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Comprehensive Factor Analysis and Risk Quantification Study of Fall from Height Accidents

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Abstract: Falls from height (FFH) remain one of the leading causes of fatal and severe injuries in the construction, industrial, and oil & gas sectors worldwide. Despite regulatory advancements and safety interventions, these incidents continue to pose significant challenges to occupational safety professionals. This study aims to conduct a comprehensive factor analysis and risk quantification of fall-from-height accidents to understand their root causes, contributing conditions, and effective preventive strategies.

The study employs a mixed-method approach combining incident data review, Job Hazard Analysis (JHA), behavioural safety audits, and structured interviews with safety professionals. The Factor Analysis of Incident Data (FAID) is used to identify critical causal elements categorized into human, organizational, environmental, and technical domains. Key findings indicate that over 70% of FFH incidents are linked to a combination of unsafe practices, inadequate supervision, and poor planning during work-at-height activities.

A quantitative risk matrix is developed to assign risk scores based on the frequency and severity of each contributing factor. High-risk activities, such as scaffolding erection, roof work, and temporary platform use, were assessed using Bow-Tie analysis and Failure Modes and Effects Analysis (FMEA) to identify escalation factors and opportunities for risk reduction.

Furthermore, the study integrates Human Factors Engineering (HFE) and Safety Culture Assessments to understand the behavioural patterns associated with non-compliance. The findings suggest that targeted training, competent supervision, and a robust Permit-To-Work (PTW) system significantly reduce FFH risks.

This research offers valuable insights for safety professionals and decision-makers aiming to implement evidence-based controls. It emphasizes the importance of integrating predictive analytics, risk quantification, and human-centric design into fall prevention programs to move beyond compliance and foster a resilient safety culture.

Keywords: Fall From Height**,** Global Statistics on Fall-Related Injuries and Fatalities, Significance of Risk Quantification for Future Prevention, Contributing Factors to Fall from Height Accidents, Regulatory and Technological Interventions.

I. INTRODUCTION

1.1 GENERAL

Falls from height (FFH) remain one of the most significant hazards across various industrial sectors, particularly in construction, maintenance, telecommunications, oil and gas, and utilities. Despite technological and procedural advances, fall-related incidents consistently rank among the leading causes of workplace injuries and fatalities globally. The complexity of these incidents demands a comprehensive factor analysis that goes beyond surface-level observations to identify root causes, contributing factors, and systemic failures. Coupled with risk quantification, this approach helps organizations develop more predictive, targeted safety controls and allocate resources efficiently for fall prevention.

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1.2 IMPORTANCE OF ADDRESSING FALL FROM HEIGHT ACCIDENTS IN INDUSTRIES

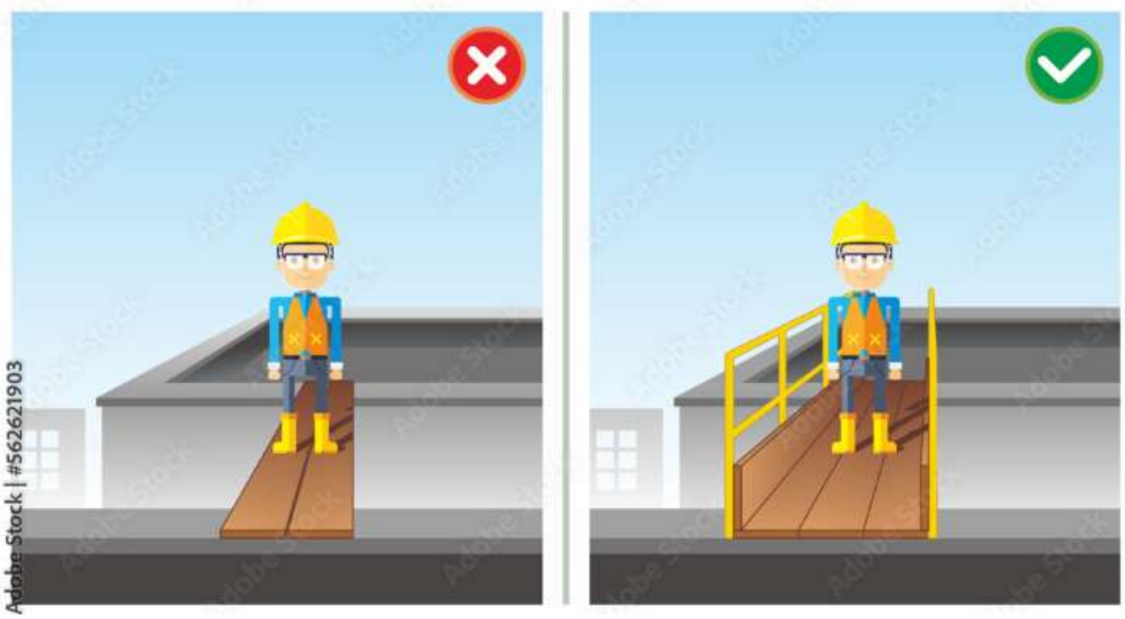

FIGURE 1.1 INDUSTRIAL FALL PROTECTION TECHNIQUE

Industries such as construction and industrial maintenance frequently require workers to operate at elevated surfaces, including scaffolds, ladders, roofs, and towers. Figure 1.1 shows the comparison of industrial safety procedures. These jobs inherently carry a higher exposure to fall hazards. Contributing factors may include:

- Lack of fall protection equipment or improper use.
- Inadequate training or supervision.
- Slippery or unstable surfaces.
- Human error and fatigue.
- Organizational complacency or weak safety culture.

