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An Integrated Safety Management Framework for Working at Height Using Smart PPE, Artificial Intelligence and Risk Assessment

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Abstract: *Working at height is one of the leading causes of occupational fatalities and serious injuries across construction and industrial sectors. Despite the implementation of engineering controls, administrative procedures, work permit systems, safety training, and personal protective equipment (PPE), fall-related accidents continue to occur, primarily due to unsafe acts, human error, and non-compliance with safety harness anchoring requirements. Conventional safety monitoring methods rely heavily on manual supervision, making it difficult to ensure continuous compliance during high-risk operations. Therefore, there is a growing need for intelligent and technology-driven safety solutions that can provide real-time monitoring and early warning to prevent fall accidents.*

This research presents the development of an AI and Internet of Things (IoT) enabled Smart Safety Harness System for enhancing working at height safety in industrial applications. The proposed system integrates sensor-based monitoring, AI communication, and real-time alert mechanisms to detect improper anchoring or unsafe usage of the safety harness. Whenever a deviation is identified, the system immediately generates an audio-visual warning to the worker while simultaneously transmitting the information to the supervisor for corrective action. In addition, all safety violations are automatically recorded in a centralized database for trend analysis, safety performance evaluation, and continuous improvement.

The study adopts a systematic methodology involving hazard identification, working at height survey, risk assessment, evaluation of existing engineering and administrative controls, validation of technological solutions, and implementation of an intelligent fall protection system. High-risk activities such as roof sheet installation, scaffold erection, maintenance work, pipeline installation, and structural construction are analyzed to identify critical areas where smart wearable technology can significantly improve safety performance. The proposed approach follows the hierarchy of risk control by strengthening engineering controls while minimizing dependence on manual observation and human intervention.

The outcome of this research is the development of a reliable, economical, and intelligent fall prevention system capable of reducing workplace injuries, improving PPE compliance, minimizing human error, and supporting proactive safety management. The integration of Artificial Intelligence, IoT, and smart wearable technology establishes a modern framework for industrial safety that enables real-time monitoring, predictive safety analytics, and data-driven decision-making. The proposed system has significant potential for application in construction, manufacturing, petrochemical, power, mining, and infrastructure industries, thereby contributing to the advancement of Industrial Safety Engineering and promoting a sustainable "Zero Harm" safety culture.

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Keywords: Working at Height (WAH), Industrial Safety Engineering, Artificial Intelligence (AI), Internet of Things (IoT), Smart Safety Harness, Machine-to-Machine (M2M) Communication, Personal Protective Equipment (PPE), PPE Compliance Monitoring, Hazard Identification, Risk Assessment, Fall Prevention, Occupational Health and Safety (OHS), Smart Wearable Technology, Safety Management System, Human Error Reduction, Real-Time Safety Monitoring, Predictive Safety Analytics, Construction Safety, Industrial Accident Prevention, Workplace Safety

I. INTRODUCTION

1.1 Background and Overview:

Working at height is universally recognized as one of the most critical occupational hazards across the construction, manufacturing, and infrastructure industries. It remains a leading cause of severe injuries and fatal accidents, particularly in tasks performed on ladders, fragile roofs, unprotected floors, open shafts, and hoists. While the surge in industrialization and the advent of Artificial Intelligence (AI) have revolutionized productivity, strategic decision-making, and quality control, similar technological advancements have yet to be fully realized in the realm of workplace safety.

Figure 1.1 Smart Safety Harness Monitor

Currently, compliance with Personal Protective Equipment (PPE) is predominantly managed manually through safety supervisors or leadership walkthroughs. Although administrative discipline is driven by top management, it often lacks consistent implementation at the operational level, leading to a continuous rise in occupational accidents.

1.2 The Problem Statement:

Despite various administrative regulations—such as the Factories Act, permit-to-work systems, and safety checklists—traditional safety monitoring mechanisms are often insufficient to prevent workplace injuries effectively. Fall injuries remain a rapidly increasing threat, driven by factors such as human error, fatigue, complacency, and lack of attentiveness. In many instances, a contract worker may simply forget to anchor their safety harness to an anchoring point. This brief lapse in human judgment, rarely noticed in real-time by supervisors, can lead to severe bodily injury or fatalities.

Alarming statistics from the Directorate General of Factory Advice Service and Labour Institutes (DGFASLI) highlight the severity of this issue:

Year	Accident Type	Total Causes (Blue)	Due to Working at Height (Orange)
2024	Fatal	212	41
2024	Non-Fatal	516	72
2025	Fatal	235	47

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2025	Non-Fatal	621	73

Table 1.1: Fatal and Non-fatal data 2024 and 2025 DGFALI

1.3 Proposed Solution: Internet of Things (IoT) Based Smart Safety Harness:
To bridge the gap between traditional safety measures and modern technological capabilities, this research introduces an Internet of Things (IoT) based Smart Safety Harness. Much like how modern automobile airbags deploy automatically upon collision, a Smart PPE system provides an error-proof, proactive safety layer. If a worker fails to connect the harness to the anchoring point, or if it becomes detached, the embedded sensors instantly detect the non-compliance. The system immediately generates an alert to warn the user and logs the deviation into a centralized system for supervisory review.

Smart Harnesses vs. Traditional Harnesses		
Feature	Traditional Harness	Smart Harness
Electrical Role	Power/signal conduit	Power, signal + data monitoring
Sensor Support	Not supported	Embedded for real-time diagnostics
Maintenance Cycle	Time-based/manual testing	Data-driven, condition-based
Failure Detection	Post-fault (after failure)	Pre-fault via sensor alerts
Communication Protocols	None	CAN, LIN, Ethernet, Wireless
Data Logging	No	Local + Cloud logging supported
Application Fit	Legacy systems	EVs, robotics, aerospace, medical
Compliance Support	ISO 9001 only	ISO 9001

Table 1.2: Smart Harnesses vs. Traditional Harnesses

1.4 Research Objectives and Scope:
The primary objective of this study is to engineer a revolutionary change in working-at-height safety by introducing a smart, wearable technological solution that mitigates human error. Specifically, this research aims to:
• Identify the root causes of fall injuries and assess the inadequacies of current administrative controls.
• Propose and evaluate a real-time smart harness system that neither requires manual surveillance nor manual recording of violations.
• Capture compliance deviation data to enable predictive analytics and targeted safety training.
• Provide an economical, scalable, and highly effective solution to achieve a "Zero Harm" workplace culture.
The scope of this study encompasses a practical implementation context, analyzing high-risk scenarios such as scaffolding erection, pipe-rack maintenance, and fragile roof tasks. By comparing traditional manual monitoring data with smart-sensor data, this paper will demonstrate the efficacy of IoT-enabled PPE in significantly reducing life-threatening risks.

