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Leveraging Near-Miss Detection Metrics to Advance Sensing Technologies for Proactive Safety in Construction

by

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CERTIFICATE OF APPROVAL

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(Aqsa Malik)

Abstract

Earlier studies have shown that near-miss events often happen before actual accidents. Most current safety methods in construction depend on accident data that comes after incidents occur, which makes it hard to handle risks as they happen, especially in complex high-rise building projects. To fix this problem, this research aims to identify a range of near miss factors and develop a metrics based on measurable near miss scenarios that could contribute to the safety at construction site. The research uses a multi-method approach based on an architecture called Relative Importance Index (RII) to identify and rank the most important risk factors. The study's findings show that metrics related to sensing systems and technology are the key foundation (RII = 0.8109). This elaborates that fast data processing and strong network performance are essential for accurate risk detection. Also, there was a strong connection ($r = 0.632$, $p < 0.001$) between worker behavior (like unsafe actions) and the physical environment (like unsafe conditions). This reveals that poor layout or setup on a construction site can lead to more safety rule violations by workers. This research turns these findings into a Proactive Near-Miss Detection Framework supported by quantified detection metrics. The framework offers clear steps using sensors to prevent dangers before they cause harm. In the end, this study adds to safety theories driven by the literature review that construction sites can be digitized to detect and fix risks on their own before injuries happen.

Key Terms: Near miss scenarios, Construction Industry, high - rise building projects, sensing technology, Near miss detection

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Abbreviations

BIM	Building Information Modeling
CV	Computer Vision
ILO	The International Labor Organization
LTI	Lost-Time Injuries
NMR	Near miss reporting
NMS	Near-Miss Management Systems
PPE	Personal Protective Equipment
RFID	Radio Frequency Identification
RII	Relative Importance Index

Chapter 1

Introduction

This chapter throws light on the critical necessity of transitioning from reactive to proactive safety paradigms within the construction of high-rise buildings by leveraging near-miss scenario detection metrics. Despite the evolution of safety protocols, the sector continues to grapple with high fatality rates, largely due to a traditional reliance on lagging indicators which only measure safety after an incident has occurred. By focusing on near-misses as vital leading indicators, this research explores the integration of advanced sensing technologies to capture high-resolution safety data in real-time. The following sections delineate the research problem, establishing a framework for how standardized metrics can bridge the gap between manual reporting and automated monitoring, ultimately fostering a more resilient and predictive safety culture on construction sites.

1.1 Background of the Study

The construction industry owing to its temporary, dynamic, decentralized and complex nature results in the highest fatality rate. The construction sector has one out of five occupational deaths [1]. Occupational fatalities refer to deaths of individuals at construction sites these include falls from heights, caught between objects, electrocutions, and struck by objects [2]. The dynamic nature of the construction site can lead to endless risks; to mention a few, improper layouts, space constraints, working in constrained spaces, and numerous others [3]. Safety problems encountered in construction project management are never-ending since accidents are frequent but relatively small-scale with varied hazards commonly experienced in the form of falling off heights, being hit by an object, collapse, mechanical injury, explosion, fire, poisoning and electrocution [4]. Although the performance of construction projects in terms of safety has improved over the past 10 years, nonfatal and fatal accidents constantly occur [3]. Thus, there is still a long way to go before attaining the goal of zero accidents or harm in the construction industry.

Construction business occupies about 7% of the working population in the globe yet it causes 30-40% of the total number of fatal injuries in all sectors [5]. Different accident investigations and reports in construction projects have suggested that accidents never take place without undergoing any precursors [6]. There are dozens of accidents which have no injuries or losses before the fatal accidents [7]. This type of incident is called a "near-miss", which is usually neglected by workers and managers on-site [8].

Near-misses have been considered as a good opportunity to promote safety performance in various sectors, such as the petrochemical, fire protection, medical care, transportation, and nuclear power industries [9]. There is a gap in knowledge of what near-miss information describes in the framework of construction project management. This research contributes to add new information to the definition of near-miss, the near-miss causation model and the near-miss occurrences. Despite the fact that prior research on near-miss management in the construction industry has given several definitions of near-miss, the aspect of construction activity processes that tend to be non-standardized (when compared with other industries like manufacturing and aviation) was overlooked [10]. The suggested general definition of the near-miss concept in this case includes six types of it, which are unsafe behavior, unsafe conditions, property-loss incidents, possible-damage incidents, potentially more-damage incidents, and a challenged baseline, and can be readily learned and identified by construction workers. Near-miss management is a method that has been suggested and applied in diverse areas with a high risk of accidents, including the aerospace industry, natural disasters, coal mining, the petrochemical industry, fire service, medical care, sports, transportation, and nuclear energy [11].

There are other terms similar to "near-miss", such as near accident, near incident, close call, near hit, non-injured accident, near collision, sentinel event, and warning event [12]. The use of near-miss information has been embraced as a significant practice in accident prevention, as a significant number of incidents of near-miss can be gathered and examined [13]. Workers or unsafe circumstances in construction projects cannot be totally avoided through individual errors of the workers [7]. Nevertheless, there can be an early warning mechanism that can be carried out to assist construction project managers to devise an effective and proactive approach towards safety management. On-site workers should be advised to report on near-misses in the process of their working. The academia in the field of construction project management has recently started to pay more attention to near-miss management for more effective safety method [14].

The near-miss causation model was created based on TCHT (Two Classes' Hazard Theory) [14], which is a clear indication of the nature of a near-miss, its interrelationships, and differences with a near-miss and an accident. One can become prey to injury or death due to a change of energy. The lack of control of the energy can often result in near-misses or accidents. The strength of the proposed model lies in its ability to uncover the nature of near-miss occurrence in an ontological manner. It is not a blame model, but attempts to find out how and why a near-miss occurs in such a scenario. This model regards near-misses as a control problem, which is beneficial to hazard estimation, injury causation analysis, and energy transference control [15]. Given that the TCHT is inadequate in hierarchical analysis of the second class of hazards, the hierarchy of the causal influences model [16] can be considered to assist in modifying the two classes' hazard model. The near-miss causation model proposed in this research aims at the transfer of the unrestrained energy in sources to potential receivers by means of possible routes. According to knowledge management, near-miss belongs to a type of tacit failure knowledge

[3]. The near-miss management framework has eight phases: discovery, reporting, identification, prioritization, solution, causal analysis, dissemination, and evaluation [14].

1.2 Research Motivation

In Pakistan construction industry, near-miss incidents remain largely underreported and no baseline study on detection metrics currently exists. This research is motivated by the need to evaluate near-miss detection metrics and examine their potential role in supporting sensing technologies for proactive safety management in construction. Although near-miss incidents provide valuable insights into potential hazards in construction environments, their application in safety management practices remains limited. Many construction organizations still rely primarily on accident statistics rather than analyzing near-miss events as early warning indicators. At the same time, emerging sensing technologies have created opportunities to automate safety monitoring and hazard detection on construction sites. However, the effective implementation of these technologies requires clearly defined detection metrics that can translate unsafe interactions into measurable parameters.

1.3 Problem Statement

Although the construction industry has seen a rise in the availability and use of a variety of sensing technologies which are increasingly becoming automated, accidents and fatal injuries remain a significant issue for the industry given its dynamic and sometimes unpredictable operating environment [1]. The current paradigm of safety management is mostly reactive and uses lagging indicators like post-collision investigations to find out what went wrong after damage or injury has already happened [11]. A major operational gap exists, however, in the way these technologies are capturing the ”near-miss” events (or minor failures, incidents, and close calls that happen before major accidents occur) and categorizing and interpreting them [10]. A lack of a comprehensive approach which can build on accurate near-miss scenarios means that sensing systems can’t deliver real-time proactive risk mitigation, enabling site managers to break the causation chain before it reaches a point of catastrophic site injury [7, 8]. This research aims to identify a range of near miss factors and develop a measurable near miss scenario metrics that could contribute to the safety at construction site.

1.4 Research Questions

This research conceives the research questions given below:

i. What are the most frequently reported near-miss scenarios on construction projects?

ii. How can correlation analysis be applied to derive near-miss detection metrics?

iii. What is a near-miss detection metrices framework, and how can it support proactive safety management?

1.5 Research Objectives

The objectives of this research study are:

i. To identify frequently reported near-miss scenarios on construction projects.

ii. To develop detection metrics using correlation analysis.

iii. To develop a near miss detection framework for proactive safety management in construction.

1.6 Research Gap

Near miss reporting (NMR) in construction industry has been explored, but there is a wide gap in understanding research in this area in Pakistan [7]. Construction sites are workplaces where creativity and labor work in harmony, but pose risks for the workers and the community. Even with progress in improving safety practices, NMR is not sufficiently explored and thus a critical component of safety ecosystem remains unaddressed [14]. Though Pakistan has its own construction system and regulation, yet there is a lack of thorough research into the value of NMR in the literature, highlighting the need for more research to fully understand how NMR affects safety and to add to this field of academic knowledge [10]. With the focus now turning to near miss reporting's potential to change the safety scene in the industry, there is a gap that needs to be filled. The research suggests that scholars, practitioners, and policymakers will need to fill the gap between what is known and what is required, between theory and application. Answering this call brings up not only as a research question, but as a call to work for creating a safer, more resilient, and enlightened construction environment. To sum up, this study helps bring together the theoretical and practical aspects of near-miss reporting, highlighting its compatibility with existing construction safety systems. The study will provide empirical data to support the ranking of the most significant barriers and success factors, which translates to actionable data for industry professionals to use to implement safer practices.

1.7 Scope of Work and Study Limitations

1.7.1 Scope

The main thrust of the study is to identify and focus on scenario based near-miss incidents and get quantitative perceptive evidence on use of sensors to track moving objects. Future studies may focus the use of algorithms that could forecast incidence before occurrence. In this research work, the value of near miss reporting

(NMR) was examined in the context of the national and international occurrence of scenarios of near-miss incidents.

The research is designed to analyze construction professionals' perceptions of near-miss incidents, focusing on current on-site safety practices and detection metrics, to increase understanding of the effectiveness and importance of near-miss reporting in improving safety behavior in construction. The research will seek to gain an understanding of the role of NMR for hazard identification, improvement of safety practices and the prevention of accidents in the construction sector. The construction industry is the main context of the study, given the presence of a well-established construction industry, strong safety regulations and viable safety culture in Pakistan. Furthermore, stakeholder feedback from construction companies, safety experts, employees and regulators were collected to gain first-hand knowledge of their experiences, problems and attitudes towards near-miss reporting. The reporting of near misses is known to be a proactive way to uncover and stop incidents, and, although this has been documented in the literature, there is a lack of information or application of it to the local construction industry.

1.7.2 Limitations

i. The study relies on survey-based responses, which may create pre-conception by the construction field personnel for systematically undermining the reliability process of near-miss reporting by the humans.

ii. Frequent underreporting of near-misses in construction may limit utilization of supreme data all-inclusiveness.

1.8 Research Significance

This research has great importance for the academia and the construction sector in general; this is due to several reasons; it is vital to investigate the value of NMR for construction safety. Reporting NM gives the opportunity to identify potential hazards and to take appropriate action.

When they have the potential to cause a real accident or injury, the action takes place first. Organizations can analyze the causes of near-misses to implement corrective actions and preventive measures, thereby minimizing risk patterns and trends. This pre-emptive approach can greatly lower the possibility of subsequent mishaps, improving all-around construction safety. The discovery of underlying systemic problems that fuel risky circumstances is made possible by documenting near-misses.

1.9 Brief Methodology

The aim of this research is to study the value of the NMR in the construction industry and to identify the method and analysis used in the research. Careful selection and application of specific statistical tests was made for primary survey data analysis to ensure accuracy and precision. The research questions used in this study were answered through the extensive testing practices, which helped to examine the most basic questions regarding the importance of near-miss incidents, and evaluation criteria in construction.

1.10 Thesis Structure

The succeeding thesis comprises of Chapters 1-5 detailing Introduction to conclusion and recommendations.

Chapter 1 (Introduction): This chapter delivers the research background, problem statement, objectives and a brief study methodology.

Chapter 2 (Literature Review): This chapter highlights a review of the literature on near-miss management including safety indicators, sensor-based technologies, existence of knowledge gaps.

Chapter 3 (Research Methodology): This chapter presents a study design, involvement of data collection techniques, and development of metrics based on occurrences of near-miss.

Chapter 4 (Results and Discussion): This chapter provides the results regarding the factor validation and their association with proactive construction safety.

Chapter 5 (Conclusion and Recommendations): This chapter presents the conclusion and recommendation regarding safe construction environment.

Chapter 2

Literature Review

This chapter tends to synthesize critical literature on construction industry and involvement of safety risk accidents. It presents a lot of research studies to learn about the significance of near-miss information and safety management. As already identified in the Introduction (Chapter 1), the use of manual safety control is a major obstacle in the way of active prevention of accidents. This chapter builds on the assumption and critically reviews the theoretical context of safety indicators and assesses the present situation in sensing technologies to comprehend why the industry needs a standardized metric-oriented approach to the digital transformation.

2.1 The Concept of Near-Miss

The concept of near-misses is vastly expanding from numerous industries, including aviation, medical, retail, chemical, construction, and manufacturing industries. This common perception reiterates the significance of reporting near-misses in improving safety. The WHO defines near-misses as a serious error that can potentially cause harm but not because of chance or interception [17]. The OSHA database defines' a near-miss as an incident which could have led to severe injury or sickness but did not [17]. According to Sadeghi, [18], defined a near-miss as an unintended incident that in different conditions might have turned to an accident [18]. Sadeghi [18] proposed two concepts of near misses in terms of the consequences of the incident, which included major near-miss and near-miss. The former concept describes near- misses as an event that could cause a major accident with a lasting effect. In the second concept, near-misses are precarious circumstances that can result in accidents. According to Phimister et al, a near-miss is an occurrence that indicates a system flaw that, if not addressed, could have severe effects in the future [19].

Under the chemical and hospital sector, Sadeghi, [18] and Caspi, [9] defined a near-miss as a safety effect, which does not lead to accidents, but injury is possible. Alsulamy *et al.* [20] in the railway industry defined a near-miss as an unsafe situation that could cause damage. All these worldwide definitions combined reveal that a near-miss results in a successful outcome, where no harmful result takes place. It is well known that accidents are the tip of the iceberg. It has been estimated that there are 300 near-misses before a workplace accident [21].

