STUDY OF NEAR MISSES AND INDUSTRIAL ACCIDENTS TO IDENTIFY HAZARDS AND UPGRADE ACCIDENT PREVENTION PROGRAM

A thesis is submitted to the
UPES

For the Award of

Doctor of Philosophy

In

Engineering

By

N. N. Pisharody

November 2023

SUPERVISORS

Dr. Kanchan D. Bahukhandi
Dr. Prashant S. Rawat
Dr. R. K. Elangovan

Department of Health, Safety & Environment
School of Engineering
UPES, Dehradun – 248007: Uttarakhand

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N. N. Pisharody
(SAP ID 500041514)

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Supervisor

Dr. Kanchan D. Bahukhandi
Professor, Department of Health, Safety & Environment
School of Engineering, UPES

Co-Supervisor

Dr. Prashant S. Rawat
Professor, Department of Applied Science
School of Engineering, UPES

External Supervisor

Dr. R. K. Elangovan
Sion, Mumbai, Maharashtra

Department of Health, Safety & Environment, School of Engineering
UPES, Dehradun – 248007: Uttarakhand

November 2023

DECLARATION

I declare that the thesis entitled **"Study of Near Misses and Industrial Accidents to Identify Hazards and Upgrade Accident Prevention Program"** has been prepared by me under the guidance of **Dr. Kanchan D. Bahukhandi**, Professor of Department of Health, Safety & Environment, School of Engineering, University of Petroleum and Energy Studies, **Dr. Prashant S. Rawat,** Professor of Department of Applied Science, School of Engineering, University of Petroleum and Energy Studies and **Dr. R. K. Elangovan**, Sion, Mumbai. No part of this thesis has formed the basis for the award of any degree or fellowship previously.

NNB

N. N. Pisharody
Industrial & Fire Safety Group
Directorate of Health, Safety & Environment
Nuclear Power Corporation of India Limited,
Anushaktinagar, Mumbai, 400094.
Date: November 03, 2023

CERTIFICATE

(Internal Supervisors)

I certify that **N. N. Pisharody** has prepared his thesis entitled **"Study of Near Misses and Industrial Accidents to Identify Hazards and Upgrade Accident Prevention Program"**, for the award of the Ph.D. degree of the University of Petroleum & Energy Studies, under our guidance. He has carried out the work at the **Department of Health, Safety & Environment, School of Engineering,** University of Petroleum & Energy Studies.

Internal Supervisors

02/11/2023

Dr. Kanchan D. Bahukhandi
Supervisor
Professor
Department of Health, Safety & Environment
School of Engineering
University of Petroleum and Energy Studies
Dehradun – 248007: Uttarakhand
Date: November 03, 2023

Dr. Prashant S. Rawat
Co-Supervisor
Professor
Department of Applied Science
School of Engineering
University of Petroleum and Energy Studies
Dehradun – 248007: Uttarakhand
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External Supervisor

Dr. R. K. Elangovan
Sion, Mumbai, Maharashtra, 400 022
Date: November 03, 2023

ABSTRACT

Accidents are unexpected events resulting in unwanted or undesirable outcomes. Unwanted outcomes include injury to personnel or loss of property or production or all. All accidents need not cause injury and loss. Depending upon the consequences, accidents are classified as Near Misses, First-Aid Injuries, Non-Reportable Injuries, Reportable Injuries, and Fatalities. Near misses, First-Aid Injuries, and Non-Reportable Injuries are accidents of High Frequency and Low Severity (HFLS); whereas reportable injuries and fatalities are accidents of Low Frequency and High Severity (LFHS) (Pisharody et al., 2018a-b [91], [92]). HFLS accidents being precursors and warning signals for LFHS accidents and the occurrence of HFLS accidents being more than LFHS accidents, identification and correction of causes of HFLS accidents give more opportunity for prevention of LFHS accidents. If HFLS accidents are monitored and kept under control by preventive and corrective measures; HFLS accidents may not escalate to LFHS accidents. However, due to shortfalls in identification and addressing the causes of HFLS accidents, there could be LFHS accidents. Therefore, it is imperative that both HFLS and LFHS accidents are investigated to identify causes, and those causes should be corrected to prevent accidents.

Organizational safety perception plays a significant role in accident prevention and control. A safety perception survey will facilitate understanding of the overall safety culture prevailing in the organization. Corrective actions on weak attributes of safety culture will support accident prevention and control (Pisharody et al., 2021[93]).

Our research is aimed at the identification of causes and contributors of accidents and hence to upgrade accident prevention programs in a prominent Public Sector Power Company in India. The Public Sector Power Company is involved in the design, construction, commissioning, and operation of Power Plants in India

(Pisharody et al., 2018a [91]). The company has a well-established organizational set-up to implement Industrial Safety requirements as per applicable statutes and regulations. The company has a system for reporting and correction of Safety Related Deficiencies (SRDs) through the Safety Related Deficiency Management System (SRDMS). The company also has an Accident Reporting System for accident reporting, investigation, and rectification of causes of accidents. Even though all accidents are analyzed and corrective measures are taken, accidents are recurring in the company. This implies that the present methods for accident prevention and control through identification and rectification of hazards in the work environment through SRDMS and correction of causes of accidents through the Accident Reporting System in the company are not effective enough to prevent accidents. Therefore, **there is a need to further reinforce accident preventive measures in the company by determining and correcting causes and contributors of accidents to upgrade accident prevention program through alternative methods. Accident prediction models are presently being considered to be at the forefront of such alternative methods.**

With this perspective, we have carried out a study on all near misses and industrial accidents in the Public Sector Power Company at its 11-twin unit Operating Station and 3-twin unit Construction Project sites during the period of 10 years from 2006 to 2015. There were 2066 HFLS accidents comprising 1539 Near Misses, 366 First-Aid Injuries, 161 Non-Reportable Injuries, and 113 LFHS accidents comprising 95 Reportable Injuries and 18 Fatalities in the company during this period (Pisharody et al., 2018a [91]). All HFLS and LFHS accidents were studied in the present work according to 'Agencies', 'Types of Accidents', and 'Locations of Injuries' as prescribed by the Indian Standard IS-3786-2022 on 'Method for the Computation of Frequency and Severity Rates for Industrial Injuries and Classification of Industrial Accidents' (IS-3786, 2022 [13]). All HFLS accidents were analyzed to identify significant 'Agencies', 'Types of Accidents', and 'Locations of Injuries' contributed to HFLS accidents. This though being quite detailed, **the prime**

achievements of the present doctoral work are the development of accident prediction models on LFHS accidents and analysis of LFHS accidents to identify significant contributors to the accidents.