1.5 Organization of the Paper:
The remainder of this paper is structured as follows: Section 2 reviews the current literature on conventional and smart fall-prevention technologies. Section 3 describes the system domain and environmental setup for the proposed solution. Section 4 details the methodology and technical architecture of the Smart Safety Harness. Section 5 discusses data collection, deviation recording, and analysis. Finally, Section 6 provides actionable recommendations, followed by concluding remarks on the future scope of wearable safety technology.

II. LITERATURE REVIEW

The integration of smart technologies, sensor-based devices, and artificial intelligence (AI) in Occupational Health and Safety (OSH and IS) has gained significant attention in recent years. This section critically reviews existing research categorized into industrial safety statistics, sensor and IMU-based wearable systems, computer vision monitoring, and broader AI frameworks for workplace safety.

2.1 Industrial Accident Trends and Regulatory Reporting:

Understanding accident patterns is essential for prioritizing safety interventions. Reports published by the Directorate of Industrial Safety & Health (DISH, 2020; DISH, 2021) for Gujarat state—submitted to the Directorate General of Factory Advice Service and Labour Institutes (DGFASLI)—provide critical empirical evidence on workplace hazards:

DISH (2020): Recorded 212 fatalities and 560 non-fatal injuries across manufacturing and chemical sectors. Fall from height was identified as the second leading cause of workplace casualties, contributing to 41 fatalities and 72 non-fatal accidents.

DISH (2021): Reflected an increasing trend with 235 fatalities and 621 non-fatal injuries. Fall-related incidents remained the second largest cause, accounting for 47 fatalities and 73 non-fatal accidents.

Critical Appraisal: While DISH/DGFASLI reports offer valuable macroscopic data, significant limitations exist. Reporting aligns with calendar years rather than financial years, creating discrepancies with corporate records. Furthermore, public data lacks granular lagging indicators—such as Lost Time Accidents (LTA), Medically Treated Cases (MTC), and First Aid Cases—and aggregates diverse hazards into broad categories, masking specific operational root causes.

2.2 Inertial Measurement Unit (IMU) and Sensor-Based Wearable Safety Systems:

Wearable sensor technologies have emerged as a promising approach for personal protective equipment (PPE) automation and fall prevention:

Awolusi (2017) evaluated various wearable sensing technologies—including RFID, Ultra-Wideband (UWB), Bluetooth, GPS, and smartwatches—for personalized construction safety monitoring. The study emphasized the potential of real-time biomechanical and environmental data capture.

Limitation: The study provided a broad overview without identifying specific, cost-effective wearable configurations tailored for elevated high-risk activities.

Tae Hyong Kim (2020) developed a pre-impact fall detection system using a waist-mounted single IMU sensor paired with a Bi-directional Long Short-Term Memory (Bi-LSTM) deep learning regression model. Tested across 24 volunteers, the system estimated impact acceleration magnitudes prior to ground collision.

Limitation: While theoretically sound, the model was tested in controlled environments. Real-world construction sites subject sensors to severe mechanical shocks, requiring specialized IP65-rated enclosures and continuous calibration.

Somareddy / Khan (2025) designed an IMU-based Smart Safety Hook utilizing an Arduino Nano 33 IoT board and calibrated accelerometer, gyroscope, and magnetometer sensors. Machine learning classification models processed kinematic data to trigger local alerts (LED/buzzer) if the hook remained unanchored.

Limitation: The tilt-angle threshold mechanism suffers from high false-positive rates during vertical movement (e.g., ascending/descending ladders). Environmental factors (dust, moisture, vibration) degrade accuracy, and the system lacks a centralized logging infrastructure for long-term violation trend analysis.

2.3 Computer Vision and Image Processing for Safety Monitoring:

Optical detection using AI models has gained traction for non-intrusive compliance tracking:

Guo (2018) explored computer vision applications to digitize traditional Safety Management System (SMS) elements. The research covered automated unsafe behavior detection, digital permit-to-work systems, and visual risk analytics.

Limitation: Converting complete operational workflows into computer vision models remains practically challenging. AI vision models cannot fully replace human emotional intelligence, contextual judgment, and physical intervention.
Khandelwal et al. (2020) implemented a multi-camera computer vision architecture across Aditya Birla Group facilities post-COVID-19. Utilizing CCTV streams and Network Video Recorders (NVR) connected to central deep learning servers, the system automated mask compliance, social distancing tracking, and thermal profiling with automated email alerts.
Limitation: The deployed system relied on single-task models without multi-use case integration, and lacked longitudinal trend analytics to measure long-term behavioral safety compliance.
Attar (2024) developed an automated workplace hazard monitoring pipeline using the YOLOv5 object detection algorithm paired with local microcontrollers and webcams to identify non-compliance (e.g., improper attire, oil spillage).
Limitation: Relying on fixed webcam infrastructure limits spatial coverage in dynamic work environments. Early-generation microcontroller integration introduced processing latency between detection and alert triggering.

2.4 Macro Perspectives on AI in Occupational Safety and Health:
Moore (2021) examined the broader impact of AI, robotics, and smart wearables on the future of work and OSH. The study highlighted how collaborative robots (COBOTs), virtual reality safety training, and interactive chatbots enhance hazard communication and reduce human error.
Limitation: The study primarily emphasized technological advantages while underestimating operational risks, such as worker privacy concerns, data intercept vulnerabilities, and over-reliance on automated systems.

2.5 Research Gap
A comparative synthesis of the existing literature highlights distinct technological trade-offs across current safety solutions:

Author(s) & Year	Core Technology	Primary Focus	Key Limitations / Research Gap
DISH (2020, 2021)	Empirical Statistics	State accident reporting	Lack of granular lagging data (LTA, MTC) and operational sub-categorization.
Awolusi (2017)	Survey of Wearables	Construction safety	General survey; lacks comparative hardware evaluation for height safety.
Guo (2018)	Computer Vision & SMS	Digitizing safety management	Highly theoretical; limited shop-floor feasibility for complex tasks.
Khandelwal (2020)	Computer Vision / NVR	COVID-19 & Mask detection	Fixed camera constraint; single-purpose algorithms without multi-hazard logging.
Kim (2020)	IMU + Bi-LSTM Model	Pre-impact fall detection	Sensitive to field noise; requires complex re-calibration on uneven surfaces.
Moore (2021)	AI & Smart Systems	OSH policy & Automation	Conceptual focus; lacks hardware implementation for specific physical hazards.
Attar (2024)	YOLOv5 + Arduino	Unsafe behavior vision models	High latency with legacy microcontrollers; restricted field of view.
Somareddy (2025)	IMU + Arduino 33 IoT	Smart Safety Hook	False alarms during ladder movement; lack of cloud logging for behavioral analytics.