2.2 Construction Safety

In construction safety literature, a high-rise building is generally described as a structure whose occupied floors sit beyond the effective reach of standard ground-based firefighting equipment. This threshold has commonly been placed somewhere between 75 feet (23 meters) and 100 feet (30 meters), or roughly 7 to 10 storeys depending on floor-to-floor height [22]. Beyond this point, buildings are considered to face heightened safety and evacuation challenges compared to low- or mid-rise structures, which is part of why proactive, technology-assisted safety monitoring becomes increasingly relevant as building height increases. The construction industry is universally considered as one of the most dangerous industries as it always records a disproportionate number of occupational deaths and injuries as compared to other industrial industries. Construction safety management is the process of implementing policies, procedures and practices, which are used to recognize workplace hazards and to reduce risk to people, equipment and the environment [23]. This management has historically been reactive as it has concerned itself with the investigation of accidents once they happen in order to avoid the incidence of similar accidents in future. The modern paradigm however is shifting to a more proactive paradigm whereby the focus is directed towards detecting precursors, including unsafe acts and near misses, before it has evolved into a tragic event. Near misses are important for the construction industry to work toward having zero injuries and play a big role in preventing accidents and making safety training better [24].

To really help the construction industry understand near-miss events and make managing them more consistent [23]. This shift is informed by the fact that the physical elements in the construction industry are getting more technologically advanced but the means of ensuring that human safety is handled must also experience a technological change to be workable in a multi-layered and high-speed construction project setting [14].

Near misses are typically called antecedents of accidents or foretellers of accidents when the fortunes fail and hence, it is proposed that near misses should be viewed as a near-term sign of accidents [21]. However, these definitions are far from being precise, especially when one is seeking to differentiate a near miss from other situations, such as unsafe acts and unsafe conditions. The near miss concept was perceived as a momentary event and this entailed sudden release of energy and could create an accident. Its effects do not cause any personal injuries or material damage, but tend to cause a loss of time only. This concept also implies that a near miss has the potential to result in accidents with exclusively material damages [25].

Near misses are acknowledged as a major source of valuable information in the safety management. They are higher occurrences than accidents and the causes can possibly lead to an accident due to slightly different circumstances [26].

Although the significance of this form of feedback is important, there is a small amount of information on the nature of near misses; and on how this information can be used in the safety management.

2.3 Safety Scenario in the International Construction Industry

The construction industry is experiencing a twofold issue around the world with a high rate of fatality and huge shortage of labor and as such safety is not only a moral obligation but also an economic requirement [27]. The International Labor Organization (ILO) records that thousands of deaths are recorded on construction sites across the world every year with falls from height, struck-by, and trench collapses being the major causes of death. This is evident in the developed economies, such as the United States and the United Kingdom, where the existence of strict regulatory bodies such as OSHA and HSE has greatly lowered the accident rates due to obligatory safety training and strict site audits. Despite having these structures, the world industry is now struggling with the shortcomings of manual safety controls [17].

With the increase in size and complexity of projects, especially the emergence of so-called megaprojects, human-based monitoring is no longer sufficient to ensure safety due to the increased concentration of machinery and people, which is why the global community is currently exploring the concept of digital twins, artificial intelligence, and automated sensing as an extension of safety nets [28].

2.4 Safety Scenario in Pakistani Construction Sector

The construction safety environment in the local environment of Pakistan is a more serious set of , which is characterized by a colossal gap between the intent of regulation and the implementation of the site [29]. Although basic safety guidelines are given by the Pakistan Engineering Council (PEC) and provincial labor laws, these are not enforced consistently especially in the high-rise projects that are rapidly growing in the cities such as Islamabad, Lahore and Karachi [30]. The industry locally is also extensively dependent on a big, mostly informal and unskilled workforce that has minimal knowledge of systematic safety measures. Most studies suggest that most local construction companies continue to see safety spending as a financial liability, as opposed to a long-term investment, and therefore, they do not have the simplest Personal Protective Equipment (PPE) or proper fall systems.

Moreover, the fact that there is no national centralized database on reporting near-misses or minor injuries implies that the local sector has to work in data vacuum, where improvements in safety cannot be made based on empirical evidence and cultural apprehension about reporting near-misses or minor injuries to safeguard their jobs or project schedule [29].

This highlights the pressing necessity of studies on automated detection system that are local to help close the safety gap in the Pakistani construction sector.

2.5 Near-Miss Incidents

The construction industry has seen researchers employ the use of near-misses, close calls, near hits, and other labels to denote near-misses in their disciplines. Such definitions revolve around the perceptions of the observer, risk tolerance, experiences and the perception of the organizations on near miss incidences [17].

To simplify the definition, others have characterized a near-miss as an unsafe event or situation that can result in injury or damage to property and others have characterized a near-miss as an unsafe event associated with some activity (e.g., release of energy). Near misses are commonly regarded as precursors of accidents, harbingers of potential accidents in the case of bad fortune, or close indicators of accidents. Muley *et al.* [31] defined a near-miss as something unexpected that takes a sudden burst of energy and could result in an accident. Williams [32] said that near-misses happen when there are no injuries, property damage, or other evidence that they had occurred. There is no standardized definition of a "near-miss".

The current definitions are on the utilization of near-miss information to enhance safety management, as opposed to the reporting of near-misses. Past definitions have considered a near-miss only as an event-driven phenomenon which involves an energy burst, and which is identified subjectively. In these definitions, there is much reliance on the observer's perspective. The main source of near-misses discovery is workers on the construction sites, though certain factors might cause workers not to report near-misses: (a) fear of administrative action; (b) risk acceptance; (c) ignorance about the use of data reports, and (d) data collection is a complicated and time-consuming task [33]. A comprehensive and simplified definition of near-misses is needed because the management efficiency of near-misses would be dependent upon how well near-misses are identified.

2.6 Near-Miss Construction Industry Measures

Main indicators represent a proactive measure of safety metrics, which aims at assessing the processes, events, and conditions that are predictive of safety performance and can predict future results [34]. An excellent example of such indicator is reporting of near-misses. The major advantage of monitoring near-miss is that it is possible to gather and analyze data that can potentially be used to create safer conditions without any real injuries [32].

The conceptualization of the causation of accidents can potentially help measure the definition of near-misses since near-misses and accidents share the same causation model [10]. On this understanding, the study of the causal factors behind accidents can help in the establishment of the past close calls, which help in alleviating doubts on the likelihood of an accident. To illustrate, falls in the construction industry are the major cause of death of workers [35].

Recognition of near-misses is crucial in preventing and stopping the occurrences that cause falls. Nevertheless, the conventional approaches to identifying near miss occurrences are based on workers self-reporting and this may result in unreliable data. Accidents can be prevented with the help of automated data collection and analysis that is possible through the adoption of modern technologies [36].

As constructions are most likely to occur safety accidents, it is important to emphasize on the management of near-misses in order to avert any type of accident. Nevertheless, due to the manual supervision of the traditional monitoring and early warning systems, it is difficult to detect the near-miss events in time. Safety management at the construction sites needs to improve [37]. By automated data collection and analysis, the implementation of modern technologies will help avoid accidents. The objective of this study is to come up with near-miss detection metrics to enable the automated identification of near-misses using sensors.

2.7 Identification of Safety Indicators

Academic foundation of the safety management is based on the possibility to quantify the performance by particular measures called safety indicators [38]. These indicators can be broadly classified into two: lagging and leading. Whereas the lagging indicators can give a backward perspective of safety failures, the leading indicators can give a forward-looking perspective of what may happen in the future in relation to hazards. To build a proactive safety culture that embraces technology in intercepting accidents before they happen, an understanding of the shift between recording outcomes to monitoring precursors is crucial.

Past safety performance has mainly relied on lagging indicators, which means safety data was only collected after an illness, injury, or fatality happened. A major improvement can be made by using leading indicators, like reporting, collecting, and analyzing near-miss incidents [39]. The goal of this study was to find out the best practices for a near-miss reporting program in construction companies. The program was developed based on a literature review and by looking at existing near-miss reporting systems used by different construction companies. This new program was then put into use on construction projects where companies had not been collecting near-miss data before. Throughout the projects, safety managers and workers were regularly surveyed to gather information on the benefits, challenges, lessons learned, and suggestions related to the near-miss reporting program [32]. The results show that construction workers can effectively report, collect, and analyze near-miss data. The research also produced several useful resources, such as guidelines for the near-miss reporting program, a flowchart for reporting processes, an employee orientation presentation, and other materials that can help set up a new near-miss reporting system or improve an existing one for construction companies.

2.7.1 Lagging Indicators: Deaths and Injuries

Lagging indicators are conventional safety measures that quantify the ultimate consequences of safety failures, including the number of fatalities, lost-time injuries (LTI) and recordable illness rates. They have traditionally been the main tools used by regulatory bodies to determine the safety performance of a firm. But as a management tool, lagging indicators have a serious weakness: They are post-facto measures [40]. Once a lagging indicator is registered, a worker has already suffered, and it is too late to do anything. The use of these metrics alone will build a reactive world where safety gains will only occur following a tragedy without considering the large number of close calls that lead to the occurrence of the actual accident [41].

2.7.2 Leading Indicators: Near-Misses in Accident Prevention

Leading indicators are proactive and are used to monitor the processes, activities, and conditions that lead to safety ahead of accident occurring. The most powerful precursors are said to be the so-called near-miss. A near-miss is an incident that did not cause harm or damage, but could have done so under different conditions [42]. Theoretically, the near-miss frequency is significantly higher than the actual accident frequency- a fact frequently depicted by Heinrich Safety Pyramid. Safety managers are able to recognize hazards (that are still dormant) and systemic vulnerabilities in real-time by detecting and analyzing near-misses. This enables corrective measures to be taken e.g. re-training or re-laying of the site, which would be a good chain breaker towards a fatality.

2.8 Near-Miss Management Systems

A Near-Miss Management System (NMS) is a formal procedure, which is created to detect, record, examines, and distribute lessons learned in relation to close-call events. The development of these systems has shifted towards informal verbal reporting, to elaborate digital databases. Nevertheless, regardless of their perceived importance, human and organizational factors tend to undermine the effectiveness of an NMS [43].

2.8.1 Reporting Mechanism Evolution:

NMS was initially based on paper-based forms and suggestion boxes, which were slow and not very detailed. The online age ushered in the use of mobile applications and web-based portals, which facilitated quicker data input and photographic evidence could be incorporated. In spite of this development, the very essence of the system has been left manual, i.e. it still involves a human observer who has to identify a hazard, make a decision to report the hazard and properly describe what has happened [43].

2.8.2 The Under-Reporting Problem:

Under-reporting of incidents is the biggest obstacle in conventional NMS. A blame culture is common among workers who are reluctant to report near-misses because they are afraid of being punished or losing their jobs because they accepted that they did a mistake. Also, on work sites that are fast moving, the time it takes to complete reports is perceived as a drag on productivity. This creates an illusion of the risk profile of a project and makes the project look safe when it is not, thus safety managers are led to believe that everything is safe yet the dangers remain unnoticed [43].

2.9 Sensing Technologies in Construction

The industry is shifting towards sensing technologies in order to eliminate the constraints of manual reporting and human subjectivity. These tools bring an unbiased, ongoing and automated field of monitoring of those sites, converting the construction environment to a smart work environment [43].

2.9.1 Computer Vision, RFID, and Wearable Sensors Overview

2.9.1.1 Computer Vision

Computer Vision uses Al algorithms to look at and understand the activities on the site using the existing CCTV or drone footage. It is also capable of automatically sensing the non-wearing of a helmet by the worker or the entrance of a person into a dangerous area by a moving machine. CV does not experience fatigue, distraction, as does human guards, and monitors multiple zones 24/7 [44, 45].

2.9.1.2 Radio Frequency Identification

RFID systems involve tags that are put on staff and equipment and readers that are installed at strategic points. This type of technology can be used especially well in proximity detection; an example of this is when an employee wearing an RFID tag approaches an excavator too closely the system will allow a loud audible alarm to be emitted to the operator and the employee to avoid a struck-by accident [44, 46].

2.9.1.3 Wearable Sensors

They are smart helmets, vests, and wristbands with IMUs (Inertial Measurement Units) and GPS. Wearables are able to monitor physiological indicators of a worker (such as heat stress) or identify when a worker falls. These sensors when combined to form a larger network will give a high-resolution map of worker movements, and as a result, it was possible to identify hotspots where near-misses are likely to happen most of the time [44–46].

2.9.2 Applications in Hazard Identification

The recent implementations of sensing technologies have not only advanced past mere surveillance but also proactive identification of hazards, especially in the most dangerous areas. These technologies are incorporated in the modern construction environment to track so-called Red Zones under the operation of heavy machinery, so that ground employees do not get too close to passing excavators or cranes [47].

An example of this is the use of Computer Vision (CV) to identify if the worker is wearing Personal Protective Equipment (PPE), including helmets and high-visibility vests, and sending an alert if the worker does not meet this requirement. Also, fall prevention involves sensing systems that can detect the close position of personnel to leading edges or open elevator shafts.

These applications give a constant flow of information that is significantly much more than a safety officer can handle, so it is possible to detect environmental hazards that could cause an accident due to being struck or caught-in-between and act upon it immediately [48].

2.10 Automated Near-Miss Detection

The trend of automated near-miss detection is a big step in the construction safety field where human error is intended to be eliminated in the observation process [44]. These include intelligent systems capable of handling raw data and categorizing certain events as close calls automatically.

2.10.1 Review of Existing Algorithms

The vast majority of current automated detection systems are based on advanced algorithms, like Convolutional Neural Networks (CNNs) to process an image or Kalman filters to track moving objects using sensors [49].

This research study examines the concept of automated detection of near misses relevant to the high-rise construction projects taking technology support from AI and algorithms that can forecast the collision by monitoring the workers' movement. Moreover, near misses and use of AI intelligence algorithms for video analytics are popular and emerging fields of research [45].

2.10.2 BIM-based Visualization Tools

Building Information Modeling (BIM) has now become a 4D and 5D tool that is connected to real-time sensor data to show near-misses [50]. By overlaying sensor events on a digital twin of the construction site, managers would be able to clearly understand where the hazards are concentrating.