Accident prediction models are chosen based on the nature of the data, prediction accuracy, required output information, speed of processing, and resource availability. Depending on the data, each approach has its own restrictions. Our literature survey revealed that even though extensive literature is available for accident prediction models on road accidents, crash models, and chemical accidents, literature on accident prediction models on conventional industrial accidents is very sparse. We have studied the suitability of generally used methodologies of Artificial Neural Networks, Bayesian Regression, and Multiple Linear Regression for the development of accident prediction models. Study indicates that models based on Artificial Neural Networks (ANN) and Bayesian Regression when compared with models based on Multiple Linear Regression, are computationally more intensive and take more time to process and derive inference. In addition, tools and aids to develop models based on Artificial Neural Networks (ANN) and Bayesian Regression are not easily available in many common scientific libraries, whereas tools for the development of models based on Multiple Linear Regression are easily available (Christina Ellis, 2022 [30] [31] [32]; Ioannis et al., 2022[61]. The data analysis tool package for Multiple Linear Regression is a standard feature of Microsoft Excel available in all computers with MS Office. Therefore, considering the simplicity, reasonable predictability and easy availability, Multiple Linear Regression is considered in our study for developing accident prediction models.

Taking cognizance of the above, **all LFHS accidents were analyzed and accident prediction models on 'Agencies' caused accidents, 'Types of Accidents' and 'Locations of Injuries' due to accidents were developed using Multiple Linear Regression Analysis and Analysis of Variance (ANOVA). The prediction capabilities of the models were found to be satisfactory. Validation of the models was carried out with independent data for the year 2018 (**Pisharody et al., 2022 [94]).

Besides these, **a Safety Perception Survey on Accident Prevention & Control was also conducted under the present work among the employees comprising of managers, engineers, officers, supervisors, and laborers of the Public Sector Power Company to identify significant organizational contributors to the accidents.**

All of the above-mentioned segments of the present doctoral study have helped to identify accident prevention and control measures that would upgrade the accident prevention and control program in the Public Sector Power Company. **Effective implementation of the corrective measures on significant contributors to accidents will prevent accidents and upgrade the accident prevention program in the company.** In addition, a focused attention to address weak attributes of safety culture will also support its accident prevention program.

Accident preventive and control measures are implemented as per the hierarchy of hazard control i.e. Elimination, Substitution, Engineering Controls, Administrative Controls, and Personal Protective Equipment (Pisharody et al., 2018a-b [91] [92]). The upper tier measures of Elimination, Substitution, and Engineering Controls are applied in the design by 'Safety through Design'. However, implementation of workers' safety during the design phase has certain limitations as the individuals involved in the accidents have unique personal characteristics and culture; and everything cannot be anticipated as accidents may happen on conditions unforeseen during the design phase. Therefore, in an effective accident prevention and control program, 'Safety through Design' should be supplemented by 'Administrative Controls' and 'Personal Protective Equipment'. Accordingly, **measures for prevention and control of accidents by 'Safety through Design', 'Administrative Controls', and 'Personal Protective Equipment' are recommended in this research work to upgrade accident prevention and control program in the Public Sector Power Company (**National Safety Council, 2001a-b [81] [82]; Pisharody et al., 2022 [94]).

A lot of scope remains for future research on accident prediction models in conventional industries. It is proposed that in future an exhaustive study may be carried out with more data and validation of predictive models be carried out with independent data from some other similar industry. It is recommended that accident data be compared with accident data of peer industry. Also, periodic benchmarking of accident data may be carried out with domestic and international data of comparable industries. HFLS accidents being precursors and warning signs for LFHS accidents, a correlation analysis of HFLS and LFHS accident data is also proposed for future works to derive a credible relationship between these types of accidents. Accident prediction models are developed using Artificial Neural Networks (ANN), and the Bayesian Regression approach also. It is suggested that future research can include the development of accident prediction models using Artificial Neural Networks (ANN) and Bayesian Regression analysis.

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CHAPTER-1

INTRODUCTION

1.1 PREAMBLE

Accidents are unanticipated events that have undesirable consequences. Personnel injury, property loss, and productivity loss are the undesirable outcomes of accidents. Injury and property loss increase an organization's operating costs by increasing production costs, increasing compensation payments, decreasing efficiency, lowering employee morale, and generating negative public perception (U.S. Department of Energy, 2012 [115]; Pisharody et al., 2018a-b [91] [92]). Any accident that causes injury or illness to an employee in the course of employment or under circumstances originating from employment or when the employee is attempting to protect or save property or human life is considered an occupational accident. "Circumstances originating from employment" include time spent at work or in work-related locations, commuting from home to work or vice versa, and attending to business or employer elsewhere (Noora Nenonen, 2013 [84]). Accidents at the workplace can be caused by a lack of information or training, lack of supervision, or lack of necessary equipment to perform the activity properly, or they can be caused by a lapse in judgment, carelessness, apathy, or outright recklessness (Sawacha et al., 1999 [103]). A biological lesion induced by acute overexposure to energy interacting with the body in amounts or rates that exceed the physiological tolerance threshold; is referred to as injury (Khanzode et al., 2012 [67]). Accidents do not always result in injury and loss. Accidents are classified as Near Misses, First-Aid Injuries, Non-Reportable Injuries, Reportable Injuries, and Fatality according to their outcomes (GOI, 1987 [42], Jones et al., 1999 [65]; Pisharody et al., 2018a-b [91] [92]).

Near Misses, First-Aid Injuries, and Non-Reportable Injuries, by their nature and rate of occurrence, are accidents of High Frequency and Low Severity (HFLS); whereas Reportable Injuries and Fatalities, by similar account, are accidents of Low Frequency and High Severity (LFHS) (Khanzode et al., 2012 [67]). The frequency and severity of accidents are estimated in terms of the number of accidents and man-days loss per million man-hours respectively (IS-3786, 2022 [13]). HFLS Accident is an accident that occurs at a frequency of more than 1 per year per Station or Project; but with a low severity, in which there is no injury attributed to the accident or the accident victim returns back to the workplace within 48 hours of the event. LFHS Accident is an accident that occurs at a low frequency of less than or equal to 1 per year per Station or Project; but with a high severity, in which there is a fatality or the accident victim returns back to the workplace only after 48 hours of the event (Heinrich et al., 1980 [46]; Jones et al., 1999 [65]; Khanzode et al., 2012 [67]; Pisharody et al., 2018b [92]).