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III. AREA OF STUDY

3.1 Organizational Context and Scope:

The study is situated within one of India's largest global infrastructure development organizations ("Company Construction"), renowned for executing mega-projects such as the Statue of Unity, Mumbai-Ahmedabad High-Speed Rail (MAHSR), Mumbai Trans Harbour Link, and various international airports and metro systems. The sheer scale and complexity of these projects—spanning bridges, highways, heavy civil infrastructure, and mining—present highly challenging and dynamic environments for working at height.

The organization operates under robust, internationally recognized frameworks, including the Process Safety Management System, Occupational Health and Safety Management System, and Environmental Management System. This organizational backdrop provides an ideal, high-risk industrial environment to study the efficacy of conventional fall protection measures versus advanced smart safety interventions.

3.2 Existing Fall Control Measures and Baseline Infrastructure:

To establish the baseline for this research, the existing safety protocols and physical infrastructures utilized for working at height were analyzed. The organization currently employs a comprehensive hierarchy of controls, categorized as follows:

A. Engineering Controls and Safe Access Environments:

Access and Egress: Provision of secure walkways, fixed platforms, and stairways with adequate lighting and slip-resistant surfaces to facilitate safe movement of personnel and equipment.

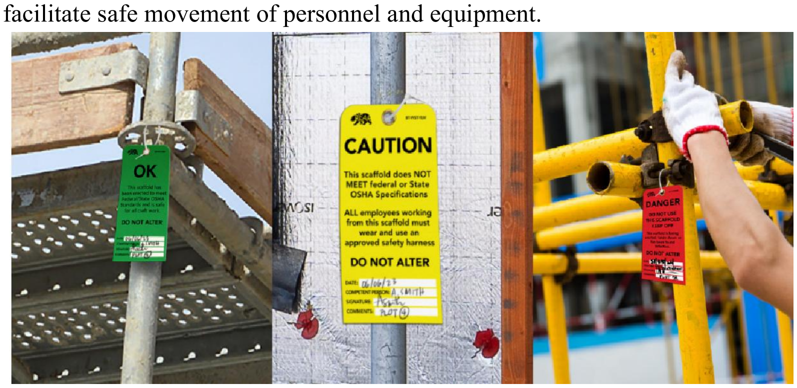

Figure 3.1 Scaffold Tag

Edge Protection and Guarding: Installation of perimeter guard-railing to mitigate risks at open sides, and MS (Mild Steel) grills or heavy-duty covers with warning signage to secure hazardous floor or lift openings.

Working Platforms: Scaffolding Systems: Extensive use of fixed and mobile (castor-wheeled) aluminum/steel scaffolds. These are strictly managed via a Red/Green tagging system, requiring inspection by a competent person every 7 days or after any structural alteration.

Mobile Elevated Work Platforms (MEWPs): Use of battery-powered or combustion-engine scissor lifts and boom lifts, operated under strict wind-speed and load-limit guidelines.

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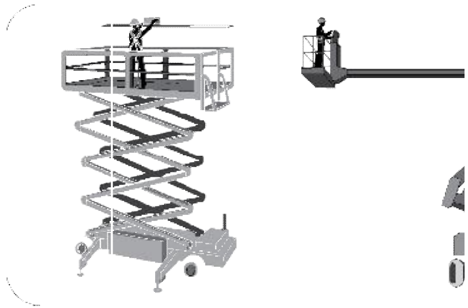

Figure 3.2 Mobile Elevated Work Platform

Ladders: Standardized use of step platforms and ladders angled at 75 degrees, restricted to a maximum vertical height of 9 meters between landings, ensuring three-point contact.

B. Fall Prevention and Arrest Systems:

Where engineering controls cannot completely eliminate the risk of a fall, active Fall Protection Systems are deployed:
Industrial Rope Access and Lifelines: Implementation of permanent and temporary Vertical Lifelines (VLL) and Horizontal Lifelines (15.9 mm polyester, capable of 22kN support) to allow secure, sliding-type fall arrest mechanisms for workers traversing high elevations.

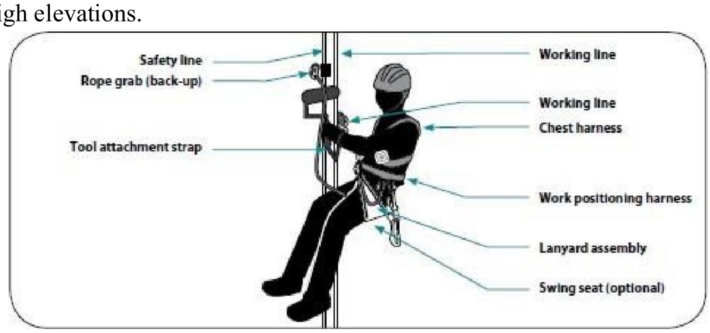

Figure 3.3 Individual Fall Protection System

Individual Fall Arrest Systems (Conventional PPE): The primary line of defense is the conventional Full-Body Safety Harness equipped with a double lanyard and in-line shock absorbers. Workers are instructed to anchor their harnesses to fixed points capable of withstanding at least 22.2kN of force.

C. Administrative and Health Controls:

Medical Fitness: Mandatory medical evaluations, including vertigo tests, to ensure workers are physically capable of performing tasks at elevation.
Fragile Roof Protocols: Specialized standard operating procedures for working on brittle surfaces (e.g., fiberglass, cellulose cement). This includes the use of crawl boards, mandatory buddy systems, continuous supervision, and the provision of immediate rescue equipment.

IV. PROBLEM IDENTIFICATION

Working at height is one of the leading causes of serious injuries and fatalities in the construction industry worldwide, including in India. Despite the existence of safety regulations and guidelines, a large number of accidents continue to occur due to various organizational, technical, and human factors.

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1. High Fatality and Injury Rates
Falls from height account for a significant proportion of occupational deaths in construction. According to reports by the Directorate General Factory Advice Service and Labour Institutes (DGFASLI), fall-related incidents consistently rank among the top causes of construction site fatalities in India.

2. Inadequate Use of Personal Protective Equipment (PPE)
Although PPE like harnesses, helmets, and guardrails are mandatory, compliance is often low due to discomfort, lack of training, or negligence. Many workers are either unaware of proper PPE usage or do not prioritize safety over productivity.

3. Poor Planning and Risk Assessment
Many construction projects lack detailed risk assessments specific to working at heights. The absence of methodical hazard identification and mitigation strategies increases the likelihood of accidents during activities like scaffolding, ladder use, roof work, and steel erection.

4. Insufficient Training and Competency
A large portion of the construction workforce in India is unskilled or semi-skilled. They often do not receive proper training in safe work practices for elevated tasks. In some cases, workers are not even briefed about the hazards involved before starting the job.

5. Unsafe Working Conditions
Factors such as unstable or incomplete scaffolding, lack of edge protection, inadequate fall arrest systems, and unguarded openings create inherently unsafe working environments. In many cases, cost-cutting measures compromise the installation of safety systems.