These tools can be used to perform a heat map analysis, where high-risk regions (e.g., congested corridors or poorly lit areas) are identified, where near-misses are most common, and data-driven site re-layouts can be made.

Apart from assessing the integration of technology, metrics play a crucial role in technology integration. Although sensing hardware (cameras, tags, and wearables) is becoming more available, its usefulness is wholly reliant on the metrics that underlie what constitutes a hazard. metrics serve as the instruction manual to the technology, specifying when the system should send an alarm [49].

2.10.3 The Necessity of Standardized Metrics

The absence of standardized metrics (e.g., defined safety radii e.g., 2 meters of stationary equipment vs. 5 meters of moving equipment) leads to inconsistent results of sensing technologies. When a system is too sensitive, it causes an alarm fatigue, in which workers disregard alarms due to the frequency of alarming. Provided that it is not sensitive enough, it does not pick up critical near-misses [50].

Standardized metrics also make sure that the data measured in various locations and using various technologies can be compared, objective, and scientifically valid, which enables application of a single approach to sensor-based safety management [1].

2.11 Automation and Safety Related Incidents

Construction management often involves a high risk of safety-related incidents. One way to improve safety is by using near-miss information, which is seen as a valuable learning tool for safety management. However, there is a lack of full understanding of what near-miss information means in the context of construction safety [14]. This study aims to address this gap.

Compared to traditional safety methods like accident analysis and checklists, using near-miss information has proven to be more effective in improving safety performance. According to Murphy's Law, anything that can go wrong will go wrong.

$$P_n = 1 - (1 - P)^n$$

Murphy's Law can be explained using probability theory. If an event has a low probability of occurring, the chance that it will happen at least once increases with more attempts. As the number of attempts increases, the likelihood of the event happening approaches 100%. This means that if near-misses occur on construction sites, they are likely to develop into serious accidents over time [14].

Construction accidents are a major social and economic issue in the US. Although this has improved in the recent past, the Construction industry in general has been left behind with other industries in terms of adopting safety as an overall management process in achieving a zero accident and high-performance safety culture [51].

One aspect of this total approach to safety that has frustrated the construction industry mostly rely on "measurement", which involves identifying and quantifying the factors that critically influence safe work behaviors. The fundamental issue credited is the challenge on what to measure and how to measure it- especially the intangible features of safety. Without measurement, the notion of continuous improvement is hard to follow [51].

2.12 The Near-Miss Construction Process

Construction projects are widely recognized as complex, dynamic, and difficult to fully define in advance, often involving tasks and site conditions that shift unpredictably as work progresses [52].

Because of this inherent unpredictability, the process of managing near-misses cannot be treated as a simple, isolated activity it must instead be understood as something shaped by the same complexity that characterizes construction work itself. Reflecting this, near-miss management is typically structured around seven distinct stages: discovery, reporting, identification, prioritization, causal analysis, solution, dissemination, and evaluation. These seven stages are not all functionally equivalent; they can be broadly grouped into two purposes.

The first three stages discovery, reporting, and identification are primarily concerned with surfacing near-miss events that might otherwise go unnoticed, ensuring that this knowledge does not remain hidden within day-to-day site operations. The remaining four stages shift focus toward making productive use of that knowledge once it has been captured, covering everything from analyzing root causes to implementing solutions, sharing lessons learned.

Stage		Objective	Core Challenge	Key Recommendation
1	Discovery	Complete detection of potential risks.	Lack of awareness/definitions.	Training on near-miss concepts.
2	Reporting	Timely submission of findings.	Fear of penalty or complex steps.	Simplify process; offer rewards.
3	Identification	Database comparison.	Knowledge/data deficiency.	Update database continuously.
4	Prioritization	Filter high-priority risks.	Deficient guidelines.	Automate prioritization models.
5	Analysis	Determine direct/ indirect causes.	Information distortion.	Use expert-led causal methods.
6	Solution	Implement corrective actions.	Selection from multiple choices.	Balance cost and safety risks.
7	Dissemination	Feedback and education.	Ineffective learning habits.	Use e-learning and video tools.

FIGURE 2.1: Seven stages of near-miss management [1]

Figure 2.1 illustrates each of these seven stages in turn, outlining the intended objective of each phase, the practical barriers organizations commonly face in applying it, and suggested approaches for overcoming those barriers. Figure 2.1 shows the step-by-step process of near-miss management. Near-miss discovery Near-misses can be analyzed in four possible ways (including all combinations) using available accident databases, analyzing near-misses using safety standards or regulations, on-site work observations, and simulating near-misses using construction simulation or virtual reality. A reported near-miss is of little use unless it is reported and analyzed with reasonable steps to prevent its recurrence or even potential accidents [53]. Not all the near-misses discovered can be reported due to certain challenges as indicated in figure 2.1. Thus, the objective of reporting stage is to see to that all the near-misses identified are reported by the general workers to the construction project managers in the field. A reported near-miss was verified that there are similar cases of near-misses in the current database (the database was created before the near-miss management was implemented; this database is to store the cases of near-misses).

Once near-misses have been made explicit (by the first three stages), the fourth stage is prioritization of near-misses. Inadequate resources, including the lack of time and of staff, allow the analysis of all near-misses not simultaneously, but there are high-priority near-misses which need to be analyzed immediately to eliminate the safety risk as soon as possible [54].

To illustrate, near-misses could lead to a major accident, which could be of a serious nature. The other instance is that multiple similar near misses are notified by various workers at the same time. Thus, the near-misses should be given priority by the safety officers, experts, and managers before carrying out the near-miss analysis.

Alsulamy *et al.* [20] suggested a near-miss decision matrix to evaluate the importance of near-misses in the petrochemical sector. Based on the peculiarities of the construction industry, it is possible to create a modified near-miss prioritization model, which is based on the outcomes of a possible accident (C), near-miss possibility (PO), near-miss proximity (PR), and near-miss learning value (LV).

The seven stages framework has three categories of individuals involved in the near-miss management process. They are government supervisors, university or institution researchers, construction project employees including safety managers, safety experts, safety officers and general workers. Safety managers, safety experts, safety officers, and general workers play key roles in near-miss management as they are stakeholders and direct executors.

2.13 Identification of Factors from Literature Review

The following Table 2.1 presents a score of factors gathered from the wider literature accumulated in the table form regarding near-miss accidents and safety management in the construction field. The table shows that near-miss research is shifting towards more unified frameworks combining reporting schemes, human factors, novel technologies, and data analytics to improve proactive safety performance.

TABLE 2.1: Factors Identified

Code	**Sr. No**	**Author(s)**	**Paper Title**	**Key Factors**
NMO-1	1	Duan & Zhou [23]	A science mapping approach-based review of near-miss research in construction	• Near-miss frequency
UA-1	2	Orvik & Albrechtsen [55]	The mismatch between conceptualization and measurements of safety performance: Insights from a qualitative study of the Norwegian construction industry	• Production pressure
UA-2 UA-4	3	Meng *et al.* [56]	Multiple configurational effects and analyses on construction workers' unsafe behaviors	• PPE non-compliance • Risky behavior
STE-1	4	Hashmi *et al.* [1]	Near-miss detection metrics for proactive safety management	• Near-miss definition
UC-4	5	Bao *et al.* [57]	Computer Vision–Based Recognition of Spatial Relevance between Engineering Vehicles and Workers for Monitoring Struck-By Accidents	• Falling object hazard
STE-3	6	Saqib *et al.* [16]	Acceptance of electronic incident reporting system	• Safety communication
NMO-5	7	Williams [32]	Exploring the value of near-miss reporting for construction safety	• Under reporting bias
NMO-4	8	Woźniak & Hoła [41]	Quantitative and qualitative analysis of hazardous events in the construction sector: Causes, classification and implications	• Equipment failure
UA-3	9	Zhou *et al.* [39]	Human dynamics in near-miss accidents	• Lack of competency
NMO-3	10	Zhou *et al.* [58]	Time series of near-miss accidents	• Schedule pressure
UA-5	11	Zhou *et al.* [14]	Use of near-miss information to improve safety performance	• Goal conflict

Table 2.1 continued from previous page

Code	Sr. No	Author(s)	Paper Title	Key Factors
STE-4	12	Elia *et al.* [48]	Applications of smart technologies for automatic near miss detection in the safety	• Risk perception
STE-5	13	Lim *et al.* [47]	Near Miss Detection Using Distancing Monitoring and Distance-Based Proximal Indicators	• Hazard recognition
UC-1	14	Woźniak & Hoła [40]	Analysing near-miss incidents in construction	• Scaffold hazard hazards
STE-2	15	Yamamoto *et al.* [44]	Classifying near-miss incidents through video, sensor, and object features	• Learning from incidents
UC-5	16	Griffey *et al.* [59]	Near-miss events detected using the emergency department trigger tool	• Missing warning signs
UC-2 UC-3	17	Ruddy *et al.* [42]	Near misses and unsafe conditions reported in a research network	• Poor Housekeeping • Low illumination
NMO-2	18	Marks *et al.* [43]	Near-hit reporting: Reducing construction injuries	• Fall related near-miss

2.14 Summary

This chapter provides a detailed look at the theory and technology related to construction safety management, especially focusing on the shift from reactive to proactive monitoring. By comparing lagging indicators like fatalities and injuries with leading indicators like near-misses, it was found that near-misses are important opportunities for preventing accidents before they happen. However, looking at traditional Near-Miss Management Systems (NMS) showed major problems, such as human bias, a culture of blaming people, and a lot of under-reporting, especially in the local Pakistani construction industry.

The analysis of sensing technologies, such as Computer Vision, RFID, and wearables, showed their potential for offering objective and continuous monitoring on the construction site. While automatic detection algorithms and BIM-based visualization tools seem promising for identifying dangers, the review of existing literature found a key missing part: there are no standardized, measurable metrics that can convert raw data from sensors into usable safety information. This gap highlights the need for this study, which aims to create the detection limits regarding near-miss and subsequent use of sensing technologies effectively for real-time, proactive safety management.

Chapter 3

Research Methodology

This chapter highlights a particular research approach to observe, analyze, and implement research on automation of near miss cases/incidents occurring in construction sector. It further explains the systematic approach taken to address the research problem and achieve the research goals. The research methodology is a critical part of any research study that provides a structured approach to guide the overall process of data collection, analysis and interpretation. This chapter gives a comprehensive description of the research process, starting with the choice of the appropriate research design and the main factors that influence the phenomenon under investigation. This chapter describes the approach used to determine sample size and profile the demographic characteristics of the sample. Then, it describes the process of questionnaire development, detailing the way the questionnaire was designed to collect the necessary data on the identified factors. This chapter also explains the data collection and data analysis techniques and how these techniques are appropriate for the problem being addressed.

3.1 Research Design

This study follows a quantitative research design not only highly appropriate for this research framework, since the quantitative data allows for objective analysis of patterns such as the frequency of occurrence of certain skill gaps that is associated with project delays, cost overruns or safety accidents [60].

Further focuses to investigate the use of advance sensing technologies on pro-active safety in Construction [60] measuring Safety and Technology Evaluation (Metrics for Near-Miss Awareness) (**IV1**), Unsafe Acts (Worker Behavior) (**IV2**), Unsafe Conditions (Site Environment) (**IV3**) and Near-Miss Occurrence (**DV**) in construction engineering management. The research opted cross-sectional with deductive approach to [61].

convert the ordinal survey observations into continuous metrics through the use of Relative Index modeling and Pearson correlation coefficients, thereby eliminating subjective biases, high replications, reliability, and inferential hypothesis testing [62].

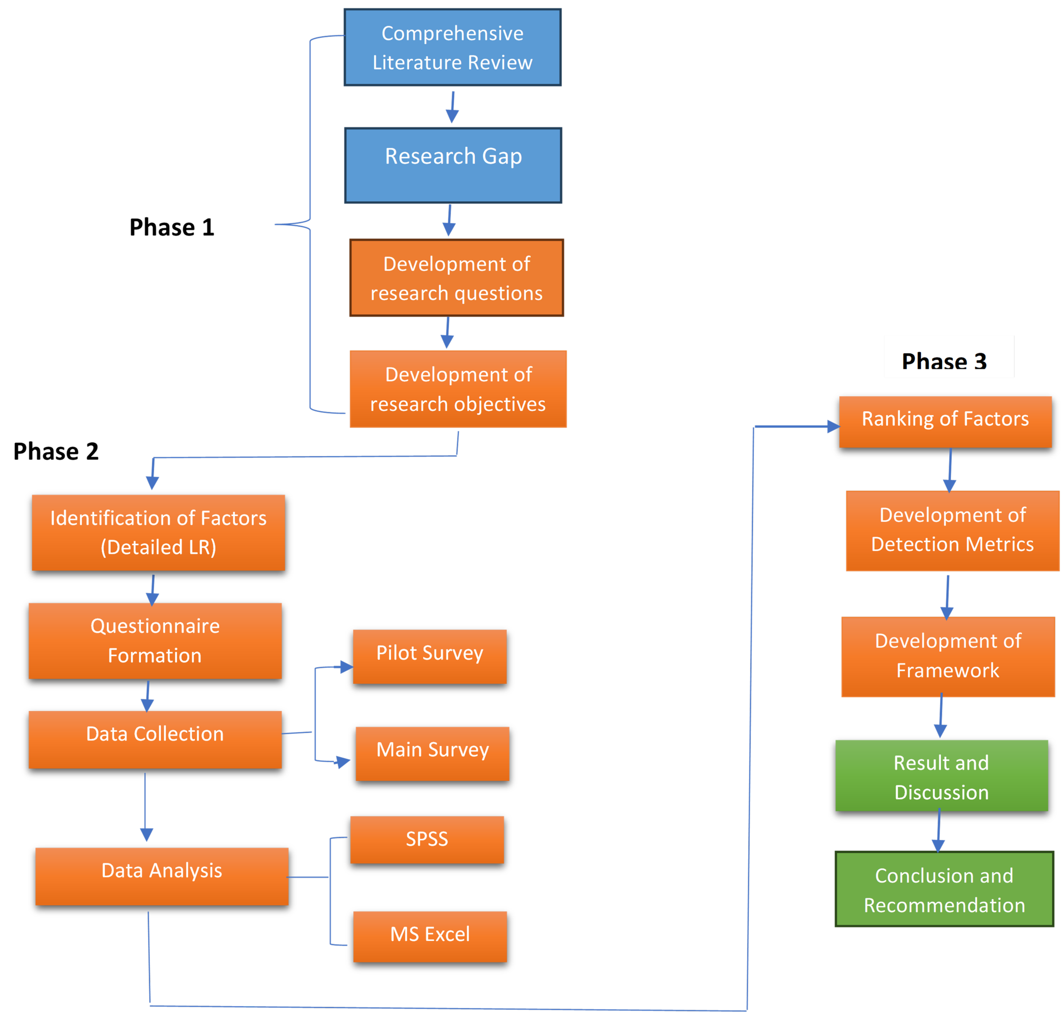

FIGURE 3.1: Systematic Process of Methodology

3.2 Phase 1

Traditionally, organizations rely on a Near-Miss Reporting System that is manual, with significant limitations on human observation, lack of reporting and entrenched perception biases that allow workers to normalize structural risks. Modern safety studies advocate using Technology-Driven Reporting Systems to overcome these cognitive and behavioral reporting problems [63]. A review of existing research on near misses in construction was gone through; many of the articles looked at quantitative patterns to assess occupational risks and qualitative patterns to find early signs of accidents, especially the reasons behind these risks. Additionally, time series studies were carried out to find unique characteristics of near-miss events. Other studies examined what workers were doing during incidents, how the safety culture affects near misses, and the materials and elements involved in construction processes.