In order to implement an effective accident prevention and control program, all accidents need to be investigated to identify significant contributors, and corrective measures need to be taken to prevent their recurrence. The Indian Standard IS-3786 on 'Method for the Computation of Frequency and Severity Rates for Industrial Injuries and Classification of Industrial Accidents' is one of the tools to identify causal factors of accidents. It gives the following 7 principal factors related to the causation of accidents:

B-1 Agency

B-2 Unsafe Mechanical or Physical Condition

B-3 Unsafe Act

B-4 Unsafe Personal Factor

B-5 Type of Accident

B-6 Nature of Injury

B-7 Location of Injury

The present doctoral research principally develops, and thus illustrates, a way to develop accident prediction models using Multiple Linear Regression Analysis and ANOVA of LFHS accidents on 'Agency', 'Type of Accident', and 'Location of Injury'. HFLS accidents being precursors and warning signals for LFHS accidents, **the research also looks into an analysis of HFLS accidents based on 'Agency', 'Type of**

Accident', and 'Location of Injury'. Since organizational safety perception plays a significant role in accident prevention and control, **a safety perception survey on Industrial Accident Prevention and Control among the employees comprising of managers, engineers, officers, supervisors, and laborers has also been conducted and analyzed as part of the research**; to understand the overall safety culture prevailing in the company for accident prevention and control, and to take corrective actions.

In the present research work, an analysis of 2179 accidents comprising 1539 Near Misses, 366 First-Aid Injuries, 161 Non-Reportable Injuries, 95 Reportable Injuries, and 18 Fatalities; occurred at 11 twin-unit Operating Plant and 3 twin-unit Construction Project sites in a Public Sector Power Company in India during the period of 10 years from 2006 to 2015; has been carried out based on 'Agency', 'Type of Accident' and 'Location of Injury' as per Indian Standard IS-3786-2022 (IS-3786, 2022 [13]; Pisharody et al., 2018a-b [91] [92]).

The accident prevention and control measures are implemented as per the hierarchy of hazard control. In the hierarchy of hazard control, Elimination, Substitution, and Engineering Controls assume the upper tiers; and Administrative Controls and Personal Protective Equipment (PPE) are at the lower tiers (NIOSH, 2020 [80]; OSHA, 2020 [85]; Pisharody et al., 2018a-b [91] [92]). Accident prevention by Elimination, Substitution, and Engineering Controls are applied by the way of 'Safety through Design' (National Safety Council, 2001a-b [81] [82]). Occupational accident prevention should commence at the planning and design stage itself, as design changes are impossible, impracticable, difficult, or expensive at later stages (Sousa et al., 2014 [109]). However, implementation of worker safety during the design phase has some limitations as the individuals involved in the accidents have unique personal characteristics and cultures, and nothing can be predicted perfectly as accidents can occur under conditions that were not anticipated during the design phase (Fonseca et al., 2014 [38]). Therefore, in an effective accident prevention and control program, 'Safety through Design' is supplemented by 'Administrative Controls' and 'Personal Protective Equipment' (Pisharody et al., 2018a-b [91] [92]).

Analysis of HFLS accidents, development of accident prediction models on LFHS accidents to identify significant contributors to accidents, analysis of significant contributors derived from the accident prediction models, and analysis of safety perception survey are utilized to identify causes of industrial accidents in the company. The implementation of corrective measures to address the causes of accidents is intended to improve the company's accident prevention program as it advances to **Zero Harm**.

1.2 DEFINITIONS (IS-3786, 2022 [13]; Pisharody et al., 2018a-b [91] [92])

1. **Accidents** are unplanned events that interrupt or interface with the orderly progress of an activity. These are unanticipated events that result in undesirable effects. Accidents do not always result in bodily injury.

2. **Agency** is the object or substance, which is most closely associated with the accident; causing injury, and with respect to which adoption of safety measures could have prevented the accident. Examples are; machines, means of transportation, flying objects, scaffoldings, ladders, lifting machines, electrical conductors, electric hand tools, chemicals, gases, working environments, live animals, etc.

3. **Fatality** is an accident that results in the death of one or more persons.

4. **First-Aid Injury** is an injury that occurs as a result of an accident and the victim returns back to work following treatment at the first-aid facility.

5. **Frequency** is the number of accidents occurring over a period of time.

6. **Frequency Rate** is the number of accidents occurring over a period of time, normalized to 1 million man-hours worked.

7. **Hazard** is any condition that may result in the occurrence of or contribute to the severity of an accident. Presence of hazards can cause accidents.

8. **High Frequency and Low Severity (HFLS) Accident** is an accident that occurs at a frequency of more than 1 accident per year per Station or Project; but with low

severity, in which there is no injury attributed to the accident or the accident victim returns back to workplace within 48 hours of the event (Heinrich et al., 1980 [46]; Jones et al., 1999 [65]; Khanzode et al., 2012 [67]; Pisharody et al., 2018b [92]). Examples are, near-misses, first-aid injuries, and non-reportable injuries.

Note: Occurrence of 1 LFHS accident per year per Station or Project is considered as the rationale for deciding frequency of HFLS or LFHS accidents for the study.

9. **Industrial Accident** is an accident occurring in an industrial environment. It includes Near miss, First-aid injury, Non-reportable injury, Reportable injury and Fatality.

10. **Location of Injury** is the part of the injured person's body, directly affected by the injury. Examples are; head, neck, trunk, upper limb; lower limb etc. Since there is no injury to persons in case of near misses, potential location of injury is considered in case near misses.

11. **Low Frequency and High Severity (LFHS) Accident** is an accident which occurs at a low frequency of less than or equal to 1 accident per year per Station or Project; but with high severity, in which there is a fatality or the accident victim returns back to workplace only after 48 hours of the event (Heinrich et al., 1980 [46]; Jones et al., 1999 [65]; Khanzode et al., 2012 [67]; Pisharody et al., 2018b [92]). Examples are, reportable injuries and fatalities.