6. Weak Enforcement of Safety Regulations
Even though regulations like the Building and Other Construction Workers (BOCW) Act and IS codes are in place, enforcement at project sites is often lax. Inspections are infrequent, and penalties for violations are minimal or inconsistently applied.

7. Management Commitment and Safety Culture
There is often a lack of genuine commitment from top management towards creating a strong safety culture. Safety is frequently seen as a regulatory burden rather than an operational priority, leading to underinvestment in training and safety infrastructure.

8. Communication Gaps and Language Barriers
On large sites with workers from diverse regions, poor communication and language differences can prevent the effective delivery of safety instructions and hazard warnings.

V. SOLUTION DOMAIN

The following outcomes shall be addressed from this study.

a) Real time smart solution for working at height which will give the significant contribution to prevent fall injuries while working at height.

b) Real time deviation will help us to collect the deviation data.

c) The number of data, including minor and major both shall be logged into the system and will help to do the data analytics to take it forward decision.

d) Very economical solution to save life while working at height.

e) This will help any organization to bring down accidents related to fall only.

f) If any single injury is prevented with the help of this smart solution, then morale of employee and contract workers will be high and there will be positive safety culture shall be inculcating.

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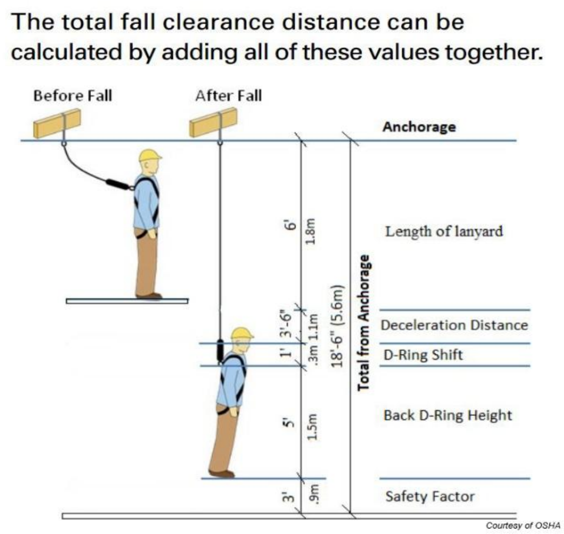

Figure 4.1 Edge Protection Calculation

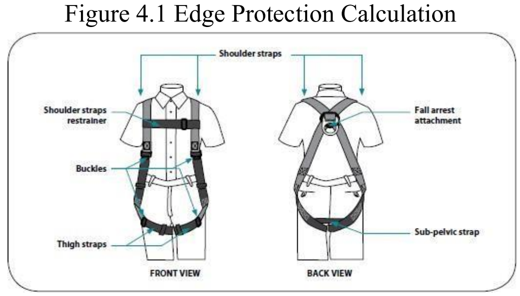

Figure 4.2 Full Body Safety Harness

g) This is a small sample project, based on the multiple use case, it will be easily expandable and under the one roof the number of activities can be monitored, and control measures can be taken accordingly.

h) This will help us to create benchmarks where a few companies adopt and take innovative solution to enhance their safety performance.

i) This will be revolutionary changes in in working at height solution where it was

VI. METHODOLOGY

In India anchoring of safety harness with anchoring point is being monitored through manually either deputing safety supervisor at workplace or walk the talk by the senior leadership team. Most of the industries are struggling for basic personal protective equipment compliance on their shop floor. Selection of advanced fall protection system while working at height involves many steps and required many inputs from engineering team and safety team and information technology team. The objective of this study is to provide the best solution for preventing fall injury from height. Working at height solution should be communicated to each contract worker those who engaged in working at height activity. Following below key steps have been involved for selection of advance fall protection system.

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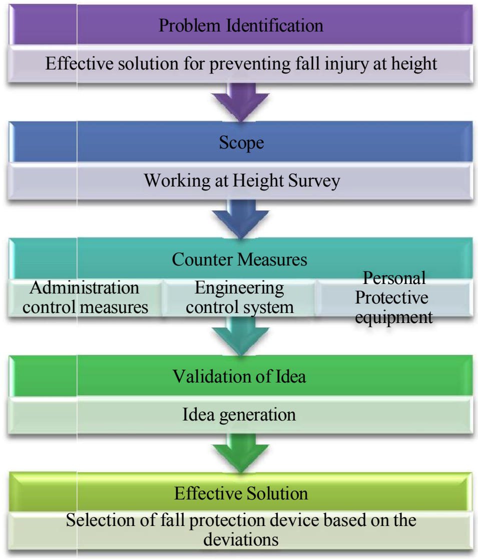

Figure 5.1: Flow of Selection of Smart Harness

Step No 1 Identification Problem:

The first step is to identify the problem. In working at height 3P principle works called 3 points contact. At least 3 points of contact must be there while working at height. Either 2 legs and one hand or one leg and two hands must be engaged while working at height. This is the thumb rule while working at height whereas there are 3 basic requirements which should be standardized across the industry. The first one is access to height. Access to height means how access to working ate height either using of ladder, movable platform, and platform with railing, monkey ladder, roper ladder or other means of access.

Step No-2 Scope of Work:

The second step is to conduct a survey in the plant and identify how many places where potential fall hazard can occur. Like process area where there is chances of fall hazard, roof sheeting activity. These activities either may be routine or non-routine activity. For routine activity in industry there is standard operating procedure is governed and accordingly work is carried out for example operating of process isolation valve at height so there is standard fixed mobile platform having toe guard, mid rail and top rail provision by which worker can work easily. The second one is the non-routine activity where a working at height permit is enforced to get the job done safely. So it is very important that the list out the area where there is possibility of fall while routine and non-routine job.

Step No-3 Control Measures:

The third step is to identify the counter measure. There are multiple counter measures that can be adopted while working at height. However, it has been classified into three categories.

- Engineering control measures
- Administrative control measures
- Personal Protective equipment.

Engineering control measures- In engineering control measures there are lot of innovation and best practices have been adopted by the industry while working at height which totally eliminate the working at height risk example Thickness monitoring by using Drone Technology, painting through Drone technology, Scraping and NDT testing by using robotic solution crawler type robot, working at height using boom lifter and advance lifting mechanism. This advanced

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technology will not only reduce the time, cost, manpower but will bring down the high risk into medium and low risk category and having reliable system if it gets failed and there is not life-threatening risk to employee and contract worker so this type of technology will help to further strengthening of working at height control measures in terms of engineering controls.