The gap in literature as identified above is addressed at this stage. In this context, construction project management often faces a high risk of safety accidents. One way is to actively improve safety by using near-miss information, which is seen as valuable learning opportunities for safety management. However, current research and practice show a lack of a full understanding of what near-miss information means in the context of construction safety (Zhang et al., 2018). Since near-misses are usually less obvious and harder to identify compared to actual accidents, the process for managing them needs to make these incidents clearer and more visible.

The Two Classes' Hazard Theory (TCHT) suggests that the occurrence of an unsafe worker action that breaks an environmental safety barrier is a Near-Miss Occurrence. This is a causal moment when it is being misjudged, and can become an imminent injury, if it is not identified and addressed immediately. A complex array of critical factors has been identified in the scientific literature that work together to determine the effectiveness of proactive safety ecosystems on construction sites [64].

The basis of automated monitoring is both Safety and Technology Evaluation and Metrics for Near-Miss Awareness and the ability of an organization to perform an audit of its technical infrastructure and to set precise and quantifiable baselines to identify subtle warning indicators that don't cause injury. Unsafe Acts (Worker Behavior) and Unsafe Conditions (Site Environment) like dynamic spatial constraints, structural failures, uncontrolled energy release, etc. that breach the safe environment.

3.3 Phase 2

The literature indicates that there is a great trend in the shift of traditional safety analysis towards more proactive and data-driven methods. Bibliometric and statistical methods employed by Duan and Zhou [23] and Woźniak and Hoła [40] were employed to determine the research trends, patterns of accidents, and gaps in knowledge, which can be used to inform future research directions.

A questionnaire has been developed to collect the data from the target respondents. The questionnaire was created using Google Forms and the responses was collected electronically to ensure reach and engagement in the region. This was developed with due consideration to its content validity, ensuring that all the items were directly related to the research objectives of the study and reflected the major themes identified in the literature review including project performance indicators and challenges on-site [65].

This grounding in the literature was not incidental each of the four constructs used in the survey was built directly from the factors consolidated in Table 1. The Safety and Technology Evaluation items were shaped by recurring concerns raised in prior studies around sensor readiness and gaps in monitoring coverage. Unsafe Acts items reflect worker-behavior patterns that multiple studies identified as precursors to near-miss events.

Unsafe Conditions items are drawn from site-hazard themes such as poor housekeeping, insufficient lighting, and unstable scaffolding, all of which appear repeatedly across the reviewed sources. Near-Miss Occurrence items capture reporting patterns that recur throughout existing near-miss research. By anchoring each item to a previously identified factor, the questionnaire was kept evidence-based rather than shaped by assumption.

The questionnaire was structured into sections. The first part of the questionnaire collected demographic and professional details of the participants such as their construction roles (e.g., engineer, supervisor, contractor), experience level, and region of practice. This provided background information and the ability to segment respondents by position and location.

The following sections of the survey asked about key variables such as Safety and Technology Evaluation, Metrics for Near-Miss Awareness, Unsafe Acts (Worker Behavior), Unsafe Conditions (Site Environment), Near-Miss Occurrence, Near-Miss Reporting System, Technology-Driven Reporting Systems. Respondents were asked to evaluate and express their opinions on the features regarding construction sites. Additionally, questions were asked to ascertain the respondents' views of the impact of skill deficiencies on projects, such as the quality of work, time, cost and safety. These questions were mostly framed in Likert scales (from Strongly Disagree to Strongly Agree) for quantitative analysis [66].

As shown in the above placed flow chart, data was collected regarding near miss detection starts in phase 2; for this purpose, a survey questionnaire is created and built on Likert scale 1-5 around variables such as Safety and Technological Evaluation further grounded in variables such as Metrics for Near-Miss Awareness, unsafe acts (Worker behavior), Unsafe Conditions (Site Environment) and Near-Miss Occurrence.

The seven-stage process shown in Figure 2.1 offers a broad conceptual map of how near-misses are typically handled within an organization, moving from initial discovery all the way to final evaluation. Rather than structuring the survey around this sequence, the questionnaire in this study was designed around specific factors pulled from the literature, since the intent was to statistically rank and correlate measurable variables rather than walk respondents through a step-by-step process. A number of the later stages in Figure 2.1, solution development, dissemination, and evaluation among them reflect decisions and actions taken at an organizational level once a near-miss has already surfaced, making them poorly suited to individual Likert-scale ratings. Figure 1 therefore functions as background theory introduced in Chapter 2, while the actual survey instrument was built around the constructs already described.

In this research, the inclusion criteria comprised peer-reviewed journal articles, conference proceedings, and technical reports that highlight high-rise construction projects and address the proactive safety mechanisms. The selected studies must address at least one of the main variables including Sensing technologies or digital safety evaluation metrics (IV1); Worker behavioral patterns on unsafe acts (IV2); Site environmental factors or unsafe conditions (IV3) affecting the near-miss occurrences (DV).

The exclusion criteria, on the other hand, exclude studies that discuss permanent operational facilities or mining or infrastructure projects other than building construction, grey literature, opinion pieces, dissertations, and studies lacking empirical metrics or clear frameworks for identifying near-misses and automated sensing detection.

There are a number of research articles devoted to data analysis and knowledge development. For this purpose, MS Excel, SPSS were deployed. The data gathered from the questionnaire survey were subjected to statistical analysis using descriptive and inferential methods [60]. The aim of analysis was to determine common trends in construction, and examine the association between near miss occurrences and construction safety measures.

3.4 Phase 3

The ranking of metrics creates a clear order of importance among the safety and technical indicators that were identified. This is done by calculating their Relative Importance Index (RII) scores. This method helps in determining which aspects of operations have the most impact on site safety. It allows project teams to move away from guesswork and instead focus their efforts on the key factors that significantly affect risk.

Creating the framework involves organizing the ranked metrics into a structured, three-level model. This model shows how data moves from initial inputs to active safety measures on site. By separating the variables into three distinct areas Sensing System Technology, Physical Site Environment, and Worker Behavior the framework offers a clear process for automatically recording near-misses. It ensures that different types of data are not mixed up during this process.

The results and discussion part offer a thorough look at the findings from the quantitative analysis. It looks at the main connections and interactions between variables. By comparing the collected data with known safety theories, this section explains how delays in technical systems, physical dangers, and worker actions work together to cause close calls on construction sites.

The conclusion and recommendations section wraps up the study's main points, showing that strong technical systems are essential for early hazard detection. It turns these findings into practical advice for the construction industry. It gives specific steps for project managers to use automated geofencing, edge computing networks, and haptic alerts to prevent accidents before they occur.

3.5 Data Analysis Methods

The objective of the data analysis was to classify and prioritize all the variables that were included in the study. The collected data was analyzed through SPSS. In this study, SPSS version 26.00 and Microsoft Excel was used for analysis.

3.5.1 Descriptive Analysis

Descriptive analysis (using SPSS Statistics package) was used in the first data analysis. Frequency distributions were used in summarizing the demographic variables of the respondents in order to profile the composition of the sample and to ensure that it is representative of the coverage. This high mean trend sets the foundation that close call incidents are common and highly visible within the work environment, and has provided a robust supply of data trends needed to support automated detection and sensing programs [67]. Baseline operational trends and perceptions within the sample (N = 75) were identified by calculating mean scores and standard deviations for each of the core continuous constructs. These descriptive summaries are used to identify pattern of response, structural variation, and gain an understanding of the patterns of distribution of each safety variable prior to moving on to inferential modeling [67].

3.5.2 Reliability Tests

A widely recognized indicator of scale reliability used in survey research is Cronbach's Alpha coefficient, which was used to rigorously examine the reliability, and internal consistency, of the survey scales [68]. In quantitative research that uses tools with multiple items, like Likert-scale surveys to track how people in the field view near-miss events, reliability checks are done to make sure the data model is consistent within itself.

The Critical Threshold Value The commonly accepted measure for checking internal consistency is Cronbach's alpha (α). The Rule of $\alpha \geq 0.70$: An alpha value of 0.70 or more is the standard used to say an instrument is reliable enough for research that explains or builds models. Reliability testing has three main purposes before moving on to more complex statistical methods, such as looking at relationships between variables, predicting outcomes, or building detailed models [68].

3.5.3 Normality Tests

Data were statistically tested for normality using the Shapiro-Wilk test to ensure that the data met the basic assumptions needed for the traditional parametric estimation. The use of non-parametric statistical methods, like the Kruskal-Wallis test, makes its way to compare differences in demographic subgroups is statistically warranted because of the spread of non-normality across the main scales of the study, which otherwise would bias study conclusions [69].

In quantitative studies, normality tests are checks to see if the data follows a normal distribution, which is like a bell-shaped curve. Normality testing is done to meet mathematical requirements, help choose the right analysis methods, and ensure that the model is valid.

3.5.4 Kruskal-Wallis Test

Kruskal-Wallis test, a non-parametric test, is applied to test the difference in three or more independent variables regarding risk perception and safety technology applicability among the various demographic subgroups [70]. Moreover, the particular choice of this test was explained by the fact that the data was non-normally distributed, which was statistically determined with the help of the Shapiro-Wilk test where major constructs deviated significantly from a normal distribution curve. The Kruskal-Wallis test evaluates significance using the Sig. (p-value) at the conventional 0.05 threshold. A p-value below 0.05 indicates a statistically significant difference between demographic subgroups, leading to rejection of the null hypothesis.

A p-value above 0.05 indicates no significant difference, meaning the null hypothesis is retained [70]. This statistical control information has vital importance in coming up with specific risk management strategies, validating the framework, and deploying proactive safety interventions based on technology [70].

3.5.5 Relative Importance Index

Responses to the survey were used to create an initial ranking of the safety constructs and near-miss detection metrics, using the Relative Importance Index (RII)

[40]. The following operational formula was used to determine each core factor:

$$\text{RII} = \frac{\sum W}{A \times N}$$

W represents the weighted score assigned by each respondent (with a Likert scale ranging from 1 to 5) and A is the maximum possible weight (5 in this study) assigned by the individual respondent who rated that construct with a 5. N is the number of respondents who rated that construct (N = 75). The resulting RII value is between 0 and 1, the higher the value the more important the issue was perceived or more frequently observed in construction sites.

The dimension calculations of RII were carried out over major continuous safety scales to create a composite prioritization priority matrix. The subsequent rankings provided a preliminary prioritization of risk and safety compliance factors that were used in the subsequent analysis steps as well as ensuring a validation process with more sophisticated inferential analysis [40]. At the end, a R-II priority based on hierarchy of Core Near-Miss Detection occurrences will come on surface.

3.6 Framework Development

3.6.1 Framework Structure

The framework leading to develop a multi-stage Framework of the Near-Miss occurrences which is targeted to apply in building high-rise construction projects particularly with reference to Islamabad/Rawalpindi. Stage 1 stands to set overall Objectives encompassing "Comprehensive predictive Evaluation and Proactive Monitoring of Near-Miss Occurrences in the Construction Industry as a baseline Target Integration Layer for the system. At stage 2 sets to undertake Safety & Tech Evaluation; Behavior Factors; Physical Site Environment Factors; by setting Dimensional Priority Indexes. At stage 3, Unsafe Acts, Unsafe Conditions, Technology evaluations are identified and carried out by computing Relative Importance Index (RII) Score based on which a framework is created.

3.6.2 Proposed Proactive Safety in Construction Matrix

This section provides a theoretical basis for the Proactive Near-Miss Safety Matrix based on the Domino Theory of Accident Causation [71] that provides a premise that the process of injuries can be avoided by intervening at the stage of unsafe acts and conditions. Besides, it uses Heinrich Safety Pyramid [72] to support the use of near-misses as statistically significant precursors. These classical theories are combined with Safety-II principles to offer the rationale of real-time and sensor-based monitoring of variability of the site. This is not a reactive post-incident investigation approach, but one that takes the view that catastrophic site failures will be followed by a train of predictable lower-level anomalies and close-calls [73]. The temporal probability of an event is used to create a multi-tiered risk classification that mathematically represents the "safety terrain" of a site. This design enables independent risk vectors of unsafe conditions (Structural Gaps), unsafe acts (Frontline Human Errors), and drop in system performance (Sensing System and Technology Metrics) to be clearly separated, providing the conceptual logic for the framework.

3.7 Survey

A perception-based survey is the most prevalent and suitable approach to ascertain the local priorities and is the standard approach before implementing any sensor in an area [65], as Pakistan does not have any accident database like OSHA. The questionnaire was sent to a variety of stakeholders in the construction industry, such as clients, contractors, consultants, etc. Google Forms was used to create the questionnaire, which was electronically distributed to increase participation levels from the Islamabad/Rawalpindi. It was structured with a focus on content validity, ensuring all questions were relevant to the study's research aims and reflected major themes identified in the literature review, measuring Safety and Technology Evaluation (Metrics for Near-Miss Awareness), Unsafe Acts (Worker Behavior), Unsafe Conditions (Site Environment) and Near-Miss Occurrences. This is imperative to ensure the stakeholder engagement [65].