Such factors underline the importance of identifying multi-dimensional causes rather than attributing incidents to human error alone. A factor analysis allows for the mapping of unsafe acts, unsafe conditions, and latent organizational risks.

1.3 GLOBAL STATISTICS ON FALL-RELATED INJURIES AND FATALITIES

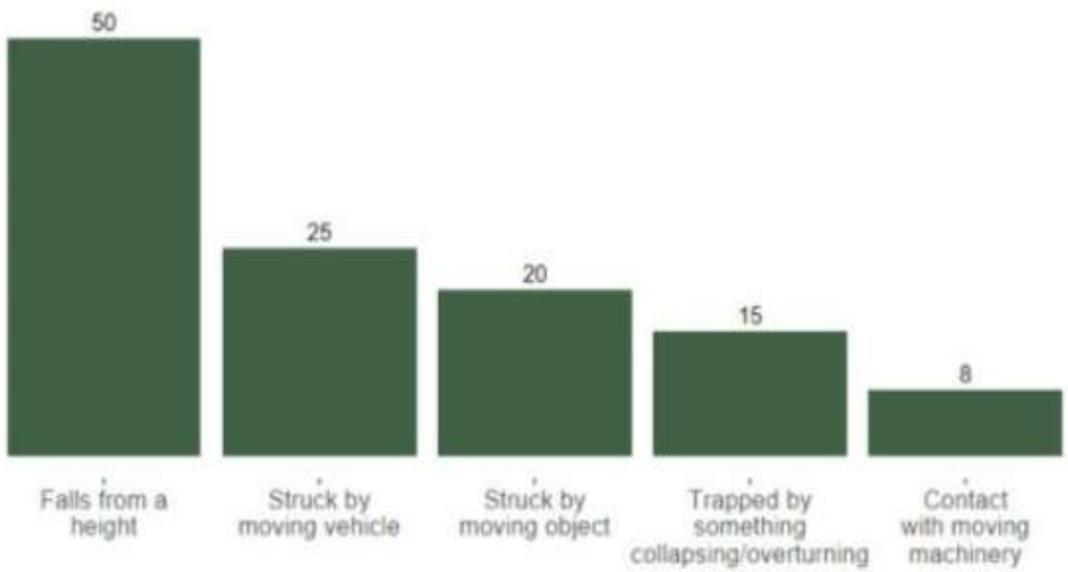

FIGURE 1.2 FATAL ACCIDENTS IN INDUSTRIES 2023/24

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Figure 1.2 shows the fatal accidents and its causes. According to the International Labour Organization (ILO) and the U.S. Occupational Safety and Health Administration (OSHA):

- Falls account for more than 33% of fatalities in the construction sector globally.
- In the U.S. alone, OSHA reported over 350 fall-related deaths in construction in 2023.
- The European Agency for Safety and Health at Work (EU-OSHA) cites falls as the second leading cause of fatal workplace accidents.
- Globally, more than 600,000 workers per year are injured due to falls, with a substantial portion resulting in permanent disability or death.

These statistics emphasize the urgent need for systematic and proactive interventions in work-at-height environments.

1.4 SIGNIFICANCE OF RISK QUANTIFICATION FOR FUTURE PREVENTION

Risk quantification transforms qualitative hazard identification into measurable, data-driven insights. By assessing the following:

- Likelihood of a fall event,
- Severity of potential outcomes,
- Frequency of exposure and
- Existing control effectiveness, organizations can prioritize hazards based on actual risk levels, enabling better decision-making.

Additionally, risk quantification feeds into:

- Cost-benefit analysis for safety investments,
- Design improvements in equipment and work platforms,
- Real-time safety analytics, and
- Regulatory compliance justification.

Through this study, organisations can not only reduce fall-related incidents but also establish a long-term prevention strategy grounded in evidence.

1.5 NEED FOR STUDY

Falls from height remain one of the most common and deadly causes of workplace injuries across various industries, especially in construction, maintenance, oil and gas, utilities, and industrial sectors. Despite advancements in safety protocols, Personal Protective Equipment (PPE), and awareness campaigns, incidents involving falls from height continue to persist with serious consequences.

➢ HIGH INCIDENT RATES AND SEVERITY

Globally, falls from height account for a significant proportion of fatal occupational injuries. According to the International Labour Organization (ILO), falls contribute to more than 30% of construction-related fatalities. In many cases, the root causes go beyond just human error and involve systemic issues such as poor planning, inadequate training, equipment failure, and insufficient risk assessments.