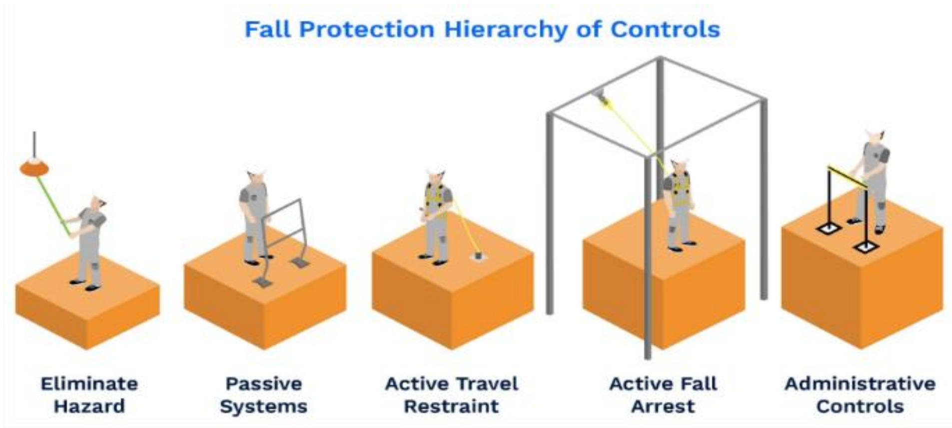

Figure 5.2: Fall protection control

Administrative Control measures- There are various administrative control measures used at industry for preventing fall injuries while working at height. All the administrative control measures are governed through the standard operating procedure for routine and non-routine activity.

- Work permit system
- Method statement
- Risk Analysis
- Training and toolbox talk
- Inspection of Lifting tool and tackles
- Vertigo test for height work
- Skill matrix for workers
- Safety display
- Deputation of supervisor.
- Monitoring through the camera or manual surveillance system etc.

Personal Protective Equipment- In working at height PPE is mandatory like safety helmet, safety shoes, safety goggle, safety hand gloves and most important double lanyard full body safety harness. FBSH is the most essential lift saving equipment by which the fall can be prevented. However, it is dependent upon the worker if he forgets to connect eh lanyard with the anchoring point which may be life-threating risk to workers. That needs to be ensured by deputing a safety supervisor or manager to comply with the PPE requirements. Apart from PPE, rescue equipment is also considered if fall occurs, and worker is hanging with the anchoring points. He must be rescued as soon as possible by using appropriate rescue equipment or method. If a person is hanging with the safety harness, he may be suffered with trauma suspension due to restriction of blood in his lower body part which again may be life-threatening risk to works so that's why rescue equipment must be considered while working at height.

Step No-4 Validation of Idea:

In above steps 1,2 &3 enable us to identify the problem and area where there is fall hazard and assess the risk and control measures in terms of engineering, administrative and personal protective equipment. Now step no. 4 enables us to select the effective fall protection system to prevent the fall injuries. For that all the control measures need to be validated whether they are reliable and having redundancy. In all the control measures need, be evaluated that if one

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layer of protection is failed then another layer of protection will overcome the situation or not. Identify the weakest control measures which is totally depending on the human behavior, knowledge, skill and try to fix it by adopting new technology or innovative solutions. There were multiple ideas that will be generated out of that the most reliable, trusted, authentication idea will be selected as advance fall protection system to prevent fall injuries while working at height.

Step No-5 Effective Solution:

After selection of Idea advance fall protection system, deviations shall be analyzed based on the basic trend. Earlier the working at height deviations were noticed either contractor supervisor or safety officer after that all the deviation were record into the system and the corrective action was taken based on the root cause like training need analysis, training effectiveness, skill development etc. Similar practice shall be followed for the advanced fall protection system and deviation will be logged in the system. Both the deviations will be analyzed, and comparison shall be made initially those have more deviations there will be more area of opportunity to work and again corrective action shall be taken accordingly.

VII. ANALYSIS AND DISCUSSION

For selection of IOT based smart solution for working at height for preventing fall injuries at height following below steps has been adopted.

Step No-1-Identification of Problem:

The plant has many working at height applications where every day working at height permits are obtained by the engineering team. This working at height job is safely executed by implementing robust administrative control like working at height permit system, Job safety analysis, Vertigo test while working at height. Toolbox talk, safety inspection for safety harness, PPE compliance, Training and other control measures based on applications.

The following majority of tasks are generally required for working at height and observed risk category.

Sr. No.	Task	Height of the Job	Risk Category
1	Roof Sheet Fixing Job	30 Mtr.	High Risk
2	Preventive Maintenance for Chimney or Stack	30 Mtr.	High Risk
3	Scaffold erection work for civil work for manufacturing building	30 Mtr.	High Risk
4	Lightening arrestor installation job	30 Mtr.	High Risk
5	Pipeline erection job	20 Mtr.	High Risk
6	Painting Job	20 Mtr.	High Risk
7	Maintenance of Isolation valve and assembly	20 Mtr.	High Risk
8	Leakage attending job inside the plant	10 Mtr.	Medium Risk
9	Project execution job inside the plant	10 Mtr.	Medium Risk

Table 6.1: High Risk Area

Step No-2 Scope of Work:

The second step is to conduct a survey in the plant and identify how many places where potential fall hazard can occur. This data can be obtained from the record of the work permit system. How many high-risk permits have been issued and what are the control measures associated with that. The scope of work involves the area where height work shall be carried out and the number of past working at height deviations. Once all the deviations are captured in one place then based on highest number of deviation where worker deviated the PPE compliance that area will be the area of opportunity where smart solution for working at height can be explored. Please find below the tabulate form for step 2.

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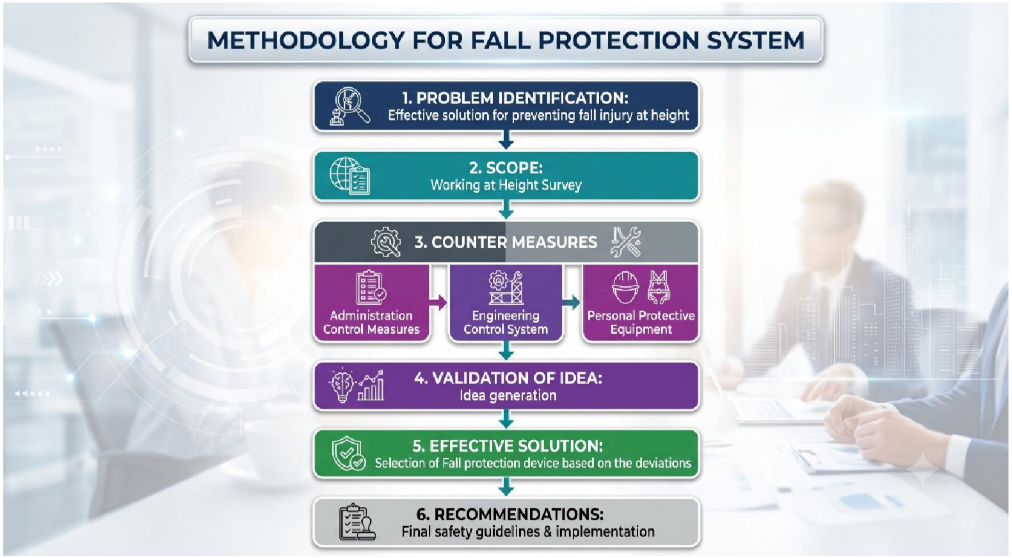