3.8 Sampling and Sample Size

The survey population for this study consisted of organizations that were actively working on, or had recently completed, high-rise residential or commercial construction projects in Islamabad and Rawalpindi. To capture a well-rounded view of near-miss occurrence and on-site safety practices, participants were drawn from three organizational categories clients, consultants, and contractors as each brings a distinct vantage point to the issue.

All respondents held positions with direct exposure to site operations, such as engineers, project managers, safety officers, and site supervisors, and each individual took part in the survey on a voluntary basis.

Islamabad and Rawalpindi were selected as the primary context because it is currently undergoing rapid vertical expansion, with a growing number of high-rise residential and commercial projects being approved under building regulations. This makes it one of the few cities in Pakistan where high-rise-specific near-miss data could realistically be collected from active projects.

A **purposive sampling** approach was used to identify industry practitioners with relevant experience in near miss incidents of construction, thereby gathering expert views and opinions [74]. With the purposeful sampling method, there is a possibility of sample selection bias which would result in findings not being statistically generalizable to the broader population, but this is acceptable since this is a specialized study. Near-miss detection is not possible and automated sensing measurements and site-specific risk dynamics are dependent on specialized and technical expertise that cannot be ensured through random sampling techniques. The choice of industry practitioners with hands-on experience will provide the scope with rich data, contextually relevant, and with a thorough knowledge of the real-world complexities, providing high-quality qualitative inputs that will enable the effective validation of research variables [74]. Harris & Quade [75] provided sample size formula for correlational studies. The formula is:

$$N > 50 + m$$

N is the minimum sample size needed; m is the number of predictor variables. That study had **m = 52 variables**; Minimum number of respondents needed N $> 50 + 52 = 102$.

According to Conroy [76], Rule of thumb, is sample size of 100 is considered as minimum sample size. In our given Scenario, (Testing 20 Key Factors): If m = 20, then N $> 50 + 20$ implies 70 respondents thus minimum sample size i.e. 70 was an adequate sample size for our study. Response rate remained 70%.

A pilot survey was conducted with 11 respondents (Contractors, Consultants and Project Managers) prior to full-scale distribution, in order to assess the clarity, technical relevance and content validity of the research instrument before a full-scale administration, the pilot survey was carried out from Islamabad/Rawalpindi region with the target construction stakeholders.

Results of this pilot group feed into the development of ambiguous wording, standardization of technical terms, and construct feasibility for sensing technology metrics and near-miss factor evaluations. The internal consistency was tested using Cronbach's alpha reliability test, and the scale of the survey constructs had reliability values above the minimum limit of 0.70.

A correlation analysis was performed to identify the most effective combination that causes near-miss. Besides the correlation analysis, normality test including the Kolmogorov-Smirnova and Shapiro-Wilk tests was used to determine whether there was a relationship between unsafe acts and conditions. Relative Importance Index (RII) Analysis was applied to determine the rank order among the constructs/variables selected for the study [74].

A range of near-miss factors such as Safety and Technology Evaluation, Unsafe Acts (Worker Behavior), Unsafe Conditions (Site Environment), Near-Miss Occurrence, was ranked as per the relative importance index method [77].

3.9 Ethical Consideration

Ethical issues were a top priority in this study to protect and keep the information of all the industry professionals involved safe and accurate. Every individual who took part in the study gave their clear agreement They were apprised exactly what the study was about, and their participation was optional, and that they could leave at any time without any problems.

Moreover, sharing details about accidents and unsafe work is a sensitive topic, everyone's identity and workplace were therefore, kept private. No name or work place were unveiled what so ever. All the information collected was kept in a secure place, only the research team could see it, and it was only used for learning purposes. By following these strict ethical rules, the study helps avoid any possible harm to the participants' responses data to make sure the information acquired is true and trustworthy.

3.10 Summary

This chapter provided an overview of the research methodology used to detect the leveraging factors contributing to Near-Miss Detection Metrics towards using Advance Sensing Technologies for Proactive Safety in Construction particularly in the capital of Pakistan i.e., Islamabad/Rawalpindi. It relied on quantitative data analysis collected through survey questions.

This approach was considered suitable to investigate the multi-dimensional of near miss incident in infrastructure construction. A questionnaire was designed as a main data collection tool to examine the perceptions through the quantitative analysis. Additionally, a structured questionnaire was given to a carefully chosen group of high-rise and commercial building projects in the twin cities. This ensured that the data collected represented the different aspects of the local construction industry. By focusing on this particular urban area i.e. Pakistan's capital, the data was then analyzed using statistical methods like reliability checks and regression analysis. This allowed for a thorough look at how safety measurements, worker actions, and site conditions are linked up. In the end, the approach described in this chapter creates a solid, repeatable foundation that turns people's opinions into useful, data-based ideas for preventing hazards before they occur.

Chapter 4

Results and Analysis

This chapter portrays an insight into the interpretation and discussion on the results developed on data retrieved through researching perceptions of 75 Islamabad/Rawalpindi based construction professionals who had a repute of skillful in high-rise building projects; their past experience and repute induced this research to engage them in our research activity. The major aim of this research has been to identify, evaluate, and rank factors relating to high rise building projects and create near-miss detection metrics by conducting a range of statistical tests reliably drawn from the results acquired through descriptive and inferential statistics, reliability Cronbach Alpha test, and using advanced analytical tools including the relative importance index (RII). As an outcome of this research, an in-depth discussion leads to create an assessment Near-Miss Detection Metrics & Sensing Framework Applications specifically related to high rise construction projects in Islamabad/Rawalpindi.

4.1 Demographic Details of Respondents

This section expresses the demographic facts of research respondents involving type of the organization to whom respondents belong, respondents' professional role, educational qualification, experience, and area of expertise.

4.1.1 Organization Type

This section highlights type of organization represented through respondents such as Client, Consultant and Contractor. It entails frequency with percentage of research participants and their type of associated organization.

Table 4.1: Organization Type

	Frequency	**Percent**
Client	14	18.7
Consultant	42	56.0
Contractor	19	25.3
Total	75	100.0

The frequency table 4.1 presents organization wise participation from client (18%), Consultant (56%) and contractor (25%) out of the total sample of 75(n). frequency of consultants outweighs the others. Demographical stats reveal that consultants outnumbered the other category of participants; this provides indication that their work has wide clientage.

4.1.2 Professional Role

Professional role of sampled respondents encompassing Engineer, project manager, safety officer, and site supervisor are displayed in the following table 4.2.

Table 4.2: Professional Role

	Frequency	**Percent**
Engineer	24	32.0
Project Manager	13	17.3
Safety Officer	35	46.7
Site Supervisor	3	4.0
Total	75	100.0

Table 4.2 displays participation from professionals such as Safety Officer (35) 46%, Engineers 24(32%), Project Manager 13 (17%) and Site Supervisor 3 (4%). Safety

Officer outperform the other participants in numbers. Professionally, safety officer showed high frequency than the remaining participants while site supervisors were in fewer numbers than required.

4.1.3 Experience

In this section, experience of research respondents is exhibited below:

Table 4.3: Experience

	Frequency	**Percent**
3-5 years	32	42.7
6-10 years	20	26.7
11-15 years	18	24.0
16-20 years	3	4.0
>20 years	2	2.7
Total	75	100.0

Table 4.3 highlights that 32 participants (42.7%) had experience of 3-5 years, 20 (26%) were having experience of 6-10 years, while 18(24%) had experience of 11-15 years. Individuals having experience of 16-20 and >20 years, were 3 (4%) and 2(2.7%). The diversity in participants' experience supports the statistical results for further generalization.

4.1.4 Education

This section presents educational profile of respondents such as Bachelor, PhD and Masters.

Table 4.4: Education

	Frequency	**Percent**
Bachelor's	54	72.0
PhD	10	13.3
Masters	11	14.7
Total	75	100.0

Results expressed in Table 4.4 about educational qualification of research participants reflected 54 (72%) Bachelors, 11(14%) were Masters and 10(13%) were having PhD level education. The results indicate that all of the research participants were educated that fulfills the foremost demographic requirement of this study.

4.1.5 Area of Project Experience

This section deals with area wise project experience of research respondents around Islamabad or Rawalpindi.

Table 4.5: Area wise Project Experience

	Frequency	Percent
Islamabad	51	68.0
Rawalpindi	24	32.0
Total	75	100.0

Table 4.5 shows city wise project experience; 51(68%) represented Islamabad and 24(32%) were from Rawalpindi. Islamabad showed more suitable place for Construction project experts than Rawalpindi.

4.2 Descriptive Statistics

Table 4.6: Descriptive Statistics

	N	Minimum	Maximum	Mean	Std. Deviation
Safety and Technology Evaluation	75	1.00	5.00	2.8507	.73160
Unsafe Acts / Worker Behavior	75	1.00	4.20	2.9040	.65953
Unsafe Conditions / Site Environment	75	1.00	4.40	2.4560	.79155
Near-Miss Occurrence	75	2.00	4.80	3.6747	.52068

Table 4.6 presents the descriptive stats of 75 industry practitioners. Among the assessed metrics, Safety and Technology Evaluation had the mean score at 2.8507 and SD = 0.73160, range in observed responses = 1.00-5.00. This shows that there is moderate level of baseline implementation and intermediate level of technological readiness for the safety sensing systems at the construction sites surveyed. The Unsafe Acts / Worker Behavior, a human centric safety variable, had a mean score of 2.9040, a standard deviation of 0.65953 and a range of 1.00 to 4.20. This indicates moderate to high levels of behavioral non-compliance or risk-taking behavior by front line site staff. The lowest baseline average was for the variable Unsafe Conditions / Site Environment with the average score of 2.4560, a standard deviation of 0.79155 and a range of 1.00 to 4.40. This reflects the fact that there is a relative sense of relatively good control over physical site hazards and environmental risks compared to human driven behavior. The most frequent mean score was 3.6747 (SD 0.52068) for the primary outcome variable of Near-Miss Occurrence which ranged from a minimum of 2.00 to a maximum of 4.80. Overall, physical environmental hazards show low tendency, actual behavioral risks and near-miss incidents emerge as diverse challenges for safety management around these projects.

4.3 Reliability Statistics

TABLE 4.7: Reliability

Constructs	**No. of Items**	**Cronbach's Alpha**
Safety and Technology Evaluation	5	0.89
Unsafe Acts / Worker Behavior	5	0.74
Unsafe Conditions / Site Environment	5	0.87
Near-Miss Occurrence	5	0.80
Overall	**20**	**0.91**

The analysis portrayed in Table 4.7 shows that all of the four sub-scales show internal consistency. Safety and Technology Evaluation displayed the high reliability (0.89;) followed by Unsafe Conditions / Site Environment (0.87) and Near-Miss

Occurrence (0.80), all of these falls reasonably inside the "good" reliability range. The Unsafe Acts / Worker Behavior construct remains at 0.74 for its 5 items fall within the acceptable threshold. On the whole, entire the constructs carrying the weight of 20 items showed excellent internal consistency at a Cronbach's alpha value of 0.91. According to Hair et al., 2019, the measuring scales are highly reliable to proceed further for inferential data analysis since these falls amid 0.70-0.80 pointing good to excellent status.

4.4 Correlation

TABLE 4.8: Correlations

		NMC	**STE**	**UA**	**UC**
NMC	Pearson Correlation	1	.370	.341	.529
	Sig. (2-tailed)		.001	.003	.000
	N	75	75	75	75
STE	Pearson Correlation	.370	1	.592	.447
	Sig. (2-tailed)	.001		.000	.000
	N	75	75	75	75
UA	Pearson Correlation	.341	.592	1	.632
	Sig. (2-tailed)	.003	.000		.000
	N	75	75	75	75
UC	Pearson Correlation	.529	.447	.632	1
	Sig. (2-tailed)	.000	.000	.000	
	N	75	75	75	75

Correlation is significant at the 0.01 level (2-tailed).

. Correlation is significant at the 0.01 level (2-tailed).

Pearson product-moment correlation analysis was carried out with a sample of 75 participants (N = 75) to examine the connections between the study variables: NMC, STE, UA, and UC. The results show that all the variables are positively and statistically significantly related to each other at a very strict significance level of $p < .01$. UA and UC (The Strongest Relationship): The strongest positive correlation in the matrix is between UA and UC ($r = .632$, $p < .001$). This shows a strong and large effect size, meaning that higher levels of UA are closely and reliably linked to higher levels of UC.STE and UA: There is a strong and highly significant positive correlation between STE and UA ($r = .592$, $p < .001$), indicating that as STE increases, UA also increases significantly. NMC and UC: NMC has a strong, highly significant positive relationship with UC ($r = .529$, $p < .001$), suggesting a solid linear connection between these two factors. STE is moderately to strongly and positively correlated with UC ($r = .447$, $p < .001$). NMC and STE / UA (The Weakest, Yet Significant Links): NMC has moderate positive relationships with both STE ($r = .370$, $p = .001$) and UA ($r = .341$, $p = .003$). While these are the lowest correlation values in the matrix, they are still statistically significant and meaningful. Overall, the matrix shows highly connected and direct relationships among all four dimensions. Since every correlation is significant at the $p < .01$ level, it suggests that an increase in any one dimension (NMC, STE, UA, or UC) is associated with a statistically reliable increase in the other variables within this sample.

4.5 Normality Test

TABLE 4.9: Tests of Normality

	Kolmogorov-Smirnov			**Shapiro-Wilk**		
	Statistic	**df**	**Sig.**	**Statistic**	**df**	**Sig.**
Near-Miss Occurrence	.190	75	.000	.937	75	.001
Safety and Technology Evaluation	.104	75	.043	.959	75	.015
Unsafe Acts / Worker Behavior	.100	75	.061	.978	75	.218
Unsafe Conditions / Site Environment	.182	75	.000	.955	75	.010

a. Lilliefors Significance Correction

Table 4.9 includes results from the Kolmogorov-Smirnov (with Lilliefors correction) and Shapiro-Wilk tests to check if the variables in the study are normally distributed. For a sample size of N=75, the Shapiro-Wilk test is typically more reliable in determining normality. The null hypothesis assumes the data follows a normal distribution. Hence, a significant p-value ($p < .05$) means we reject the null, indicating the data is not normally distributed. A non-significant p-value ($p > .05$) means we fail to reject the null, meaning the data is normally distributed.