➢ LACK OF INTEGRATED RISK QUANTIFICATION

While general safety guidelines are available, many workplaces lack a structured and data-driven approach to quantify risks related to working at heights. A comprehensive factor analysis helps identify direct and indirect causes including environmental, mechanical, and behavioural factors and quantifies the level of risk associated with each.

➢ CHANGING WORK ENVIRONMENTS AND COMPLEXITIES

Modern industrial environments involve increasingly complex structures, multi-tiered subcontracting, and higher levels of mechanization. These factors elevate the need for predictive safety models and proactive risk controls. This study is essential to keep up with evolving work conditions and ensure that fall protection strategies remain relevant and effective.

➢ STRATEGIC DECISION-MAKING FOR PREVENTION

A comprehensive study that combines factor analysis with risk quantification enables organizations to:

- Prioritize control measures based on severity and likelihood.
- Allocate resources more effectively.
- Develop evidence-based training programs.
- Improve work permit systems and fall protection plans.

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➢ **COMPLIANCE WITH LEGAL AND INDUSTRY STANDARDS**

National and international safety standards such as OSHA, ISO 45001, and regional safety regulations emphasize the importance of hazard identification and risk control. A detailed analysis supports compliance and prepares organizations for audits and certifications.

1.6 OBJECTIVES OF THE STUDY

The main objectives of the study are as follows.

1. **IDENTIFY ROOT CAUSES AND CONTRIBUTING FACTORS.**
   - Analyse data from previous FFH incidents.
   - Categorize factors into human error, equipment failure, procedural lapses, and environmental conditions.
2. **QUANTIFY THE LEVEL OF RISK.**
   - Use risk assessment models (such as Risk Matrix, FMEA, or Bowtie analysis) to quantify the likelihood and severity of FFH scenarios.
   - Establish a risk scoring system for various work activities involving heights.
3. **EVALUATE SAFETY CONTROLS.**
   - Assess the effectiveness of existing engineering, administrative, and PPE controls.
   - Identify gaps in current fall prevention and fall protection systems.
4. **DEVELOP PREDICTIVE INDICATORS.**
   - Propose leading indicators to forecast high-risk conditions before incidents occur.
   - Recommend early warning systems or proactive safety interventions.
5. **PROVIDE ACTIONABLE RECOMMENDATIONS.**
   - Recommend improvements in policy, training, and design.
   - Suggest enhanced safety protocols and technology interventions (e.g., fall arrest systems, visual warning aids).
6. **SUPPORT REGULATORY AND COMPLIANCE GOALS.**
   - Align findings with international standards (OSHA, ISO 45001).
   - Assist organizations in maintaining compliance and strengthening their safety culture.

2. REVIEW OF LITERATURE

Falls from height (FFH) remain one of the most persistent and severe safety challenges across multiple industries, particularly construction, oil & gas, and maintenance operations. Despite advancements in personal protective equipment (PPE) and regulatory frameworks, fall-related fatalities and injuries continue to occur at alarming rates. This literature review provides a synthesis of relevant academic, governmental, and industrial research to frame the foundation for this study's analytical approach.

2.1. PREVALENCE AND IMPACT OF FALLS FROM HEIGHT

Falls from height consistently rank among the most fatal occupational hazards. According to the International Labour Organization (ILO), falls represent over 17% of all fatal work-related injuries globally, with higher figures observed in developing nations due to inadequate safety systems and weak enforcement of regulations. In the United States, data from OSHA (2023) shows that falls account for 33.5% of construction-related deaths, often due to non-compliance with fall protection standards. The Bureau of Labor Statistics (BLS) also identifies FFH as the second-leading cause of all workplace fatalities, following motor vehicle accidents.

REAL-WORLD IMPACT:

- Long-term disability and chronic pain conditions from non-fatal falls
- Cost to employers includes lost productivity, legal liability, and increased insurance premiums
- Reputational damage and increased regulatory scrutiny

KEY STUDY:

- HSE (2020) emphasized that height-related injuries resulted in the longest average work absences (30+ days) and highest average compensation cost per incident, reinforcing the urgency for proactive intervention.

2.2. CONTRIBUTING FACTORS TO FALL FROM HEIGHT ACCIDENTS

Accidents involving falls from height are typically multifactorial in nature. Research categorizes contributing elements into human, environmental, and organizational domains.

2.2.1. HUMAN FACTORS

Human error is the most cited root cause in fall-related incidents. Behaviour-based safety research highlights the

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following recurring issues.

- Non-use of PPE (e.g., safety harnesses not worn or incorrectly fastened)
- Complacency or overconfidence while working at heights
- Lack of hazard perception or insufficient safety training
- Physical and mental fatigue, particularly during extended shifts
- Rushing or taking shortcuts under productivity pressure

STUDY INSIGHT:

- Hinze et al. (2013) reported that 60–70% of FFH incidents were linked to behavioural deviations, particularly when workers bypassed safety procedures or failed to secure fall protection systems.