Figure 6.1: Methodology for Fall Protection System

Task	Height of the Job	Risk Category	Area	Number of Violation/ 2023-24
Roof Sheet Fixing Job	30 Mtr.	High Risk	Construction work- Process Area	45
Preventive Maintenance for Chimney or Stack	30 Mtr.	High Risk	Utility DG and Boiler	10
Scaffold erection work for civil work for manufacturing building	30 Mtr.	High Risk	Production- Process Area	5
Lightening arrestor installation job	30 Mtr.	High Risk	Admin Building	7
Pipeline erection job	20 Mtr.	High Risk	Process Area	15

Table 6.2: High Risk Area with Safety Violations

The Highest deviation or violations have been recorded while roof sheet fixing job where there is inadequate supervision was observed most of the time and majority of time supervisor won’t be able to supervise the worker’s activities whether he has anchored his safety harness with anchoring point or not.


Figure 6.2: Working on Rooftop

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Step No-3 Control Measures:

The third step is to identify the counter measure. There are multiple counter measures that can be adopted while working at height. The highest number of observations was observed while roof sheet fixing job at Manufacturing plant in process area. There were 45 nos. of PPE deviations were recorded where all the observations belonging to full body safety harness where worker did not connect the safety harness while roof sheet fixing activity. However, the following control measures were adopted while roof sheeting fixing job.

• Engineering control measures- Proper platform was provided while access to height apart from that safety net was provided to prevent the fall injuries. Generally, all the working at height is executed through the proper scaffold having access to height, toe board, mid rail and had rail and working platform which assure the working at job.

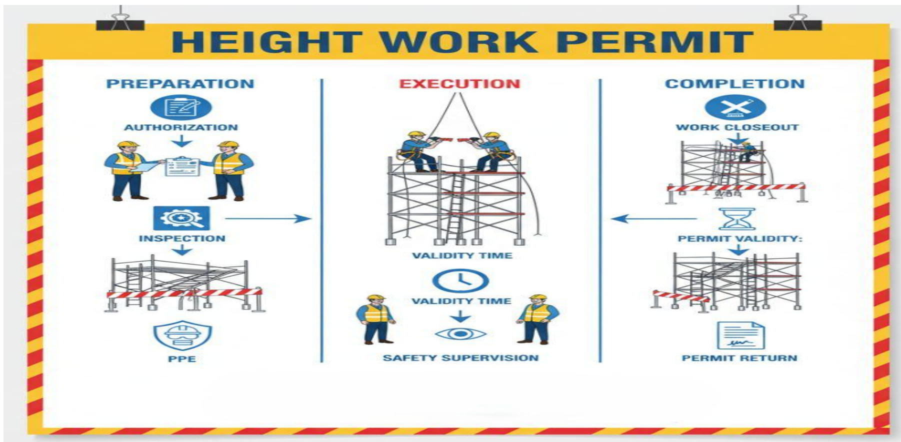

Figure 6.3 Height work permit

• Administrative control measures- Administrative control measures are the most important control measure while working at height. The following below list of administrative control measures is adopted while roof sheet fixing activity.

o Job Safety Analysis- for all the non-routine activity job safety analysis is done before carrying out the working at height job. It is very essential for preparing the working at height job.

o Working at Height Permit System- This is the second most important legal document which requires while working at height. The height permit is filled out by the issuer and executor department, and they fill all the details for the person who will be working at height. It is a legal document, and a copy of the permit must be displayed at the location while carrying out the job. The work permit is signed by the all the authorized person and safety personnel also.

o Tool Box Talk- Training is given before starting the height work job to all the contract workers who engaged in the working at height activity.

o Height Pass Test- Vertigo test is performed for all the contract workers for checking their fitness while working at height. All contract workers must be qualified to work at height pass the test. This is mandatory test for working at height.

o Safety Inspection- There are multiple inspections carried out like PPE inspection, Safety harness inspection, Work permit audit inspection etc.

o Personal Protective equipment. - For working at height there are specific personal protective equipment are used like.

- Safety Helmet
- Safety Shoes
- Safety Goggle
- Safety Hand Gloves
- Double Lanyard Full Body Safety Harness,

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Figure 6.4: PPE for Working at Height

Step No-4 Validation of Idea:

In above steps 1,2 &3 enable us to identify the problem and area where there is fall hazard and assess the risk and control measures in terms of engineering, administrative and personal protective equipment. Now step no. 4 enables us to select the effective fall protection system to prevent fall injuries. For that all the control measures need to be validated whether they are reliable and having redundancy. Based on the above problem working at height for of sheet fixing work is more challenging and has many deviations and having limited control measures and mainly depended upon the administrative control measures not engineering control measures. Please find below the risk matrix.

Table 4.3: High Risk Area with Safety Violations& Control Measures

Task	Height of the Job	Risk Category	Area	Number of Violation2023-24	Control Measures
Roof Sheet Fixing Job	30 Mtr.	High Risk	Construction work place Area	45	Administrative control measures

To overcome this problem IOT based safety harness has been introduced to prevent fall injury while working at height. This full body harness will bring a unique solution to avoid fall from height. If operator or worker who is working on the roof at 30-meter height missed to attached safety harness hook to anchoring point the alert will be released to the supervisor who is standing at ground floor. All the deviations shall be recorded in the system so that analyses can be done, and appropriate action can be taken accordingly. Please find below the process of smart safety harness system and its associated assembly.

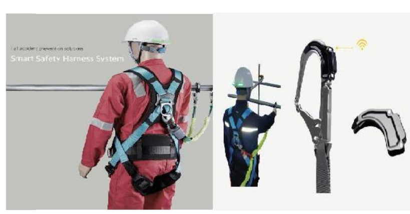

Figure 6.5: Smart Safety Harness

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Figure 6.6: Assembly of Smart Safety Harness

Smart Hook- This is the major and important component of smart safety harness system. It is totally based on an IMU based sensor built with hook assembly. This IMU Inertial Measurement Sensor 9- Axis is calibrated for accelerometer, gyroscope, and magnetometer readings. The data is acquired from the IMU sensor and sent through the BLE Bluetooth low energy sensor. Following below are the functions of smart hook assembly.

 Detection hook fastening- within 55 mm of scaffold pipe, 15 mm of lifeline rope.

 Switch to sleep mode when unused in 10 minutes.

 8 hours per day battery 3 V.

 Wireless frequency 2402-2840 MHz

 Light weight 30 gm

Operating Criteria for Smart Hook Assembly

 The hook sensor activated when an impact is applied or when the hook lever is operated for anchoring this time alert will be release

 When anchoring the hook, the front and rear angle of hook must be in the range of -10 to + 30 degree for hooking detection to work.