Unsafe Acts / Worker Behavior (Normally Distributed): This is the only variable that meets the normality assumption. Its Shapiro-Wilk significance is .218 (Kolmogorov-Smirnov is .061), both above the .05 threshold. This suggests worker behavior scores closely follow a normal distribution.

Near-Miss Occurrence (Non-Normal Distribution): This variable shows a significant deviation from normality. Both the Kolmogorov-Smirnov ($p < .001$) and Shapiro-Wilk ($p = .001$) tests are significant, leading to rejection of the normality assumption. Safety and Technology Evaluation (Non-Normal Distribution): This variable also fails the normality assumption. Both tests show significant deviations: Kolmogorov-Smirnov ($p = .043$) and Shapiro-Wilk ($p = .015$). Unsafe Conditions / Site Environment (Non-Normal Distribution): This variable also lacks normality. It has a highly significant Kolmogorov-Smirnov ($p < .001$) and a significant Shapiro-Wilk ($p = .010$) result.

4.6 Kruskal - Wallis Test

Hypothesis Test Summary

	Null Hypothesis	Test	Sig.	Decision
1	The distribution of STE is the same across categories of Education.	Independent-Samples Kruskal-Wallis Test	.374	Retain the null hypothesis.
2	The distribution of UA is the same across categories of Education.	Independent-Samples Kruskal-Wallis Test	.190	Retain the null hypothesis.
3	The distribution of UC is the same across categories of Education.	Independent-Samples Kruskal-Wallis Test	.773	Retain the null hypothesis.
4	The distribution of NMC is the same across categories of Education.	Independent-Samples Kruskal-Wallis Test	.541	Retain the null hypothesis.

Asymptotic significances are displayed. The significance level is .05.

FIGURE 4.1: Kruskal - Wallis Test

Since a p-value above 0.05 indicates no significant difference, a higher significance value (e.g., .773) is not a concern, it simply provides stronger evidence that respondents perceptions did not vary meaningfully across demographic subgroups (organization type, role, or experience level).

In this study, all four constructs (STE, UA, UC, and NMC) returned significance values well above 0.05, supporting the conclusion that near-miss perceptions were broadly consistent across the sample, rather than being driven by any single demographic group.

4.7 Relative Importance Index Analysis

To determine the importance of each of the 20 near-miss factors, the Relative Importance Index (RII) is used. This index changes the 5-point ratings into a standardized score between 0 and 1, making it possible to compare the importance of different risk categories [78].

The following tables present Relative Importance Index (RII) separately for each of the construct category:

TABLE 4.10: Relative Importance Index of Near-Miss Awareness

Code	**S. No.**	**Questions (Near Miss Awareness)**	**Relative Importance Index (RII)**	**Overall Priority Rank**
STE-1	1.	The difference between a ‘near-miss’ and a minor accident is clearly understood.	0.5546	2
STE-2	2.	Near-misses are considered valuable learning opportunities that help prevent future accidents or fatalities.	0.5146	4
STE-3	3.	Regular briefings are provided by site management on how to identify a near-miss.	0.5386	3
STE-4	4.	The potential consequences of ignoring a ‘close call’ on site are well understood.	0.5973	1
STE-5	5.	Workers on site understand that a near-miss is a warning sign of a hazard.	0.4693	5

Table 4.11: Relative Importance Index of Unsafe acts

Code	S. No.	Questions (Unsafe Acts)	Relative Importance Index (RII)	Overall Priority Rank
UA-1	1.	Workers often bypass safety protocols to complete tasks faster.	0.5893	2
UA-2	2.	PPE (harnesses, helmets, etc.) is ignored sometimes when working at heights.	0.5733	3
UA-3	3.	Operatives frequently use tools or equipment they are not formally trained for.	0.5466	4
UA-4	4.	There is a tendency for workers to take "short-cuts" in high-risk areas.	0.6480	1
UA-5	5.	Safety rules are viewed by workers as a secondary priority to project deadlines.	0.5253	5

Table 4.12: Relative Importance Index of Unsafe Conditions

Code	S. No.	Questions (Unsafe Conditions)	Relative Importance Index (RII)	Overall Priority Rank
UC-1	1.	Scaffolding and working platforms are often unstable or lack proper guarding.	0.5386	1
UC-2	2.	Housekeeping (debris management) is poor, leading to trip and fall hazards.	0.5066	2
UC-3	3.	Lighting and ventilation in confined high-rise shafts are frequently inadequate.	0.4826	3
UC-4	4.	Material storage at heights often poses a risk of falling objects to lower levels.	0.4586	5
UC-5	5.	Safety signage and hazard warnings are missing in critical areas of the site.	0.4693	4

Table 4.13: Relative Importance Index of Near-Miss Occurrence

Code	S. No.	Questions (Near Miss Occurrence)	Relative Importance Index (RII)	Overall Priority Rank
NMO-1	1.	At least one near-miss incident is observed on the project site every week.	0.4586	3

Table 4.13 continued from previous page

Code	S. No.	Questions (Near Miss Occurrence)	Relative Importance Index (RII)	Overall Priority Rank
NMO-2	2.	Most near-misses involve falling objects or falls from heights.	0.8053	1
NMO-3	3.	Near-misses occur more frequently during night shifts or rushed deadlines.	0.8053	1
NMO-4	4.	Equipment failure (hoists/cranes) is a common source of near-miss events.	0.8000	2
NMO-5	5.	Near-misses are often ignored because no visible injury occurred.	0.8053	1

Table 4.14: Near-Miss Detection based on RII Index

Operational Framework Dimension	Core Construct Category	Relative Importance Index (RII) Score	Priority Rank	Threshold Significance Classification
Proactive Site Frequency	Near-Miss Occurrence	0.7349	1	High-to-Critical Significance
Worker Behavior	Unsafe Acts	0.5808	2	Moderate-to-High Significance
Sensing System & Technology	Safety & Technology Evaluation	0.5701	3	Moderate-to-High Significance
Physical Site Environment	Unsafe Conditions	0.4912	4	Low-to-Moderate Significance

The results presented in Tables 4.10 through 4.14 show the Relative Importance Index (RII) scores, the priority order for each main category of core constructs, and what each classification means. These traditional measures help set a clear priority for safety risks, but turning these fixed rankings into a tool that works in real time needs a shift from manual checks to automated data handling. To do this accurately and efficiently with safety logs and field reports, this study uses a method based on the BERT framework, which is a top-of-the-line deep learning technique. Unlike older models that read text one direction at a time, either left to right or right to left, this model reads all the words at once. By looking at the text from both directions at the same time, it understands the full context, technical terms, and subtle language patterns related to safety, technology assessments, unsafe actions, and environmental factors. This method turns raw descriptions from workers into organized, automatically sorted safety data, creating a strong base for predicting potential safety issues on job sites [40].

Table 4.15: Matrix showing Bidirectional Correlational Relationships

Operational Framework Dimensions	**(A) Proactive Site Frequency Metrics**	**(B) Worker Behavior Factors**	**(C) Sensing System & Technology Metrics**	**(D) Physical Site Environment Factors**
(A) Proactive Site Frequency Metrics	$r = 1.000$	$r = .341$ $p = 0.003$	$r = .370$ $p = 0.001$	$r = .529$ $p < 0.001$
(B) Worker Behavior Factors	$r = .341$ $p = 0.003$	$r = 1.000$	$r = .592$ $p < 0.001$	$r = .632$ $p < 0.001$
(C) Sensing System & Technology Metrics	$r = .370$ $p = 0.001$	$r = .592$ $p < 0.001$	$r = 1.000$	$r = .447$ $p < 0.001$
(D) Physical Site Environment Factors	$r = .529$ $p < 0.001$	$r = .632$ $p < 0.001$	$r = .447$ $p < 0.001$	$r = 1.000$

Correlation is significant at the 0.01 level (2-tailed); Sample size N = 75.

The Bidirectional Correlation Mesh Matrix confirms that the four operational dimensions do not function in isolation but interact as a connected safety system. Every pairwise relationship in Table 16 is positive and significant at the 0.01 level (N = 75), with strength ranging from moderate (r = .341, Proactive Site Frequency–Worker Behavior) to strong (r = .632, Worker Behavior–Physical Site Environment). The strongest association occurs between Worker Behavior Factors and Physical Site Environment Factors, while the weakest, though still significant, occurs between Proactive Site Frequency Metrics and Worker Behavior Factors. These results establish that behavioral, technological, environmental, and frequency-based indicators of near-miss risk are statistically interlinked, supporting an integrated rather than siloed approach to near-miss detection.

Reading the matrix bidirectionally shows that each pair of dimensions carries two distinct, direction-specific implications rather than a single shared one. Between

Proactive Site Frequency and Worker Behavior, unsafe acts are shown to directly shape close-call patterns, while conversely, worker risk-taking behavior supplies the core targets that computer-vision and wearable-sensor systems are calibrated to track. Between Proactive Site Frequency and Sensing Technology, a well-built sensor infrastructure is linked to a higher baseline of logged near-miss detections, while sensing-driven visibility, in turn, sharpens the parameters used for early hazard detection. Between Proactive Site Frequency and Physical Site Environment, uncontrolled site hazards are shown to drive the frequency of predictable near-miss events, a pattern that simultaneously validates the use of automated spatial tools and cameras to flag emerging structural risk. Between Worker Behavior and Sensing Technology, technology-driven logging platforms are shown to substantially strengthen behavioral surveillance, while system-readiness evaluation, in the reverse direction, optimizes processing speed, data latency, and alert responsiveness. Between Worker Behavior and Physical Site Environment the strongest pathway in the matrix non-compliant behavior and structural deficiencies are shown to compound one another most heavily at active project boundaries, justifying multi-layered sensing systems that track dynamic worker actions within structurally constrained zones. Finally, between Sensing Technology and Physical Site Environment, surveillance systems prove highly effective at mapping spatial hazards, while the complexity of those hazards is, in turn, what necessitates increasingly advanced sensing technology in the first place. Collectively, these directional implications confirm that intervening at any one dimension produces measurable, traceable effects on the other three, reinforcing the treatment of near-miss risk as a dynamic socio-technical system rather than a set of independent variables.

4.7.1 A Practitioner's Guide to Reading the Matrix

For a reader without a background in statistics, Table 16 can be read simply as a map of how strongly four site-safety factors move together. Each cell reports two numbers: the correlation coefficient (r), which shows how closely two factors rise and fall together on a scale from 0 (no relationship) to 1 (a perfect relationship), and the significance value (p), which shows how confident the result can be trusted rather than being due to chance, any p-value below 0.01 in this study is treated as highly reliable. A higher r value, such as the .632 recorded between Worker Behavior and Physical Site Environment, means that as one factor increases on a site for example, more unsafe worker actions the other factor, such as structural or environmental deficiencies, tends to increase as well. In practical terms, a site manager can use this table to identify where problems are most likely to spread: because every relationship in the matrix is positive and statistically significant, improving conditions in any one area training workers, repairing structural hazards, or upgrading sensing equipment is likely to produce a measurable improvement in near-miss reporting and detection across the other three areas as well.

4.8 Integrated Near-Miss Detection Framework Architecture

Drawn from the above, four factors based on 3-IVs and one DV, Near-Miss Detection Framework is created using the integrated results from the above RII Sections. This framework combines to incorporate and provide a roadmap to create a workable tool for systematic Near-Miss Detection, that can be used by project stakeholders.

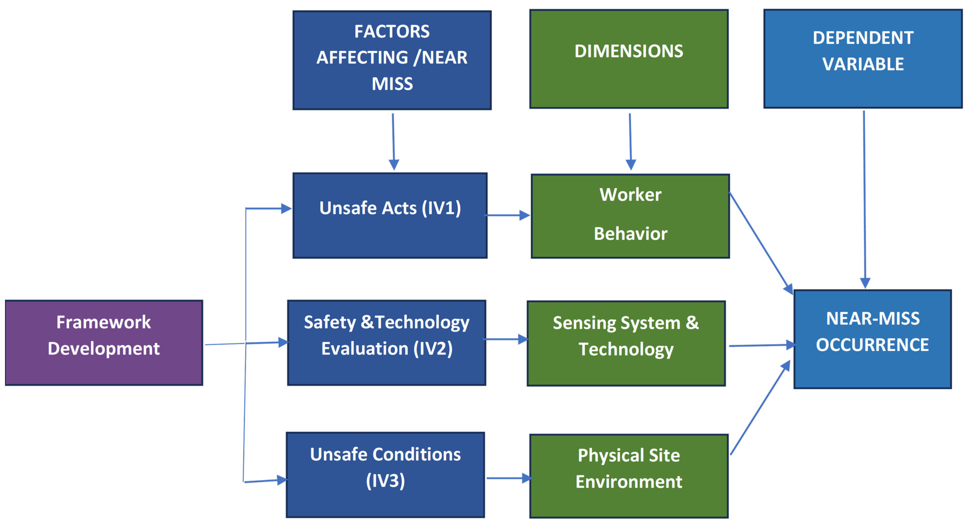

Figure 4.2: Conceptual Framework of the Proactive Near-Miss Detection

The Integrated Near-Miss Detection Framework Architecture is the main structure and technical plan of this study. It connects modern sensing technologies with real-time monitoring at construction sites to reduce safety risks. This system works by constantly gathering environmental and behavior-related data from active construction areas using tools like computer vision cameras and proximity tracking devices.

This raw data is then processed through local safety standards that automatically check for spatial relevance, detect unsafe worker behaviors, and identify dangerous environmental conditions. By handling these variables at the same time, the framework becomes an intelligent system that can send immediate alerts as soon as potential risks reach a critical level. This architecture helps bridge the gap between traditional safety records and active, technology-based prevention measures, giving project managers the predictive data, they need to stop accidents before they happen.