Note: Occurrence of 1 LFHS accident per year per Station or Project is considered as the rationale for deciding frequency of HFLS or LFHS accidents for the study.

12. **Manhours worked** is the total number of employee hours worked by all the employees working in the industrial premises. It includes managerial, supervisory, professional, technical, clerical and other workers including contract workers.

13. **Near Miss** is an unplanned event, which did not result into injury or property damage. These are Low Level Events occurring either due to unsafe conditions or unsafe acts or due to combination of both, posing challenges to Industrial Safety measures prevailing in the organization.

14. **Non-Reportable Injury** is an injury due to accident in which victims are sent to hospital with or without treatment at first-aid centre for further medical examination and accident victim returns back to workplace within 48 hours of the event.

15. **Reportable Injury** is an injury due to accident in which the accident victim remains absent from the workplace due to injury for more than 48 hours of the event.

16. **Risk** is a combination of frequency and severity. It is estimated as the product of frequency and severity.

17. **Safety** is a measure of relative freedom from risks or dangers. It is also the degree of freedom from risks and hazards in work environment and its surroundings.

18. **Safety Related Deficiency** is an unsafe act or unsafe condition in the work area, which has potential to cause accident or injury, resulting into undesirable consequences to human beings or damages to equipment, property or environment.

19. **Severity** is degree of damage caused by an accident over a period of time.

20. **Severity Rate** is the number of man days lost on account of reportable injuries and fatalities occurring over a period of time, normalized to one million-man hours worked.

21. **Type of Accident** is the manner in which the object or substance causing the injury comes into contact with the person or the movement of the injured person which resulted in the injury. Examples are; falls of objects, falls of persons, stepping or striking against or struck by objects, being caught in or between the objects, over-exertion or wrong movements, exposure or contact with extreme temperature or electric current or harmful substances, explosions, etc.

22. **Unsafe Act** is a deviation from accepted and laid down safe procedures, which may contribute to the causation of accidents, Examples are; operating without authority, failure to secure or warn, operating at unsafe speed, marking safety devices inoperative, using unsafe equipment or hand instead of equipment, using equipment unsafely, unsafe loading, placing, mixing, combining and taking unsafe position or posture etc.

23. **Unsafe Condition** is the existence of physical, chemical, mechanical, or environmental conditions, which may contribute to accident sequences. Examples are; improperly guarded agency, defects in agency, hazardous arrangement or procedure in or on apparel, improper illumination, unsafe dress or apparel, improper ventilation, etc.

1.3 PROBLEM STATEMENT

We have considered a Public Sector Power Company to be a representative of the industry, and have studied it here for the Industrial Safety scenario. The Public Sector Power Company is involved in the design, construction, commissioning, and operation of Power Plants in India. The company has a well-established organizational set-up to implement Industrial Safety requirements as per applicable statutes and regulations.

The company has the following systems for the identification of hazards and prevention of accidents as part of the Accident Prevention Program: -

1. **Safety Related Deficiency Management System (SRDMS) for Identification, Reporting, Tracking, Follow-Up, and Correction of Safety Related Deficiencies.**

   Safety Related Deficiency Management System (SRDMS) is a proactive method for the identification of hazards or Safety Related Deficiencies (SRDs) through Plant Safety Inspections while performing jobs by the job performers or during job observations by independent agencies other than the job performers. By reporting and correcting hazards through SRDMS, Near Misses and Industrial Accidents can be prevented. However, there are occurrences of Near Misses and Industrial Accidents in the company, which indicate that despite the SRDMS; there are some residual hazards in the work environment that could not be identified and corrected through SRDMS. This indicates a scope for further improvement in the existing approach to the identification of hazards and accident prevention.

2. **Accident Reporting System for Reporting, Investigating, and Correcting the Hazards, that cause Near Misses and Industrial Accidents.**

   Accident Reporting System is a Reactive Method for the identification of hazards and prevention of accidents. Near Misses being precursors of major accidents, the company has a system for reporting, investigating, and correcting causes of Near Misses as part of the Industrial Accident prevention program. Though hazards that cause Near Misses are identified and corrected, there are occurrences of Industrial Accidents. Although all Industrial Accidents are investigated and causes are corrected through the Accident Reporting System, there are recurrences of some Industrial Accidents. This indicates that there is a scope for improvement in existing methodology of identifying and correcting the causes and contributors of Industrial Accidents.

   The above shows that **in spite of having a Safety Related Deficiency Management System and Accident Reporting System, there are occurrences and recurrences of Near Misses and Industrial Accidents. This indicates that existing systems for the identification of hazards and accident prevention are not sufficient to prevent accidents. This needs to be addressed through alternative methodologies.**

1.4 MOTIVATION FOR THE RESEARCH

Even though workplace hazards are identified and corrected through SRDMS; and all accidents are analyzed through the Accident Reporting System and corrective measures are taken, accidents are occurring and recurring in the company. This implies that the present methods for accident prevention and control in the company are not effective in preventing accidents. Therefore, **it is a necessity to further reinforce accident preventive measures by identifying and correcting causes and contributors through alternative methods. The accident prediction model is one such method.**

An accident prediction model is an algorithm of pitting a dependent variable against several independent variables, each of which is assigned a constant. Accident prediction models help to identify significant contributors to accidents and to take appropriate corrective actions. Multiple linear regression analysis is one of the methods for the development of accident prediction models.

Multiple linear regression analysis is a statistical method used for the development of models for estimating the relationship between a dependent variable and certain independent variables. It is a widely used prediction technique to understand which independent variables are significantly related to the dependent variable.