Figure 6.7: Images of Smart Hook

Data Collector – It is one type of data collector it can scan the smart safety harness within 100-meter radius and connect the RS422 and having BLE sensor Bluetooth low energy sensor. It can collect data up to 50 smart safety harness and also having LTE provision.

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Figure 6.8: Images of Smart Safety Harness Data Collector

Field Monitoring Device- It is one kind of table to monitor all the deviations. All the events are logged into this. It shows the deviations log user wise, location wise and safety harness tagging wise.

 Display number of workers having smart safety harness
 Display status of hook anchoring or not
 Battery Status will be shown.
 Communication status will also be displayed.
 Location of the area.

This field monitoring device is also available in the flame proof type enclosure because in the chemical industry all the electrical and instrument must be FLP type to avoid fire and explosion risk at site.

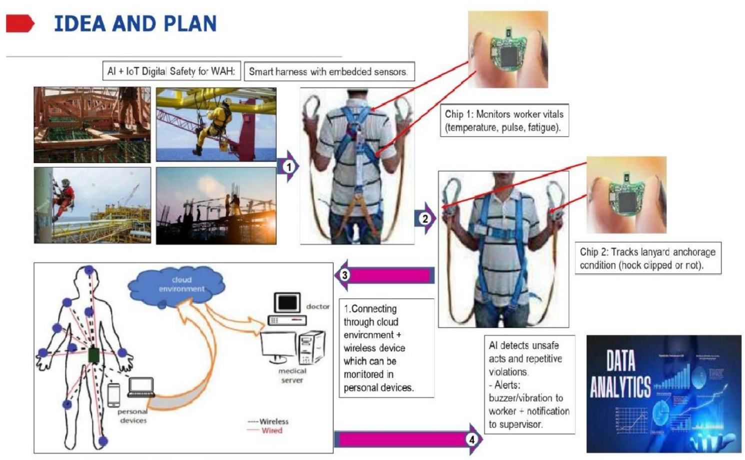

Figure 6.9: Images of Smart Safety Harness Field Monitoring Device

Audio/ Visual Alarm- This will be utilized if any deviation is recorded, if will give the alarm and will be blinking during the night shift if any deviation is observed this will be helpful for work and supervisor to acknowledge the deviations. This audio and visual device is also available in the flame proof type enclosure because in chemical industry all the electrical and instrument must be FLP type to avoid fire and explosion risk at site.

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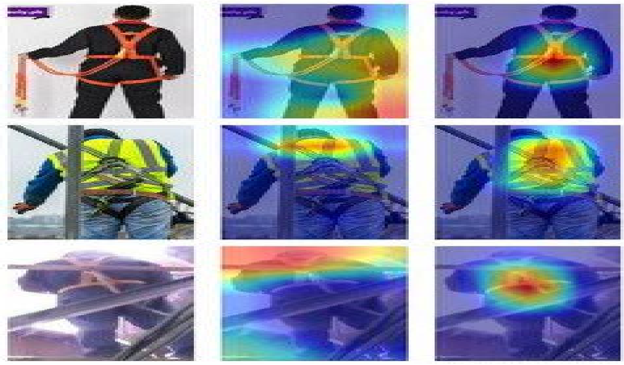

Figure 6.10: Images of Smart Safety Harness Audio Visual Device

Step No.-5 Effective Solution:

After implementing this smart solution at work place it is important to have analyze the data, based on accuracy it will be decide whether it can be used for further application or not. For that is very important how the data is communicated from one device to another, if is there any communication breech then what will be the consequence associated with that. The IMU sensor is provided in the hook assembly. The data is acquired from the IMU sensor and sent through the BLE Bluetooth low energy sensor to the data collector. Data collector collects all the data and transfers all the data through BLE to Field monitoring device. It is a total cloud-based data storage facility which collects all the data and archives the same. All the deviations are logged into the system and a data analytics facility is also available where the area is seeking attention to avoid accidents based on the numbers of serious deviations. This filed monitoring device can be replaced with a smart phone or laptop to record all the deviations. Initially the more deviations are recorded the more attention will be given to addressing the same.

VIII. RESULT

Based on the above assessment the following result has been derived to conclude the best solution to prevent fall injuries. Below following table and graph has been extracted from the smart safety harness modules in which the number of violations and deviations were found significantly higher. The more numbers of deviation or violations shall be observed, the more opportunity to address the same. Initially the data trend will be increased and after a few years an exact result will be shown in the form of advantage

Task	Number of Violation/ Deviation (Nos.) 2024-25 with Simple Safety Harness	Number of Violation/ Deviation (Nos.) 2024-25 with Smart Safety Harness
Roof Sheet Fixing Job working at height	45	62
Preventive Maintenance	10	15
Scaffold erection work for civil work for manufacturing building	5	10
Lightening arrestor installation job	7	12
Pipeline erection job	15	23
Painting Job	12	14
Maintenance of Isolation	6	7
Leakage attending job inside the plant	27	41
Project execution job inside the plant	16	21

Table 7.1; Result Based on the Deviations

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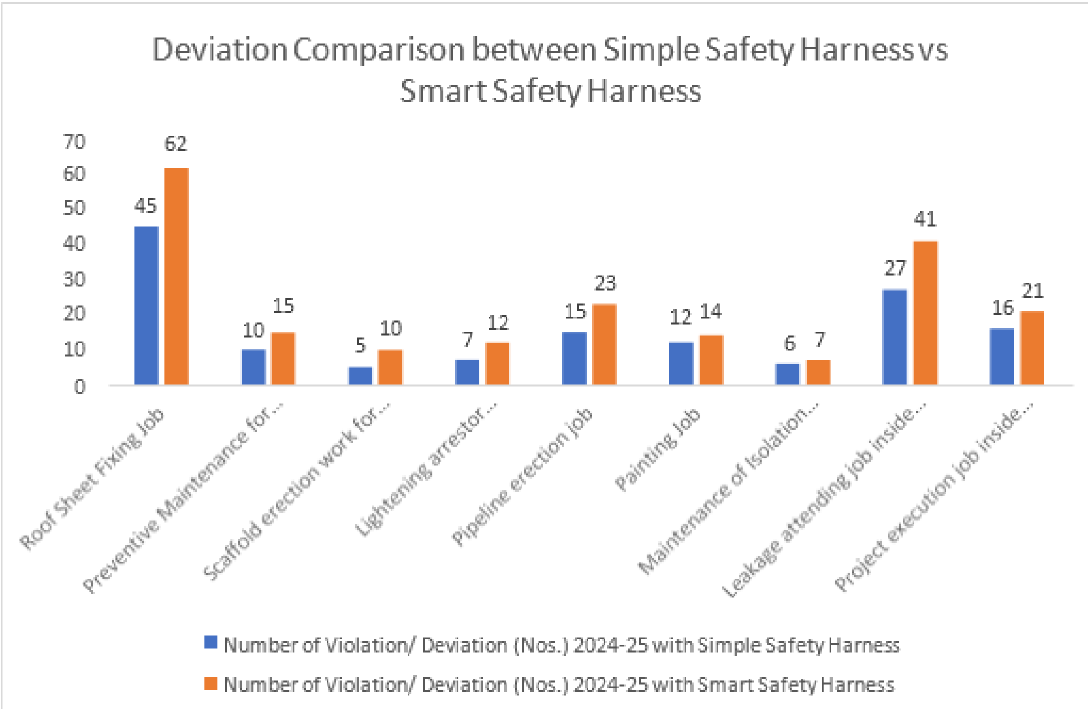