This research conceives the premise that four factors are involved behind near missed. These are Unsafe Acts, Safety & Technology Evaluation, Unsafe Conditions that contribute to near miss occurrences. Unsafe acts pertain to worker behavior; safety & Technology Evaluation relate to Sensing System & Technology whilst unsafe condition relate to physical site environment. All of these combines to form framework development.

4.9 Summary

Chapter 4 provided a detailed analysis of data collected from high-rise and commercial construction projects in the Islamabad/Rawalpindi area. It started with basic statistical summaries that outlined the demographics and site characteristics of the industry professionals involved. The chapter then moved on to more advanced statistical methods, such as reliability checks, correlation analyses, and regression models, which confirmed the connections within the theoretical framework. These methods showed how safety and technology evaluation metrics (IV1), unsafe actions (IV2), and unsafe conditions (IV3) directly impact the frequency and predictability of near-miss incidents (DV). Additionally; the developed Integrated Near-Miss Detection Framework Architecture showed how these statistical results can be used to build automated real-time monitoring systems on construction sites. These findings help transform how professionals view safety into practical, data-driven evidence, setting a strong foundation for the discussion of theoretical and practical implications in the final chapter.

Chapter 5

Conclusion and Recommendations

Drawing from the extensive empirical results, and the new bidirectional sensing architecture designed and tested in Chapter 4, this chapter tends to conclude the academic debate by presenting the Conclusions and Recommendations, as well as implications for theory and practice. Limitations and Future Recommendations are also a part of this chapter.

5.1 Conclusion

The main objective of the research was to identify near-miss scenarios, develop detection metrics to develop a near miss detection framework for proactive safety management in construction. This research was able to successfully conceptualize, develop and recommend a Proactive Near-Miss Detection Framework particularly for Construction Industry. This study helped to connect the dots between automated sensor networks and site safety analytics, and that's a big industry issue because of the fact that they're dependent on lagging accident indicators. This research employed the Relative Importance Index (RII) method, to systematically isolate and rank the operational variables that control the close-call events.

The empirical results clearly show that safety on a site is not an aggregated set of near-miss but a very intertwined network of near-miss. The distinction among the roles of workers, the technology of the architecture and the space configuration is a blur phenomenon. In particular, Sensing System & Technology Metrics (Rank 3, RII = 0.5701) turned out to be the basic level of the framework. This clearly demonstrates that the technical infrastructure (processing latency, integrity of data networks) has to be totally reliable before starting reduction in any behavioral or environmental hazard. Additionally, strong statistical linkage between Worker Behavior Factors and Physical Site Environment Factors ($r = .632$, $p < 0.001$) verifies that at the construction site that create hazards and subsequent compliance at the frontline reinforce each other.

Overall, this dissertation offers a conceptualized and empirically ranked framework" and "data-supported proactive safety planning towards proactive mitigation from historic, retrospective accident reporting.

5.2 Recommendations

To support high rise building projects and construction management teams, the following strategic actions are recommended based on the empirical insights gained and validated structures of the study framework:

i. Ensure fall hazard spot-checks are completed daily (RII = 0.8053 for falls).

ii. Provide environmental inspection ($r = 0.632$) for every behavior correction.

iii. Put in place a Green-Tag scaffold sign-off before 8:00 AM (Scaffolding has RII = 0.5386).

iv. Add a verbal 2-minute check point for high-risk tasks to prevent "short-cuts" (RII = 0.648).

v. Project teams should deploy decentralized sensor nodes and real-time Building Information Modeling (BIM)-to-sensor APIs (Priority – Establish a Multi-Layered Edge Network Prioritizing System Readiness): Field tracking loops should only be switched on after ensuring that the data transmission latency of communication networks.

vi. To measure the frequency of near-miss events on site pathways, instead of counting injuries, management should use video cameras with edge - computing technology, which are installed on site pathways and are used to monitor a high number of traffic events. If thresholds for a sector are exceeded, automated alerts should go straight to field supervisors when close call thresholds are elevated in a sector.

vii. Develop smart safety vests, and inertial measurement unit (IMU) motion tags for workers on the front lines. If a worker does cross a spatial hazard buffer, the system should immediately stop and send localized haptic feedback to the vest and not to any cloud processing.

viii. All of these recommended sensors need to trigger instant audio-visual warnings to alert occupants to their proximity to the danger zones and instant digital safety locks to stop the machine from entering the danger zones if a boundary is crossed.

5.3 Theoretical Implications

In some ways, this dissertation is a significant addition to the overall literature on construction safety: This work contributes to evolution of Accident Prevention Theory and builds on existing theories in accident prevention, by expanding them to include today's cyber physical ecosystems. It shows that "holes" in safety barriers can be dynamically surveyed and closed prior to an accident.

The results of this research include the quantification of the Sociotechnical Safety Mesh. This research creates the bidirectional correlation matrix for the mesh, thereby mathematically validating the complex interaction between the human actors, the environmental constraints and the technology layers. This is a challenge to traditional binary research models which address human error from site physical contexts. Theoretical Utility of multi-paradigm Decision Models: It is demonstrated in this study that the application of RII methodology is theoretically useful. This hybrid methodology combines analytical approaches and provides a reproducible, mathematically based method for converting subjective observations at the sites to objective, prioritized controls for safety.

5.4 Practical Implications

The lessons from this framework are very practical and immediately applicable for project management professionals, safety engineers, and the regulatory community:

By leveraging the quantified detection metrics and multi-tiered risk classification developed in this framework, safety managers can shift from uncoordinated inspections around the site. Rather, they can concentrate investment capital and equipment specifically on "Critical" and "High" Near-Miss Occurrence areas, optimizing the benefit of technological investments with enhanced safety. Minimization of Alert Fatigue: Field supervisors won't be overwhelmed with minor alerts due to a hierarchical flow. Low level is automatically corrected using device self-calibration and high severity path breaches are escalated immediately. Predictive analytics enable safety teams to create highly targeted safety briefs that are actionable. If a computer vision system records a rise in the number of improper lifts or non-compliance of PPE in a particular sector, then the supervisor has the opportunity to discuss that specific problem at the next shift briefing. Regulatory agencies and enterprise contractors can apply the framework's metric scores to audit and compare safety performance on any project, based on the verified close-call logs, not after occurrence of work injury.

5.5 Limitations and Future Recommendations

This research provides an empirically supported proactive safety model, but there are a number of limitations that suggest avenues for further research.

5.5.1 Research Limitations

Sample data collected from the high-rise building projects in a certain urban construction environment posed the foremost limitations to this study. The results might differ if the project relates to a long-line infrastructure project, such as a highway, tunnel, or marine project. Secondly, the study is based on self-reported data on unsafe acts and near-miss events and, therefore, may have social desirability bias and retrospective recall bias. Industry practitioners and workers may underreport their own unsafe behavior or minimize site risks to ensure the safety of their workplace image and/or corporate safety expectations may obscure the true frequency of unsafe behavior. Finally, the cross-sectional nature of this study is a time constraint because opinions and safety climates of experts are only recorded at one time. The social aspects, safety cultures and technological acceptance are evolutionary in nature, and thus, this snapshot approach cannot fully address long-term behavioral adaptation or changing human-machine relationships as workers grow accustomed to automated sensing technologies

5.5.2 Future Research Directions

Future research may consider the use of algorithms to monitor, track, and prevent negative incidences before occurrence. For this purpose, AI generated models should be employed to boost the effectiveness of near-miss prediction accuracy. Further research may examine how cutting-edge vision architectures can better understand the sophisticated, unscripted human-object interactions to boost the effectiveness of near-miss prediction accuracy. To generalize the priority ranking factors computed in this study, it is suggested that the three-level hierarchical model be cross-validated with projects of different types, whether they are industrial infrastructure or horizontal civil works.

Bibliography

[1] Hashmi *et al.*, "Near-miss detection metrics: an approach to enable sensing technologies for proactive construction safety management," *Buildings*, vol. 14, no. 4, p. 1005, 2024.

[2] Khodabandeh *et al.*, "Factors associated with the severity of fatal accidents in construction workers," *Medical Journal of the Islamic Republic of Iran*, vol. 30, no. 469, 2016.

[3] Sarasanty, "Safety hazards identification of construction site layout based on geographic information system (gis)," *International Journal on Advanced Science, Engineering and Information Technology*, vol. 10, pp. 21–27, 2020.

[4] Das, "Occupational fatalities in the construction sector: A medico-legal viewpoint," *Medico-Legal Journal*, vol. 83, no. 2, pp. 93–97, 2015.

[5] Lingard *et al.*, "Leading or lagging? temporal analysis of safety indicators on a large infrastructure construction project," *Safety Science*, vol. 91, pp. 206–220, 2017.

[6] Gray and Mendeloff, "Preventing construction deaths: The role of public policies," *Law & Policy*, vol. 17, no. 3, pp. 726–754, 2023.

[7] Cañaveras *et al.*, "How to prevent 3 million deaths worldwide: a systematic review of occupational accident research—a factor-and cost-based approach," *Safety Science*, no. 35, pp. 91–100, 2025.

[8] Costin *et al.*, "Leading indicators—a conceptual iot-based framework to produce active leading indicators for construction safety," *Safety*, vol. 5, no. 4, p. 84, 2019.

[9] Caspi *et al.*, “Managing near-miss reporting in hospitals: The dynamics between staff members’ willingness to report and management’s handling of near-miss events,” *Safety Science*, vol. 164, p. 106147, 2023.

[10] Park *et al.*, “Analysis of fatal accidents and their causes in the korean construction industry,” *Sustainability*, vol. 12, no. 8, p. 3120, 2020.

[11] Lee *et al.*, “Fall-from-height detection using deep learning based on imu sensor data for accident prevention at construction sites,” *Sensors*, vol. 22, no. 16, p. 6107, 2022.

[12] Woźniak and Hoła, “Research areas of near misses in the construction industry: Literature review,” in *International Conference on Sustainable Development in Civil, Urban and Transportation Engineering.* Singapore: Springer Nature Singapore, 2024, pp. 75–83.

[13] Cui *et al.*, “Public response to a near-miss nuclear accident scenario varying in causal attributions and outcome uncertainty,” *Journal of Risk Research*, vol. 8, no. 5, pp. 947–961, 2018.

[14] Zhou *et al.*, “Exploring the potential use of near-miss information to improve construction safety performance,” *Sustainability*, vol. 11, no. 5, p. 1264, 2019.

[15] Ma *et al.*, “Systematic risk analysis and mitigation strategies for near-miss events in interventional operating room nursing,” *Journal of Nursing Management*, pp. 239–248, 2025.

[16] Saqib *et al.*, “Investigating the acceptance of an electronic incident reporting system in the construction industry: An application of the technology acceptance model,” *Journal of Construction Engineering and Management*, vol. 149, no. 5, p. 04023021, 2023.

[17] Awolusi *et al.*, “Incident analysis and prediction of safety performance on construction sites,” *CivilEng*, vol. 3, no. 3, pp. 669–686, 2022.

[18] Sadeghi *et al.*, “A systematic review of scholarly works addressing crane safety requirements,” *Safety Science*, vol. 133, p. 105002, 2021.

[19] Phimister *et al.*, "Near-miss system analysis: Phase i," Risk Management and Decision Processes Center, The Wharton School, University of Pennsylvania, Tech. Rep., 2000.

[20] Alsulamy *et al.*, "Machine learning applications for predicting safety incidents in construction industry," *Journal of Building Engineering*, 2026.

[21] Alfayez *et al.*, "Factors affecting patient safety near miss reporting: a systematic review," *BMC Health Services Research*, vol. 82, no. 3, 2026.

[22] B. Manzoor, I. Othman, J. C. Pomares, and H.-Y. Chong, "A research framework of mitigating construction accidents in high-rise building projects via integrating building information modeling with emerging digital technologies," *Applied Sciences*, vol. 11, no. 18, p. 8359, 2021.

[23] Duan and Zhou, "A science mapping approach-based review of near-miss research in construction," *International Journal of Injury Control and Safety Promotion*, vol. 30, no. 6, pp. 2582–2601, 2023.

[24] Smolarz, "Analysis of accidents in construction in 2015-2017," *Occupational Safety – Science and Practice*, vol. 29, no. 4, pp. 149–156, 2019.

[25] Hoła and Szóstak, "Modeling of the accidentality phenomenon in the construction industry," *Sustainability*, vol. 9, no. 9, p. 1878, 2019.

[26] Hasanzadeh *et al.*, "Role of personality in construction safety: Investigating the relationships between personality, attentional failure, and hazard identification under fall-hazard conditions," *Journal of Construction Engineering and Management*, vol. 145, no. 9, p. 04019052, 2019.

[27] Olcay *et al.*, "A study of the shift in fatal construction work-related accidents during 2012–2019 in turkey," *International Journal of Occupational Safety and Ergonomics*, vol. 28, no. 3, pp. 1522–1532, 2022.

[28] Tözer *et al.*, "Classification of construction accidents in northern cyprus," *Environmental Science and Pollution Research*, vol. 29, no. 2, pp. 8295–8316, 2019.

[29] Newaz *et al.*, "A critical analysis of construction incident trends and strategic interventions for enhancing safety," *Safety Science*, vol. 187, p. 106865, 2025.

[30] Cabello *et al.*, "Occupational accident analysis according to professionals of different construction phases using association rules," *Safety Science*, vol. 144, p. 105457, 2021.

[31] Muley *et al.*, "Assessing construction near-miss detection proficiency for workers under stressor conditions using psychophysiological measures: An eye-tracking investigation," *Buildings*, vol. 15, no. 3, p. 1558, 2025.

[32] Williams, "Exploring the value of near-miss reporting for construction safety," Ph.D. dissertation, Anglia Ruskin University, 2025.

[33] Thoroman *et al.*, "Evaluation of construct and criterion-referenced validity of a systems-thinking based near miss reporting form," *Journal of Safety Research*, vol. 63, no. 2, pp. 210–224, 2020.

[34] Hallowell *et al.*, "Methods of safety prediction: Analysis and integration of risk assessment, leading indicators, precursor analysis, and safety climate," *Construction Management and Economics*, vol. 38, no. 4, pp. 308–321, 2020.

[35] Hislop, *Construction site safety: A guide for managing contractors.* CRC Press, 1999.