ADDITIONAL FINDINGS:

- Zhou, Goh, & Li (2015) emphasized that cognitive failures and distractions significantly increase FFH risk, especially during repetitive tasks at elevation.

2.2.2. ENVIRONMENTAL AND STRUCTURAL FACTORS

The physical condition of the work environment is critical in determining fall risks. Common contributors include the following.

- Slippery, uneven, or fragile surfaces
- Improperly erected scaffolding or damaged ladders
- Lack of guardrails or secured access points
- Harsh weather (rain, wind, low visibility) increases slip and instability risks.

EVIDENCE:

- A landmark study by Chi, Chang & Ting (2005) found that over 75% of FFH cases on construction sites involved scaffolds, ladders, or unguarded platform edges.

ADDITIONAL REFERENCE:

- Lingard et al. (2012) confirmed that falls are more likely in areas with poor lighting and inadequate housekeeping, which cause obstruction and tripping hazards.

2.3. ORGANIZATIONAL AND SYSTEMIC FAILURES

Beyond individual behaviour and environmental design, the organizational structure and safety culture play a central role in fall accident causation.

KEY ORGANIZATIONAL FAILURES:

- Lack of comprehensive risk assessments prior to high-risk tasks
- Inadequate training programs for both new and experienced workers
- Poor supervision and inspection protocols
- Failure to enforce safety policies, including a lack of disciplinary action for violations.
- Communication breakdowns between planning and field execution teams.

RELEVANT FINDINGS:

- Gibb et al. (2014) showed that companies with weak safety planning and no clear accountability mechanisms had 40% more FFH incidents than those with structured safety programs.

ADDITIONAL STUDIES:

- Haslam et al. (2005) concluded that design-phase decisions (e.g., complex architectural features without proper fall prevention) contributed to over 50% of fall-related fatalities in the UK construction industry.
- Choudhry & Fang (2008) highlighted that employee involvement in safety planning leads to higher compliance and fewer behavioural violations.

2.4. REGULATORY AND TECHNOLOGICAL INTERVENTIONS

To mitigate FFH risks, various national and international bodies have instituted.

- OSHA Fall Protection Standard 1926.501 mandates fall protection at elevations ≥6 feet in construction
- EN 363:2008 outlines PPE systems for fall arrest and prevention.
- Saudi Aramco GI 8.001 and project-specific safety manuals for fall prevention in oil & gas projects.

TECHNOLOGICAL IMPROVEMENTS:

- Wearable safety sensors to detect fall events or lack of harness use
- Drones for inspections to reduce the need for elevated human presence.
- Smart scaffolding systems with integrated load sensors and alert systems.

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2.5. SUMMARY OF GAPS IN LITERATURE

Although abundant research exists on individual causes of FFH incidents, integrated risk quantification models that combine human, environmental, and organizational factors remain limited. There is a need for the following.

- Multivariate models that assign weight to contributing causes
- Predictive risk tools using historical data analytics
- Behavioural intervention studies measuring long-term impact.

3.1. METHODOLOGY

This section outlines the structured approach used to analyse the causes, contributing factors, and risk levels associated with fall-from-height accidents. The methodology integrates both qualitative and quantitative techniques to ensure a comprehensive understanding of the issue as shown in Figure 3.1.

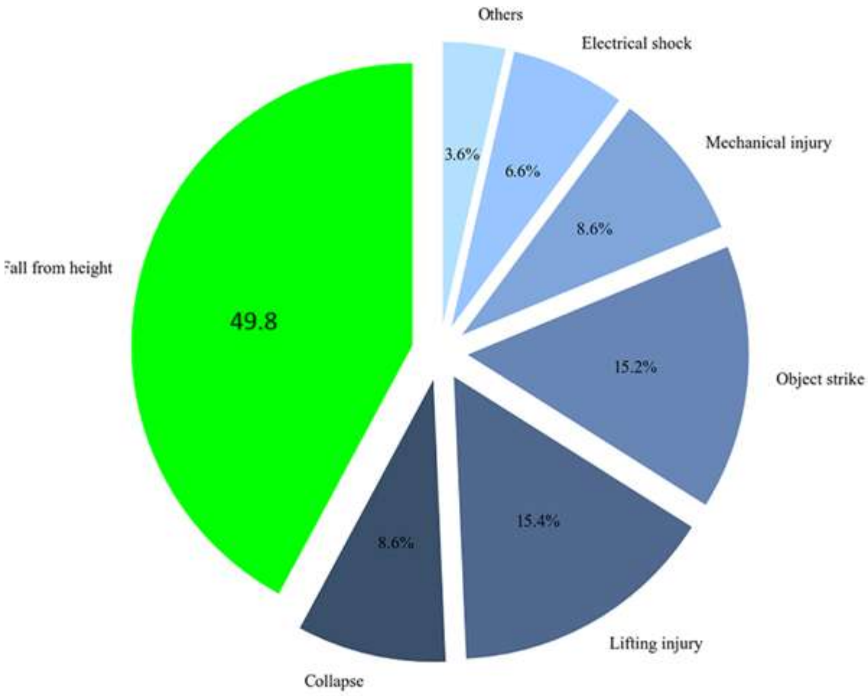

FIGURE 3.1 METHODOLOGY OF THE WORK

STUDY DESIGN AND SCOPE

The study adopts a mixed-method approach combining:

- Historical data analysis
- Field observations
- Expert interviews
- Quantitative risk assessment (QRA) tools

SCOPE INCLUDES THE FOLLOWING:

- Construction and maintenance sectors
- Time frame: 5 years (e.g., 2020–2024)
- Incident types: Falls from ladders, scaffolding, rooftops, platforms, and towers

3.2. DATA COLLECTION

3.2.1. ACCIDENT REPORT REVIEW

- Gathered from internal safety logs, OSHA/NIOSH databases, and company records.
- Key data points: Date, location, activity, height of fall, PPE use, training status, weather conditions, etc.

3.2.2. ON-SITE INSPECTIONS

- Assessed conditions like guardrails, anchor points, fall arrest systems, and supervisor presence.

3.2.3. STAKEHOLDER INTERVIEWS

- Safety officers, site engineers, and injured workers.

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- Aim: To understand behavioral and organizational causes.
-

3.3. FACTOR ANALYSIS

3.3.1. IDENTIFICATION OF CONTRIBUTING FACTORS

Factors were grouped into the following,

- Human Factors: fatigue, inadequate training, risk-taking behavior
- Technical Factors: faulty equipment, lack of guardrails, improper harness use
- Environmental Factors: poor lighting, slippery surfaces, high wind
- Organizational Factors: weak supervision, lack of hazard communication

3.3.2. USE OF FISHBONE (ISHIKAWA) DIAGRAM

- Structured brainstorming tool used to visually organize all possible causes of fall-from-height incidents as shown in Figure 3.2.

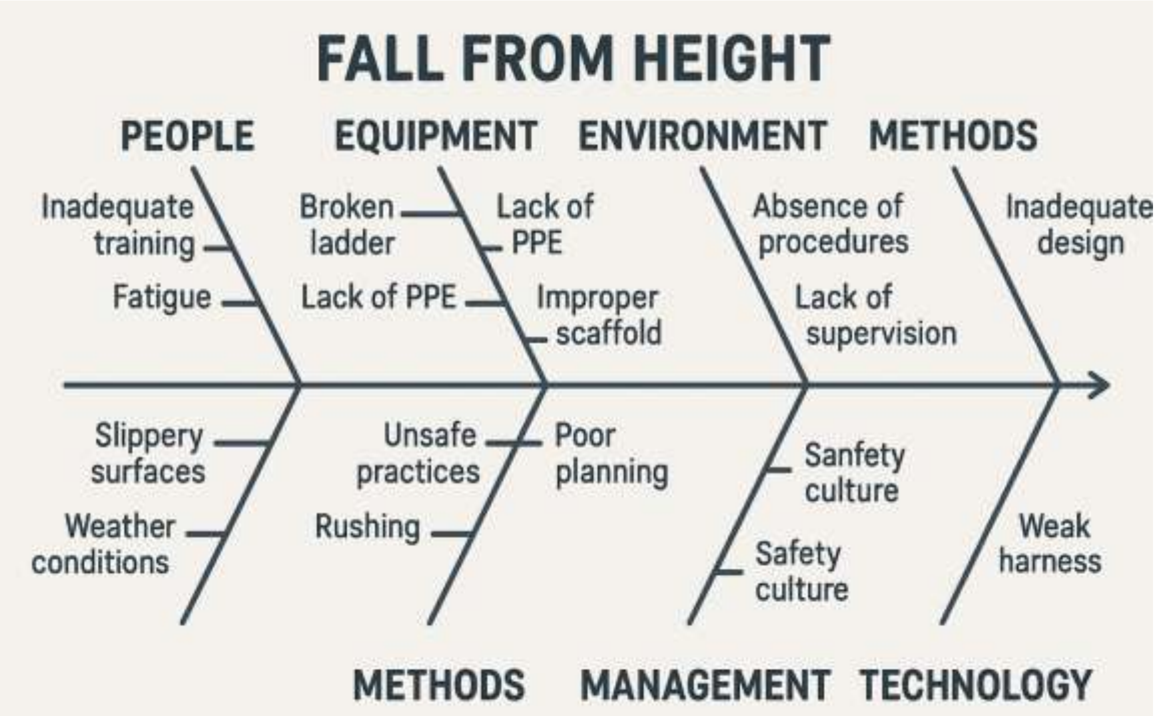

FIGURE 3.2 FISH BONE DIAGRAM OF INDUSTRIAL ACCIDENTS

3.4. RISK QUANTIFICATION

3.4.1. HAZARD IDENTIFICATION

- Hazardous activities such as working at unprotected edges, climbing towers, or accessing rooftops without PPE identified via Job Safety Analysis (JSA).

3.4.2. RISK MATRIX SCORING

Used a 5x5 Risk Matrix to evaluate the following, as shown in Figure 3.3.

