accidents
Critical task errors	Use of checklists and SOPs for all critical activities	↓ 45% procedural errors / accidents
Non-compliance or oversight	Enhanced supervision & monitoring using digital tools	↑ 60% compliance with safety rules

V. CONCLUSION

This research demonstrated that effective risk identification using FMEA not only highlights failure modes but also offers targeted interventions to enhance construction quality. The collaborative involvement of all stakeholders—architects, designers, engineers, supervisors & workers—is critical to reducing failure occurrence and ensuring safety across all construction phases which will accommodating to sustain the quality and also improves.
FMEA reveals phase-specific risks and accountability hotspots. Addressing training, supervision & PPE use can reduce failures by 40–60%**.** Future work should integrate IoT sensors for real-time risk monitoring.

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