The Indian Standard IS-3786 (IS-3786, 2022 [13]) gives guidelines for the classification of accidents based on seven principal factors for accident causation mentioned earlier. Out of these, Agency, Type of Accident, and Location of Injury are used in our study to develop accident prediction models on LFHS accidents. Independent variables considered in the models are the number of LFHS accidents based on Agencies, Types of Accidents, and Locations of Injuries and the dependent variable is man days lost on account of LFHS accidents. **Accident prediction models on LFHS accidents based on Agencies, Types of Accidents, and Locations of Injuries will give significant Agencies, Types, and Locations of Injuries attributed to the LFHS accidents, and Corrective actions on these significant contributors will prevent LFHS accidents.**

LFHS Accidents are preceded by numerous HFLS accidents. These are warning signals of an impending LFHS accident. Hence **if HFLS accidents are monitored and kept under control by preventive and corrective measures, those accidents may not escalate to LFHS accidents.** Analysis of HFLS accidents based on Agencies, Types of Accidents, and Locations of Injuries will help to identify Significant Agencies of Accidents and Significant Types of Accidents and Significant Locations of Injuries due to HFLS accidents. **Corrective actions on the significant contributors of HFLS accidents will supplement the accident prevention program.**

Workplace injuries are caused by both individual and organizational factors. Individual factors are employees' educational level and their organizational role. Organizational factors are organizational culture, organizational support, job satisfaction, and workers' perception of workplace safety. **Workers' perception of workplace safety and organizational safety culture have a very high impact on accident frequency.** A safety perception survey among the employees of the organization will give an insight into organizational safety culture. **Corrective measures on weak attributes of organizational safety culture will support the accident prevention program.**

The motivation behind the study is that effective implementation of corrective measures based on analysis of significant contributors of LFHS accidents derived from accident prediction models, analysis of HFLS accidents, and analysis of results of organizational safety perception survey **will reinforce and upgrade accident prevention program in the company** in its tread towards **Zero Harm.** This will make the accident prevention and control program in the company more effective, **which ultimately will lead to reduced accidents and enhanced reputation of the company.**

1.5 RESEARCH OBJECTIVES

This research has been carried out with the purpose of fulfilling the following objectives:

1. **To study Near Misses and Industrial Accidents** that occurred in the Public Sector Power Company during the period of 10 years from 2006 to 2015 to identify causes and contributors with reference to Agencies, Types of Accidents, and Locations of Injuries as per Indian Standard IS-3786-2022.

2. **To analyze HFLS accidents based on Agencies, Types of Accidents, and Locations of Injuries** as per Indian Standard IS-3786-2022 **to identify significant contributors of HFLS accidents.**

3. **To develop Accident Prediction Models on Agencies, Types of Accidents, and Locations of Injuries of LFHS accidents** as per Indian Standard IS-3786-2022 **to identify significant Agencies, Types of Accidents and Locations of Injuries of LFHS accidents.**

4. **To analyze significant Agencies, Types of Accidents, and Locations of Injuries derived from Accident Prediction Models** on LFHS accidents as per Indian Standard IS-3786-2022 and **to identify significant contributors to LFHS accidents.**

5. **To carry out a Safety Perception Survey** on Accident Prevention and Control among the employees of the Public Sector Power Company **to identify significant organizational contributors to accidents.**

6. **To identify accident prevention and control measures by 'Safety through Design',** reinforcement of **'Administrative Controls'** and strengthening use of **'Personal Protective Equipment', hence to upgrade accident prevention and control program** in the Public Sector Power Company.

1.6 RESEARCH METHODOLOGY

The following methodology is considered for our research:

1. **Literature survey on accident prevention and control and accident prediction models** by study of research papers, books, journals, standards, legislations, and internet resources.

2. **Collection of accident data on Near Misses and Industrial Accidents that** occurred in the Public Sector Power Company during the period of 10 years from 2006 to 2015.

3. **Analysis of accident data on Near Misses and Industrial Accidents based on Agencies, Types of Accidents, and Locations of Injuries** as per the Indian Standard IS-3786-2022.

4. **Analysis of HFLS accidents** that occurred in the Public Sector Power Company during the period of 10 years from 2006 to 2015 based on Agencies, Types of Accidents, and Locations of Injuries as per the Indian Standard IS-3786-2022 **to identify significant contributors of HFLS accidents.**

5. **Development of Accident Prediction models on LFHS accidents** that occurred in the Public Sector Power Company during the period of 10 years from 2006 to 2015 based on Agency, Type of Accident, and Location of Injury as per the Indian Standard IS-3786-2022 **to identify significant Agencies, Types of Accidents and Locations of Injuries of LFHS accidents.**

6. **Validation of Accident Prediction models on LFHS accidents** through verification of goodness of fit, statistical significance and prediction capability by independent data for the year 2018.

7. **Analysis of significant Agencies, Types of Accidents, and Locations of Injuries derived from Accident Prediction Models** on LFHS accidents as per Indian Standard IS-3786-2022 **to identify significant contributors to LFHS accidents.**

8. **Conducting a Safety Perception Survey on Industrial Accident Prevention and Control** among the employees of the Public Sector Power Company and analysis of results **to identify significant organizational contributors to accidents.**

9. **Identification of accident prevention and control measures by 'Safety through Design'; and by reinforcement of 'Administrative Controls' and use of 'Personal Protective Equipment'** to upgrade accident prevention and control program in the Public Sector Power Company.