Figure 7.1; Deviation Comparison between Simple and Smart Harness

	Task Activity	Number of Violation/ Deviation (Nos.) 2024-25 with Smart Safety Harness
1.	During Ascending and Descending of Ladder	81
2.	During Task Change Over	34
3.	During Fixing of Lifeline	26
4.	During Preparatory Work	32
5.	During Scaffold Erection	32

Table 7.2; Task based Violation Analysis

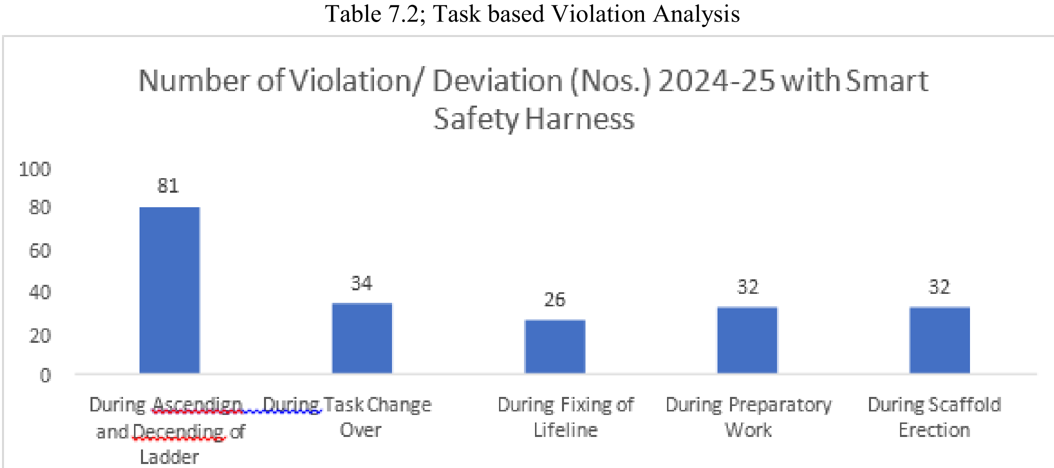

Figure 7.2; Task Based Violation Analysis

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Sr. No.	Year	Near Miss Pertaining to Working at Height
1.	2021-22	16
2.	2022-23	15
3.	2023-24	12
4.	2024-25	1

Table 7.3; Near Miss Record on Yearly Basis

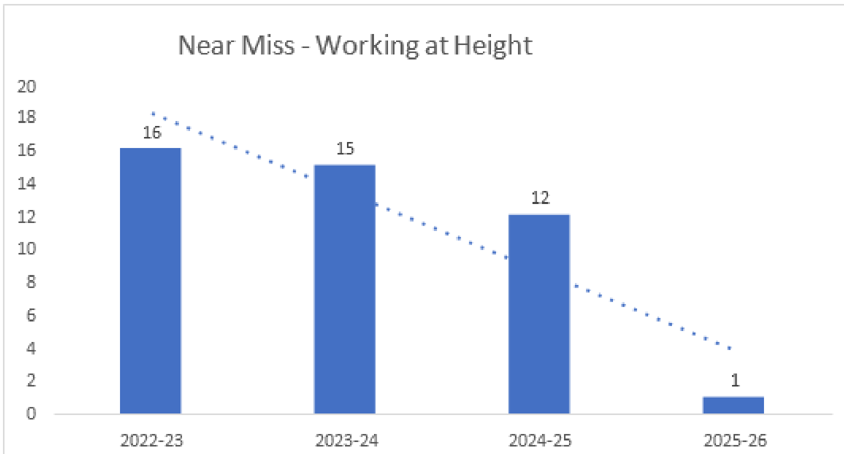

Figure 7.3; Near Miss Record on Yearly Basis

IX. CONCLUSION

In this research study it has been concluded that the Machine to machine M2M based smart solution called smart safety harness is very effective for fall injuries while working at height. It gives real time violation/ deviation by which contract worker will enable to know their mistake and reconnect his safety harness with the anchoring point. This is a full proof or error proof solution in workplace safety which will not only improve the safety performance of the company. It will improve the productivity and morale of the employees and contract employees. The conventional monitoring system in which the contract supervisor or safety personnel were used to stand to supervise the high-risk job whether contract worker is complying with the personal protective equipment (Anchoring of safety harness) if it deviates the supervisor counselling them to strict adherence with PPE while working at height. Sometimes supervise or contract workers ignore the safety regulation which can lead to sever health injury or sometime 100% surveillance was very difficult task or most of the time Height work activities used to carry out on roof where there is no adequate solution however now there are many technologies are available like Drone surveillance, Fixed camera surveillance but it has not yet improved to detect safety harness anchoring compliances. The program needs to be configured on the latest technology however they are not much cost effective as compared to smart safety harness. This smart harness can be used by any contract workers and anywhere it can be used even including remote location also. In the result section it has been found that the near miss pertaining to safety harness has dropped drastically which can contribute to save the life while working at height.

X. FUTURE SCOPE

In this research machine to Machine M2M based smart solution has been introduced which gives the alert and warning if contract worker misses to connect the safety harness while working at height. It is very unique solution which will bring revolutionary changes to personal protective equipment. There are much research being done on smart PPE across the world but the best solution yet to come. The audio-visual alarm trigger or remind the human being to recall their act however at some time contract worker is engrossed too much which he forgets to listen or watch the warning signal or during emergency it is very difficult to complying the PPE requirement at that time violation occurred which could lead to accident or injury. Audio-visual signal plays a critical role when it comes to very close call, but effective engineering solution can bring the unique solution, even after the audio-visual alarm if fall occurs the person will not be harming the same principle which work in the car where immediately air bags activated when car met with an accident and save the life. There are many solutions and upgrades yet to be done for the upcoming edition to enhance safety while working at height. This dissertation can be extended if other additional engineering control measures are collaborated like secondary fall protection system. If one fails, the secondary fall protection system can overcome the near miss situation to avoid injury at workplace.

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