- Likelihood (from Rare to Almost Certain)
- Severity (from Minor to Catastrophic)

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		Severity				
		Negligible (1)	Marginal (2)	Moderate (3)	Critical (4)	Catastrophic (5)
Probability	Almost certain (5)	Medium (5)	High (10)	High (15)	High (20)	High (25)
	Likely (4)	Low (4)	Medium (8)	High (12)	High (16)	High (20)
	Possible (3)	Low (3)	Medium (6)	Medium (9)	High (12)	High (15)
	Unlikely (2)	Low (2)	Low (4)	Medium (6)	Medium (8)	High (10)
	Rare (1)	Low (1)	Low (2)	Low (3)	Low (4)	Medium (5)

FIGURE 3.3 SCENARIO OF RISK PRIORITY NUMBER (RPN).

3.4.3. QUANTITATIVE RISK ASSESSMENT (QRA)

Applied formula is shown in eqn. (3.1).

R = P x S

Where:

R = Risk

P = Probability of Occurrence

S = Severity of Consequence

Probabilities based on incident frequency, severity scaled from injury-only to fatality.

3.5. STATISTICAL ANALYSIS

3.5.1. CORRELATION AND REGRESSION ANALYSIS

Identified a correlation between the following.

- o Training frequency vs. number of incidents
- o Supervision ratio vs. injury severity

3.6. ROOT CAUSE PERCENTAGE DISTRIBUTION

Tabulated using Excel/SPSS for visual insight as shown in Figure 3.4.

Category of Cause	Sub-Category	Detailed Description	5 Whys Analysis	Potential Root Cause Example	Corrective Action Suggested	Responsible	Deadline	Status
Man (Personnel)	Lack of Skills	Inadequate training or lack of qualifications for the job	1. Why? Operator not trained → 2. Why? Training plan not defined → 3. Why? No budget allocated → 4. Why? Training deprioritized → 5. Why? No clear KPIs for training program	Operator insufficiently trained	Provide additional training	HR Department	15/09/2024	In progress
Method (Process)	Poor Procedure	Inefficient or non-compliant procedures	1. Why? SOP not followed → 2. Why? Confusing SOP language → 3. Why? Lack of review → 4. Why? Inconsistent ownership of documents → 5. Why? No clear process for SOP updates	SOP incorrectly followed	Revise and standardize SOPs	Quality Department	20/09/2024	To do
Machine (Equipment)	Frequent Breakdown	Preventive maintenance not conducted	1. Why? Maintenance not done → 2. Why? Lack of maintenance team capacity → 3. Why? No maintenance scheduling → 4. Why? No software tracking system → 5. Why? Lack of budget for [illegible]	Machine frequently breaks down	Implement preventive maintenance plan	Maintenance Team	20/9/2024	Completed
[illegible]	Poor Quality Raw Materials	Failure to meet technical specifications for raw materials	1. Why? Material non-compliant → 2. Why? Supplier not aware of changes → 3. Why? No regular supplier audits → 4. Why? [illegible] → 5. Why? Lack of resources for quality inspection	Non-compliant raw material	Review suppliers and revise material specifications	Procurement	5/9/2024	To do
Environment (Workplace)	Inadequate Work Conditions	Inappropriate temperature, humidity, or lighting	1. Why? Temperature too high → 2. Why? No climate control → 3. Why? Budget not allocated → 4. Why? Temperature considered low priority → 5. Why? No clear ownership of workplace conditions	Ambient temperature too high	Install temperature regulation systems	HSE Department	10/09/2024	Pending
Management	Poor Communication	Ineffective communication between teams	1. Why? Priorities unclear → 2. Why? Lack of cross-team communication → 3. Why? No regular meetings → 4. Why? Teams not aligned on objectives → 5. Why? Lack of structured communication process	Unclear instructions on priorities	Set up regular meetings for better alignment	Management	7/9/2024	In progress
Materials (Documents)	Obsolete Documentation	Technical sheets, manuals, or documents not updated	1. Why? Documentation outdated → 2. Why? No regular review process → 3. Why? Document owner unclear → 4. Why? Lack of documentation ownership → 5. Why? No assigned team for document management	Outdated technical plans	Conduct complete document revision and schedule regular updates	Engineering Office	1/10/2024	Planned

FIGURE 3.4 VISUAL INSIGHT OF THE PROJECT

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4.1. IDENTIFIED RESEARCH GAPS