10. **Development of research conclusions and suggestions for future works**

11. Flow diagram of research methodology is given in the **Figure 1.1.**

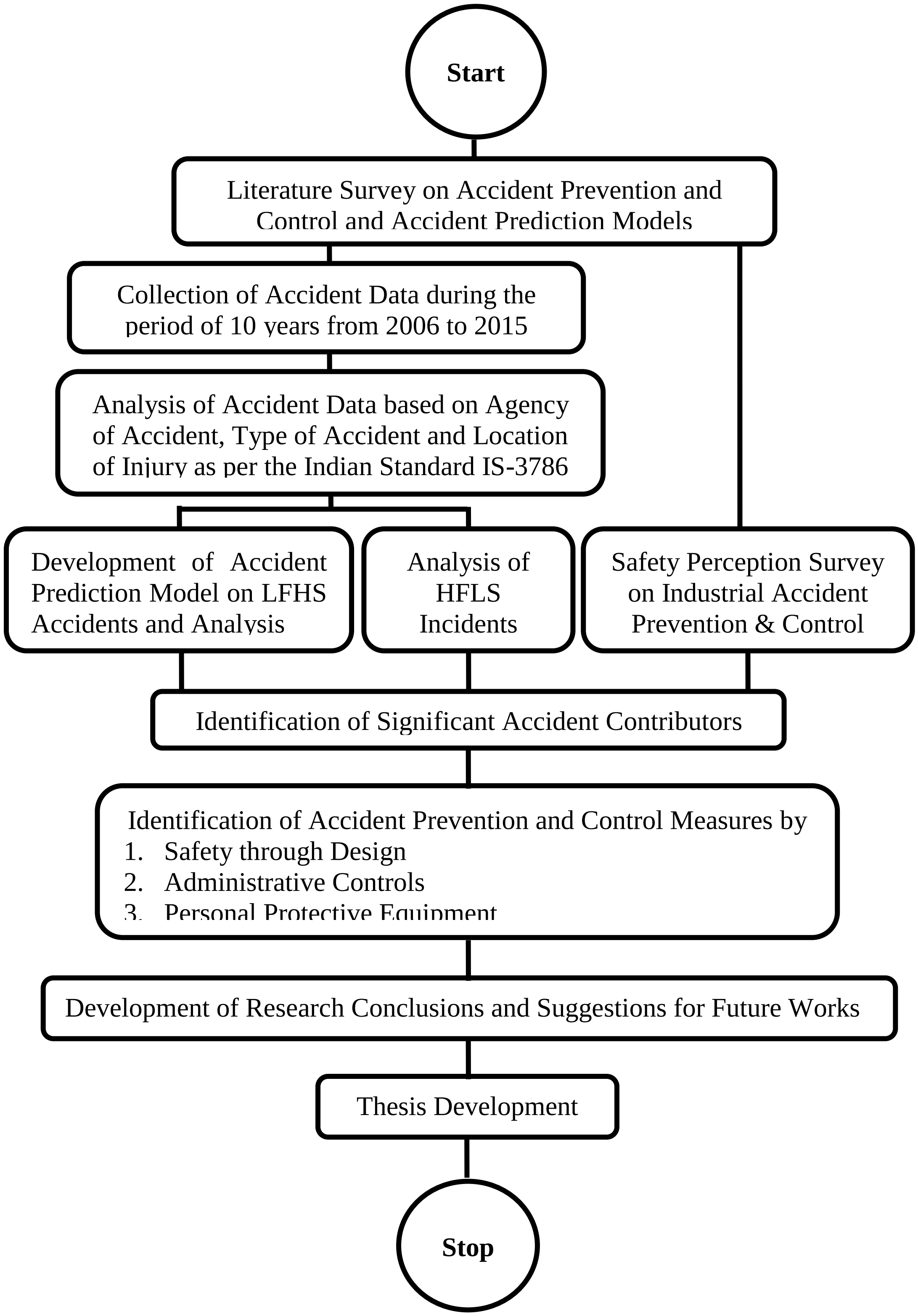

Figure 1.1: Flow Diagram of Research Methodology

1.7 CHAPTER SCHEME

The entire doctoral work has been presented in terms of the following Chapters:

Chapter 1	Introduction
Chapter 2	Literature Survey
Chapter 3	Data Collection, Data Classification, and Rationale for Rationale for Selection of Accident Prediction Model
Chapter 4	Analysis of High Frequency and Low Severity (HFLS) Accidents
Chapter 5	Development of Accident Prediction Models on Low Frequency and High Severity (LFHS) Accidents and Analysis
Chapter 6	Analysis of Significant Contributors of High Frequency and Low Severity (HFLS) and Low Frequency and High Severity (LFHS) Accidents
Chapter 7	Safety Perception Survey on Industrial Accident Prevention and Control
Chapter 8	Conclusions and Suggestions for Further works

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CHAPTER-2

LITERATURE SURVEY

2.1 PREAMBLE

A hazard is a source or a situation with the potential to cause harm in terms of injury or ill health, property damage, damage to the environment, or a combination of these. It is also a characteristic of a system or process that represents the potential for accident, causing injury to people or damage to property or the environment (IS-15656, 2006 [11]; IS-18001, 2007 [14]; Pisharody et al., 2018b [92]). In any system, risk cannot be eliminated; however, it can be reduced to an acceptable level by additional corrective measures. Hazards in the work environment are unsafe conditions in structures, systems, components, and processes; and are identified through plant safety inspections or by monitoring system parameters or from the annunciation systems. Hazards are corrected through the Safety Related Deficiency Management System (SRDMS). Despite this, there could be some residual hazards, which on interaction with external agencies or human beings can cause near misses.

Near misses are relatively harmless disruptions from normal operations without any personal injury or property loss. Near misses under different circumstances could cause accidents or events of serious consequences. Near misses are prevented from escalating into accidents by providing safety barriers. Safety barriers may be physical such as machine guards, and protection systems, etc., or non-physical such as administrative controls, work permits, procedures, Job Hazard Analysis and hazard control measures, etc. Accidents occur due to a series of failures or errors occurring in a sequential path. Safety barriers break this sequential path and prevent accidents. Failure of safety barriers may exacerbate near misses into accidents (Kinnersley and Roelen, 2007 [68]; Rathnayaka et al., 2011a-b p [95] [96]; Pisharody et al., 2018b [92]).

All accidents are investigated and additional safety barriers are provided to prevent recurrence. However, failure of existing or additionally installed safety barriers may cause recurrence of accidents as shown in **Figure 2.1** (Pisharody et al., 2018b [92]). Whenever safety barriers are challenged, the situation becomes closer to accidents. Even if many safety barriers are in place, barrier maintenance is necessary to avoid accidents. Around 30-40% of accidents and precursor events are caused by barrier maintenance deficiencies, development of new hazards during maintenance, or non-maintenance related factors (Okoh and Haugen, 2013 [87]).