[36] Zaidi *et al.*, "Vision-based construction safety monitoring utilizing temporal analysis to reduce false alarms," *Buildings*, vol. 14, no. 6, p. 1878, 2024.

[37] Pan *et al.*, "Enhancing construction safety: A computer vision approach for proactive near-miss events identification," in *Proceedings of the International Conference on Construction and Real Estate Management (ICCREM)*, 2024, pp. 840–851.

[38] Marks *et al.*, "Using near misses to enhance safety performance in construction," 2017.

[39] Zhou *et al.*, "Human dynamics in near-miss accidents resulting from unsafe behavior of construction workers," *Physica A: Statistical Mechanics and its Applications*, vol. 530, p. 121495, 2020.

[40] Woźniak and Hoła, "Analysing near-miss incidents in construction: a systematic literature review," *Applied Sciences*, vol. 14, no. 16, p. 7120, 2024.

[41] Wozniak and Hoła, "Quantitative and qualitative analysis of hazardous events in the construction sector: causes, classification and implications," *Scientific Reports*, vol. 15, p. e154729, 2025.

[42] Ruddy *et al.*, "Near misses and unsafe conditions reported in a pediatric emergency research network," *BMJ Open*, vol. 5, no. 9, p. e008453, 2017.

[43] Marks *et al.*, "Near-hit reporting: Reducing construction industry injuries," *Professional Safety*, vol. 61, no. 5, pp. 56–62, 2016.

[44] Yamamoto *et al.*, "Classifying near-miss traffic incidents through video, sensor, and object features," *Transportation Research Part C: Emerging Technologies*, vol. 105, no. 2, pp. 377–386, 2022.

[45] Zhang *et al.*, "Automated detection of grade-crossing-trespassing near misses based on computer vision analysis of surveillance video data," *Safety Science*, vol. 110, pp. 276–285, 2018.

[46] Yang *et al.*, "Semi-supervised near-miss fall detection for ironworkers with a wearable inertial measurement unit," *Automation in Construction*, vol. 68, pp. 194–202, 2016.

[47] Lim *et al.*, "Near miss detection using distancing monitoring and distance-based proximal indicators," *Sensors*, vol. 25, no. 1, p. 112, 2025.

[48] Elia *et al.*, "Applications of smart technologies for automatic near miss detection in industrial safety," *Procedia Computer Science*, vol. 200, pp. 1282–1287, 2022.

[49] Thallinger *et al.*, "Near-miss accidents–classification and automatic detection," in *First International Conference on Intelligent Transportation Systems*, 2017, p. 144.

[50] Li *et al.*, "Research on near-miss incidents monitoring and early warning system for building construction sites based on blockchain technology," *Journal of Construction Engineering and Management*, vol. 149, no. 12, p. 04023124, 2023.

[51] Zhou and Irizarry, "Integrated framework of modified accident energy release model and network theory to explore the full complexity of the hangzhou subway construction collapse," *Journal of Management in Engineering*, vol. 2, no. 5, p. 05016013, 2016.

[52] Khatsuriya and Gaur, "Perceived effectiveness of near-miss reporting on proactive safety performance in construction: A mixed-methods study from india," *International Journal of Construction Management*, vol. 15, no. 3, pp. 209–221, 2025.

[53] Yan *et al.*, "Real-time digital twin–driven 3d near-miss detection system at construction sites," *Journal of Construction Engineering and Management*, vol. 151, no. 4, p. 04025021, 2025.

[54] Dillon and Tinsley, "Near-miss events, risk messages, and decision making," *Journal of Risk Research*, vol. 36, no. 1, pp. 34–44, 2016.

[55] Orvik and Albrechtsen, "The mismatch between conceptualization and measurements of safety performance: Insights from a qualitative study of the norwegian construction industry," *Safety Science*, vol. 182, pp. 1–18, 2026.

[56] Meng *et al.*, "Multiple configurational effects and analyses on construction workers' unsafe behaviors: A qualitative approach of fuzzy-set qualitative comparative analysis," *Safety Science*, vol. 173, pp. 1–18, 2025.

[57] Bao *et al.*, "Computer vision–based recognition of spatial relevance between engineering vehicles and workers for monitoring struck-by accidents," *Journal*

of Construction Engineering and Management, vol. 151, no. 11, p. 04025163, 2025.

[58] Zhou *et al.*, “Characterizing time series of near-miss accidents in metro construction via complex network theory,” *Safety Science*, vol. 98, pp. 145–158, 2017.

[59] Griffey *et al.*, “Near-miss events detected using the emergency department trigger tool,” *Journal of Patient Safety*, vol. 19, no. 2, pp. 59–66, 2023.

[60] Kavanagh and Ward, “What is known about near miss events in the operating room? a systematic review of studies of mixed methods design,” *Surgery*, vol. 194, no. 1, pp. 297–310, 2025.

[61] Diaz, “Lived experiences of texas construction workers reporting near misses on their jobsite,” Ph.D. dissertation, Walden University, 2026.

[62] Suresh *et al.*, “Examining the satisfaction level of construction workers on safety management in the kingdom of saudi arabia,” *International Journal of Construction Management*, vol. 17, no. 4, pp. 289–301, 2017.

[63] Gnoni *et al.*, “Near miss management systems in the industrial sector: A literature review,” *Safety Science*, vol. 150, p. 105704, 2022.

[64] Feng *et al.*, “Near miss research in the healthcare system: a scoping review,” *JONA: The Journal of Nursing Administration*, vol. 52, no. 3, pp. 160–166, 2022.

[65] Lingard *et al.*, “A qualitative analysis of crane safety incident causation in the australian construction industry,” *Safety Science*, vol. 133, p. 105028, 2021.

[66] Emerson, “Likert scales,” *Journal of Visual Impairment & Blindness*, vol. 111, no. 5, pp. 488–488, 2017.

[67] West *et al.*, *Applied Survey Data Analysis*, 2nd ed. Chapman and Hall/CRC, 2025.

[68] Novak, "A comparison of the appropriateness of various internal consistency coefficients—an alternative to cronbach's alpha," *Psychometrika*, vol. 90, no. 1, pp. 45–62, 2025.

[69] Lin *et al.*, "Reliability and validity of the integrated wisdom scale (long- and short-form) for adolescents in a chinese sample," *Journal of Adolescence*, vol. 35, no. 3, p. e70060, 2025.

[70] Sezer *et al.*, "Occupational health and safety culture in coal mining: a comparative study of underground and surface workers in türkiye," *International Journal of Occupational Safety and Ergonomics*, vol. 32, no. 1, pp. 102–115, 2026.

[71] Rahiman and Mahat, "The influence of domino theories in preventing construction accidents," *International Journal of Engineering & Technology*, vol. 7, no. 4, pp. 120–125, 2018.

[72] Hosseinian and Torghabeh, "Major theories of construction accident causation models: A literature review," *International Journal of Science and Technology*, vol. 4, no. 2, p. 53, 2012.

[73] Bracco and Ivaldi, "How metaphors of organizational accidents and their graphical representations can guide (or bias) the understanding and analysis of risks," *Safety*, vol. 11, no. 10, p. 199, 2023.

[74] Nyimbili and Nyimbili, "Types of purposive sampling techniques with their examples and application in qualitative research studies," *International Journal of Research and Innovation in Social Science*, vol. 8, no. 3, pp. 412–421, 2024.

[75] Harris and Quade, "The minimally important difference significant criterion for sample size," *Journal of Educational and Behavioral Statistics*, vol. 17, no. 1, pp. 27–49, 1992.

[76] Conroy, "The rcsi sample size handbook," Dublin, pp. 59–61, 2016.

[77] Holtom *et al.*, "Survey response rates: Trends and a validity assessment framework," *Human Resource Management Review*, vol. 75, no. 8, pp. 1560–1584, 2022.

[78] Antoniou and Tsavlidou, "Ranking public infrastructure project success using multi-criteria analysis," *Sustainability*, vol. 15, no. 16, p. 2807, 2025.

Appendix

Leveraging Near-Miss Detection Metrics to Advance Sensing Technologies for Proactive Safety in Construction

Dear Respondent,

I am a student of MS Civil Engineering (Construction Engineering & Management) at Capital University of Sciences & Technology, Islamabad. I am conducting research on the title: **Leveraging Near-Miss Detection Metrics to Advance Sensing Technologies for Proactive Safety in Construction.**
A near miss is when something almost goes wrong on a construction site, an incident that could have caused injury or damage but luckily didn't. Advanced technologies, like sensors, AI systems, and drones, are tools used to monitor the site, identify potential risks early, and help prevent accidents before they occur.
This survey consists of five sections focusing on key factors that influence near miss detection in construction projects:

1. Personal Information
2. Safety and Technology Evaluation
3. Unsafe Acts (Worker Behavior)
4. Unsafe Conditions (Site Environment)
5. Near-Miss Occurrence

Please take 5-10 minutes to complete the following survey. Your responses will contribute significantly to a better understanding of this research. Please note that all information provided will be kept strictly confidential and used solely for academic purposes.

Thank you for your time and cooperation.

Best Regards,
Aqsa Malik
MS Civil Engineering
CUST, Islamabad
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* Indicates required question

Section 1: Demographic Details

This section asks about basic information. Please select or fill in the option that best describes you.

1. Email *

2. **Organization Type:** *

   Mark only one oval.

   - Client
   - Consultant
   - Contractor

3. **Professional Role** *

   Mark only one oval.

   - Project Manager
   - Safety Officer
   - Engineer
   - Site Supervisor
   - Other:

4. **Experience in High-Rise Projects:** *

Mark only one oval.

- 0-2 years
- 3-5 years
- 6-10 years
- 11-15 years
- 16-20 years
- >20 years

5. **Education Level:** *

Mark only one oval.

- Diploma
- Bachelor's
- Masters
- PhD

6. **Please specify the area of your project experience.** *

Mark only one oval.

- Islamabad
- Rawalpindi
- Other: ____

Section II: Safety and Technology Evaluation(Metrics for Near-Miss Awareness)

This section focuses on awareness of safety practices, near-miss incidents, that help improve site safety. Please respond based on your understanding and experience.

7. The difference between a 'near-miss' and a minor accident is clearly understood. *

Mark only one oval.

- Strongly disagree
- Disagree
- Neutral
- Agree
- Strongly agree

8. Near-misses are considered valuable learning opportunities that help prevent future accidents or fatalities. *

Mark only one oval.

- Strongly disagree
- Disagree
- Neutral
- Agree
- Strongly agree

9. *

Regular briefings are provided by site management on how to identify a near-miss.

Mark only one oval.

- Strongly disagree
- Disagree
- Neutral
- Agree
- Strongly Agree

10. The potential consequences of ignoring a 'close call' on site are well understood. *
(Close call: An incident that almost caused harm or damage but did not occur)

Mark only one oval.

- Strongly disagree
- Disagree
- Neutral
- Agree
- Strongly agree

11. Workers on site understand that a near-miss is a warning sign of a hazard. *

Mark only one oval.

- Strongly Disagree
- Disagree
- Neutral
- Agree
- Strongly Agree

Section III: Unsafe Acts (Worker Behavior)

This section is about unsafe actions by workers that may lead to accidents, such as not following safety rules or using equipment incorrectly. Please indicate how often you observe or experience such behaviors at your site.

12. Workers often bypass safety protocols to complete tasks faster. *

Mark only one oval.

- Strongly Disagree
- Disagree
- Neutral
- Agree
- Strongly Agree

13. PPE (harnesses, helmets, etc.) is ignored sometimes when working at heights. *

Mark only one oval.

- Strongly disagree
- Disagree
- Neutral
- Agree
- Strongly Agree

14. Operators frequently use tools or equipment they are not formally trained for. *

Mark only one oval.

- Strongly disagree
- Disagree
- Neutral
- Agree
- Strongly Agree

15. There is a tendency for workers to take "short-cuts" in high-risk areas. *

Mark only one oval.

- Strongly disagree
- Disagree
- Neutral
- Agree
- Strongly Agree

16. Safety rules are viewed by workers as a secondary priority to project deadlines. *

Mark only one oval.

- Strongly disagree
- Disagree
- Neutral
- Agree
- Strongly Agree

Section IV: Unsafe Conditions (Site Environment)

This section refers to unsafe situations at the construction site, such as poor lighting, unstable structures, or lack of safety equipment. Please respond based on what you have seen on your site.

17. Scaffolding and working platforms are often unstable or lack proper guarding. *

Mark only one oval.

- Strongly disagree
- Disagree
- Neutral
- Agree
- Strongly Agree

18. Housekeeping (debris management) is poor, leading to trip and fall hazards. *

Mark only one oval.

- Srongly disagree
- Disagree
- Neutral
- Agree
- Strongly Agree

19. Lighting and ventilation in confined high-rise shafts are frequently inadequate. *

Mark only one oval.

- Strongly disagree
- Disagree
- Neutral
- Agree
- Strongly agree

20. Material storage at heights often poses a risk of falling objects to lower levels. *

Mark only one oval.

- Strongly disagree
- Disagree
- Neutral
- Agree
- Strongly agree

21. Safety signage and hazard warnings are missing in critical areas of the site. *

Mark only one oval.

- Strongly disagree
- Disagree
- Neutral
- Agree
- Strongly Agree

Section V: Near-Miss Occurrence

This section asks about incidents that almost caused an accident but did not result in injury or damage. Please indicate how often such situations occur at your workplace.

22. At least one near-miss incident is observed on the project site every week. *

Mark only one oval.

- Strongly disagree
- Disagree
- Neutral
- Agree
- Strongly Agree

23. Most near-misses involve falling objects or falls from heights. *

Mark only one oval.

- Strongly disagree
- Disagree
- Neutral
- Agree
- Strongly Agree

24. Near-misses occur more frequently during night shifts or rushed deadlines. *

Mark only one oval.

- Strongly Disagree
- Disagree
- Neutral
- Agree
- Strongly Agree

25. Equipment failure (hoists/cranes) is a common source of near-miss events. *

Mark only one oval.

- Strongly disagree
- Disagree
- Neutral
- Agree
- Strongly agree

26. Near-misses are often ignored because no visible injury occurred. *

Mark only one oval.

- Strongly disagree
- Disagree
- Neutral
- Agree
- Strongly Agree