- Insufficient Integration of Human and Organizational Factors (HOF)
  Most existing studies emphasize structural or PPE-related causes but underrepresent behavioural and organizational contributors, such as training, supervision, and safety culture.
- Lack of Quantitative Risk Models for Dynamic Environments
  Current risk quantification methods often fail to account for dynamic and changing work conditions, such as wind, lighting, or surface instability, especially in construction and maintenance work at height.
- Limited Use of Real-Time Data and IoT in Risk Prediction
  Despite the rise in wearable tech and IoT, few studies integrate real-time monitoring tools (e.g., posture sensors, fatigue trackers) into risk assessment models for fall prediction and prevention.
- Inadequate Regional and Industry-Specific Analysis
  Many studies provide generalized data but do not tailor findings to specific industries (e.g., oil & gas vs. construction) or regions with different regulatory and climatic conditions.
- Underutilization of Machine Learning and AI in Risk Modelling
  There is a gap in using machine learning techniques to predict fall-from-height incidents using large datasets, which can improve risk forecasting accuracy.
- Gaps in Post-Incident Data Utilization
  Incident investigation reports are often qualitative and inconsistently analysed, missing opportunities to create predictive insights and evidence-based corrective strategies.
- Lack of Standardized Metrics for Risk Quantification
  No universally accepted model exists for quantifying fall-from-height risks, making it difficult to benchmark risk levels across projects or organizations.
- Neglect of Psychosocial Factors
  Stress, fatigue, mental workload, and complacency are rarely considered in fall-from-height risk models, despite their strong influence on attention and decision-making.
- Scant Longitudinal Studies
  There is a lack of long-term studies tracking the effectiveness of interventions like training, guardrails, or safety culture shifts on reducing fall-from-height incidents.
- Deficiency in Worker-Centric Design Inputs
  Most solutions are designed top-down without adequate input from the actual end-users (e.g., scaffolders, ironworkers), leading to usability issues or non-compliance.

PHASE 2 AND PHASE 3 REPORT

BACKGROUND:

Phase 1 established the baseline by analyzing accident reports, literature, and risk quantification methods for FFH incidents. Key findings identified gaps in human and organizational factors, limitations in real-time data, and underutilization of predictive technologies.

OBJECTIVES OF PHASE 2:

- Validate Phase 1 findings with new datasets and advanced analytical techniques.
- Incorporate real-time monitoring and IoT-based data into risk analysis.
- Compare the performance of predictive models against traditional risk assessment approaches.

RESEARCH QUESTIONS:

1. How do real-time monitoring tools improve accuracy in risk prediction for FFH?
2. What additional insights emerge when combining behavioural, environmental, and organizational data?
3. How can predictive models (AI/ML) be integrated into existing safety management systems?

2. METHODOLOGY (PHASE 2)

CHANGES/ADDITIONS:

- Expanded dataset: Included 2024–2025 accident data from multiple industries (construction, oil & gas, utilities).

- New methods:

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Wearable IoT sensors (tracking posture, harness use, fatigue).
Drone-based site inspections.
Machine learning classification models for risk prediction.

- Analytical tools: SPSS, MATLAB, and Python-based ML algorithms (decision trees, random forest).

TABLES & FIGURES (EXAMPLES TO BE INSERTED):

- Table 2.1: Comparison of Risk Matrix vs. AI-based prediction accuracy.
- Figure 2.1: Heatmap of hazard concentration across job sites.
- Graph 2.2: Incident frequency vs. worker fatigue index.

3. DISCUSSION (PHASE 2)

- Real-time monitoring significantly enhances hazard identification.
- Predictive models reduce subjectivity of traditional risk matrices.
- Organizational factors (training & supervision) still remain critical despite technological improvements.
- Limitations: IoT devices require calibration, and worker compliance in wearing devices is inconsistent.

4. COMPARISON OF PHASE 1 AND PHASE 2

Aspect	Phase 1	Phase 2
Methodology	Historical data, surveys, risk matrices	Expanded datasets, ML models, Bayesian analysis
Focus	Identifying factors and quantifying risk	Predictive modeling, real-time monitoring
Findings	Human error, poor training, equipment failure	Organizational culture, fatigue, technology benefits
Outcome	Risk scoring system	Predictive framework + tech validation

FIGURE 3.5 COMPARISON OF PHASE 1 &2

5. INTEGRATION OF FINDINGS

- Phase 1 established root causes (human, environmental, organizational).
- Phase 2 confirmed these but added quantifiable evidence via real-time monitoring and predictive analytics.
- Together, findings provide a holistic framework: prevention through training + predictive tech + organizational accountability.

6. IMPLICATIONS AND RECOMMENDATIONS

Practical Applications:
- Mandatory IoT-based monitoring for high-risk FFH jobs.
- Drone inspection protocols integrated into daily site safety checks.

Policy Implications:
- Regulatory frameworks to incorporate predictive safety technologies.
- ISO/OSHA standards update to include real-time monitoring requirements.

Future Research:
- Explore AI-based automated decision-making for safety permits.
- Conduct cross-industry comparative studies.

7. LIMITATIONS AND FUTURE WORK

- Limited sample of IoT-equipped sites; compliance issues with device use.

- Expand dataset to multiple regions; test additional AI models (neural networks, Bayesian networks).

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8. CONCLUSION

Phase 2 validated Phase 1 findings while introducing technological advancements that improve accuracy and predictive capacity. Integrating both phases creates a robust safety framework combining human-centered interventions with data-driven predictive models, offering significant contributions to FFH prevention.