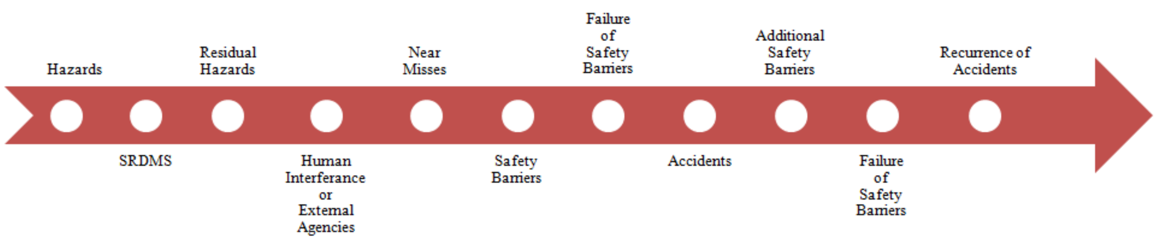

Figure 2.1: Escalation of Hazards to Accidents [Ref. Pisharody et al., 2018b [92]]

Accidents can result in injury or need not cause injury. When a person is subjected to an amount of energy that exceeds his physiological limits, he suffers an injury (ICECI, 2004 [58]; Pisharody et al., 2018b [92]). Energy can be mechanical, thermal, electrical, chemical, or radiant energy. Injury can be intentional or unintentional. Intentional injuries are caused by individuals' deliberate actions, such as homicide, assault, or suicide etc. Unintentional injuries occur due to accidents such as fall of persons, fall of objects, caught in or between objects, struck by moving parts of machines, electric shock etc. This study looks into unintentional injuries due to accidents.

2.2 TAXONOMY OF LITERATURE

Hazards in combination with favorable workplace interfaces cause accidents and injuries. Since all accidents are caused, all should be investigated for identifying and correcting the causes. Organizational safety perception also affects accident prevention and control. Accident prediction models help in analysis of accident.

Considering the above sequence, literature on industrial accident prevention and control are categorized as:

1. Hazard Control
2. Accident Causation
3. Accident Investigation
4. Human Factors, Organizational Safety Culture, and Safety Perception
5. Accident Prevention and Control
6. Accident Prediction Models.

A total of 123 kinds of literature comprising research papers, books journals, standards, and legislations on Industrial Accident Prevention and Control were referred as part of the research, apart from internet sources.

2.3 HAZARD CONTROL

Hazard control is a function, directed towards recognizing, evaluating, and eliminating or reducing destructive effects of hazards, hence protecting workers from injuries (National Safety Council, 2001a-b [81] [82]; Pisharody et al., 2018b [92]). The primary objective of the hazard control program is to eliminate or reduce hazards in the workplace, hence to prevent and control accidents to protect workers. The hazard control process involves systems for identification, evaluation, prediction, prevention and monitoring of hazards (Rathnayaka et al., 2011a-b [95] [96]).

Hazard control involves six essential processes given below and depicted in **Figure 2.2** (National Safety Council, 2001a-b [81] [82]; Pisharody et al., 2018b [92]):

1. Hazard identification
2. Hazard ranking

3. Management decision making

4. Establishing preventive and corrective measures

5. Monitoring, and

6. Evaluating program effectiveness

Figure 2.2: Hazard Control Process
(Ref. National Safety Council, 2001a-b [81 [82]; Pisharody et al., 2018b [92])

2.3.1 Hazard Identification

A hazard is a source or a condition that has the potential to cause human injury or illness, property damage, environmental damage, or a combination of these. Hazard identification is the process of recognizing a hazard in existence and defining its characteristics or impact (IS-18001, 2007 [14]; Pisharody et al., 2018b [92]). Hazards in work environment may result in occurrence of an accident or contribute to the severity of an accident. Working in the presence of hazards exposes a person to the risk of accident and injury. Primary objective of hazard identification is to identify all potential hazards and to analyze how these hazards would lead to an accident.

Hazard identification involves the identification of hazards associated with all activities and facilities which includes (IS-18001, 2007 [14]; Pisharody et al., 2018b [92]):

1. Activities that are done regularly and those that are done on a non-regular basis;
2. Activities of all employees, including subcontractors and visitors, who have access to the workplace; and
3. Workplace amenities, whether supplied by the company or others.

It is essential to categorize the hazards in terms of severity of consequences such as High Frequency and Low Severity (HFLS) accidents or Low Frequency and High Severity (LFHS) accidents. Since the frequency of occurrence of HFLS accidents is more than LFHS accidents and HFLS accidents are warning signals or precursors of LFHS accidents, HFLS accidents give more opportunity for hazard control and elimination. The amount of energy transferred to the victim's body during the accident determines the severity of the consequences. Occurrences of HFLS accidents are symptoms of unidentified hazards. Therefore, it is essential to identify the causes of HFLS accidents to prevent LFHS accidents through hazard identification (Rathnayaka et al., 2011a-b [95] [96]). Since the presence of hazards can cause accidents and injuries, it is essential to identify and remove hazards from the workplace to prevent accidents. Hazards may be due to unsafe acts, unsafe conditions, or both. These are symptoms of shortcomings in hazard identification and hazard control. Therefore, it is essential to identify and control hazards that cause accidents and consequent injuries. This implies that the first step in accident prevention and control is to identify hazards systematically.

The goal of hazard identification is to detect and analyze hazards so that unexpected events, such as accidents and injuries, can be avoided. There are many methods to identify hazards in a work place. Interaction with workers, manufacturers of the equipment, tools and machinery; review of inspection reports of internal or external agencies, accident investigation reports; job hazard analysis and plant safety inspection etc are a few methods of hazard identification.

There are two types of hazard identification methods: (1) comparative method and (2) fundamental method (IS-15656, 2006 [11]; Pisharody et al., 2018b [92]).

Comparative methods of hazard identification are carried out by comparing plant conditions with standards such as checklists, safety audits, hazard indices, and preliminary hazard analysis (IS-15656, 2006 [11]; Lees, 2004 [71]; Pisharody et al., 2018b [92]).

1. **Checklists** are prepared for the quick qualitative identification of hazards based on prior experience, standard operation or maintenance procedure, and knowledge of the system or plant, which leads to a 'Yes' or 'No' decision on whether or not the standard procedure has been followed.

2. **Safety Audit** comprises of intensive inspection of plant areas and observation of jobs performed by a team of internal or external experts for the qualitative evaluation to verify compliance of procedures and practices with codes, standards, and design intent.

3. **Hazard Indices** are used during the design and operation phases of a plant, as an early screening approach for fire or explosion potential to rank plant process units relative to the degree of risk.

4. **Preliminary Hazard Analysis** is a technique for detecting hazards early in the design process and making recommendations for reducing hazards in the final version.

Fundamental methods are hazard identification strategies based on an organized way of encouraging a group of people to use foresight and knowledge to identify hazards by asking a series of questions. Major techniques available in this method are What-if Analysis, Failure Modes and Effects Analysis (FMEA) and Hazard and Operability Study (HAZOP), Job Hazard Analysis (JHA) (Lees, 2004 [71]; National Safety Council, 2001a-b [81] [82]; IS-15656, 2006 [11]; Rozenfeld et al., 2010 [99]; Cheng et al, 2012 [27]; Rathnayaka et al., 2011a-b [95] [96]; Pisharody et al., 2018b [92]).