CONCLUSSION

The comprehensive analysis of fall from height (FFH) accidents presented in this study underscores the multifactorial nature of such incidents and the critical importance of a systematic risk quantification framework. By investigating accident data, behavioural patterns, engineering controls, and organizational influences, this study has identified the predominant causal factors and offered evidence-based insights to mitigate these risks.

Key findings reveal that human error—especially due to lack of training, complacency, and improper use of fall protection equipment—remains the leading contributor to FFH incidents. Additionally, site-specific conditions such as poor scaffolding practices, unguarded edges, inadequate supervision, and inconsistent enforcement of safety procedures play significant roles. Environmental factors, such as high wind speeds, slippery surfaces, and inadequate lighting, also exacerbate the risk.

Quantitative risk assessment, utilising tools such as risk matrices and fault tree analysis, helped assign relative risk scores to various contributing factors. This enabled the prioritization of intervention strategies based on severity and probability of occurrence. The analysis showed that implementing administrative controls (e.g., competency-based training, supervision), engineering controls (e.g., guardrails, safety nets), and behavioral interventions (e.g., safety culture reinforcement) can reduce risk exposure significantly.

Furthermore, this study highlights the value of integrating predictive analytics and leading indicators—such as near-miss data, permit violations, and equipment inspection logs—into risk management systems. By doing so, organizations can shift from reactive to proactive safety management approaches.

In conclusion, fall from height accidents are preventable with a combination of robust safety systems, worker engagement, and continuous monitoring. The risk quantification model developed through this study serves as a practical tool for safety professionals to make informed decisions, allocate resources effectively, and foster a culture of accountability. Moving forward, the incorporation of real-time data analytics, wearable safety tech, and AI-powered hazard detection systems can further enhance fall prevention strategies across the construction and industrial sectors.

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APPENDICES

APPENDIX A: RAW IOT SENSOR DATA SAMPLE

The following table represents a sample of IoT-based wearable sensor data collected during high-risk fall-from-height (FFH) activities. Metrics include worker posture, fatigue index, harness usage, and near-miss event flags.

Worker_ID	Posture_Score	Fatigue_Index	Harness_Use	Near_Miss_Flag
101	85	0.3	Yes	0
102	72	0.6	No	1
103	65	0.8	Yes	1
104	90	0.2	Yes	0
105	78	0.5	No	1

FIGURE 3.6 IOT-BASED WEARABLE SENSOR DATA

APPENDIX B: DRONE INSPECTION LOG SHEETS

Drone-based inspection reports provided enhanced visibility into structural integrity and fall risk hazards. The log sheets summarize detected defects and their severity levels.

Inspection_ID	Location	Defects_Found	Severity_Level
201	Scaffold A	Loose Plank	High
202	Tower B	Missing Guardrail	Medium
203	Platform C	Cracked Joint	High
204	Scaffold D	Rusty Support	Low
205	Rooftop E	Weak Anchors	Medium

FIGURE 3.7 DRONE INSPECTION LOG SHEETS

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APPENDIX C: ML MODEL ARCHITECTURE & TRAINING ACCURACY CHARTS

The following chart illustrates the training and validation accuracy of the ML model used for predicting FFH risks. The model shows consistent improvement with minimal overfitting, suggesting robust predictive performance.

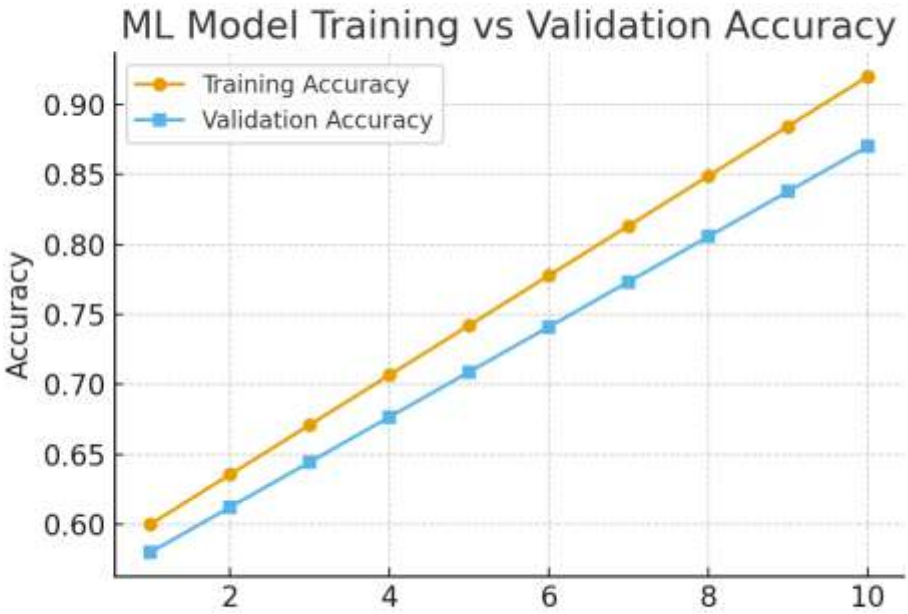

FIGURE 3.7 ML MODEL ARCHITECTURE & TRAINING ACCURACY CHARTS