1. **What-if** analysis is used to determine possible event sequences, their effects, and risk reduction approaches under various accident situations.

2. **FMEA** is a qualitative method used to identify various modes of equipment failures and the consequences of such failures.

3. **HAZOP** study is a technique for identifying risks and operational issues and making recommendations for modifications to the design and procedure.

4. **Job Hazard Analysis (JHA)** is a proactive approach for assessing safety risks by identifying, evaluating, and reducing risks throughout the planning and execution of jobs. The probability of loss-of-control incidents while performing a task is given more weightage in JHA than the probability of accidents. It includes the following three main stages:

    i) Identification - Selecting a certain job or activity and breaking it down into stages, as well as identifying any potential loss-of-control situations that may occur during the work.

    ii) Assessment - Evaluating the relative level of risk for all identified loss-of-control incidents.

    iii) Action - Controlling risks by taking sufficient measures to reduce or eliminate the risks. Work supervisors shall ensure compliance to risk control measures identified through JHA while planning and performing jobs.

Approaches for hazard identification can be classified as biased reactive approach, biased proactive approach and unbiased proactive approach (Khanzode et al., 2012 [67]; Pisharody et al., 2018b [92]).

1. **Biased Reactive Approach,** where following an accident, hazards are identified based on the information gathered. This category includes accident investigations and general engineering approaches.

2. **Biased Proactive Approach**, where before the event, the hazards are derived from similar systems or previous data. This is a method of tracking both forward and backward using fault tree analysis, event tree analysis, cause consequence analysis, Failure Mode and Effect Analysis, etc.

3. **Unbiased proactive approach**, where hazards are identified without having to wait for events to happen and without making any assumptions about past specific hazards in the work system. This method concentrates on potentially hazardous elements such as energy concentrations, hazardous materials, and potential targets as persons or equipment. During hazard identification, critical or significant elements influencing safety are focused on to identify the paths leading to accidents. Generally adopted methodologies are Change Analysis, Energy Analysis, Deviation Analysis, HAZOP studies, Job Hazard Analysis, Management Oversight and Risk Tree (MORT) analysis, etc.

The results of a biased reactive approach rely on the experience and professional competence of those performing the job. Biased proactive approach relies on previous knowledge of processes and systems. Even an unbiased proactive method isn't totally unbiased because past data and prior job experience are required for this strategy to succeed. Therefore, effective hazard identification depends on the domain knowledge of persons involved in hazard identification, on the structures, systems, components and processes.

2.3.2 Hazard Ranking

After the hazards have been identified, the next step is to rate them according to their risk. The objective of hazard ranking is to prioritize corrective actions based on risk assessment. Risk is defined as a combination of frequency or likelihood of occurrence and effect of a particular hazardous event (IS-18001, 2007 [14]; Pisharody et al., 2018b [92]). It is also a measure of possible economic loss or human injury based on the likelihood of the loss or injury occurring as well as the magnitude of the loss or injury (IS-15656, 2006 [11]; Pisharody et al., 2018b [92]). Risk assessment involves identifying possible threats, calculating the likelihood, and assessing the consequences. It is the process of determining the degree of risk and determining whether or not the risk is tolerable. Injury risk refers to the possibility of being injured while doing a specific task. Identifying hazards, evaluating risk, and ranking hazards based on risk are part of the injury risk assessment process (Khanzode et al., 2012 [67]; Pisharody et al., 2018b [92]).

Risk levels are categorized as trivial risk, tolerable risk, moderate risk, substantial risk, and intolerable risk. Trivial risk means there is no appreciable risk associated with that activity as there has been no harm attributed to the activity in the past. It is difficult to identify activities with trivial risks. No action is required and no documentary records need to be maintained for the trivial risks. Tolerable risk is defined as a risk that has been minimized to the lowest level practical. In case of tolerable risks, no further controls are required. Efforts should be made to reduce moderate, substantial and intolerable risks to tolerable risks. **Table 2.1** gives Risk Matrix for estimating risk for deciding whether the risk is tolerable and **Table 2.2** gives actions to be taken based on the risks (IS-3786, 2022 [13]; IS-18001, 2007 [14]; Manuele, 2014 [75]; Pisharody et al., 2018b [92]).

Table 2.1:
Risk Matrix (Ref. IS-18001, 2007 [14])

Probability of Occurrence	**Severity of Occurrence**		
	Slightly Harmful	**Harmful**	**Extremely Harmful**
Highly Unlikely	Trivial Risk	Tolerable Risk	Moderate Risk
Unlikely	Tolerable Risk	Moderate Risk	Substantial Risk
Likely	Moderate Risk	Substantial Risk	Intolerable Risk

Table 2.2:
Risk Based Action Plan (Ref. IS-18001, 2007 [14])

Trivial Risk	• There is no need to take any action. • There is no need to keep a documentary record.
Tolerable Risk	• There are no additional controls necessary. • A cost-effective solution or upgrade that does not incur any additional costs. • Controls must be monitored to ensure that they are kept in good working order.

Moderate Risk	• Attempts should be made to reduce the risk. • Cost of prevention should be calculated and kept to a minimum. • Risk-reduction measures should be put in place in a reasonable timeframe.
Substantial Risk	• Work should not begin or continue until the risk has been mitigated. • Where risk is present in the task in progress, significant resources may be provided to mitigate risk. • Immediate action is required to mitigate the risk.
Intolerable Risk	• Work should not begin or continue until the risk has been mitigated. • Work should be prohibited if risk reduction can't be achieved even with limitless resources.

Major pit falls in risk assessment are (HSE UK 2001 [49], HSE UK, 2003a-e [51] [52] [53] [54] [55], HSE UK 2014 [57]; Pisharody et al., 2018b [92]):

1. Risk assessment is carried out to justify a decision that has already been made.

2. When a site-specific assessment is necessary, a generic assessment is used.

3. Inappropriate definition of sample events, use of data, risk criteria and cost benefit analysis are made to suit the outcome.

4. Risk from only one activity is considered.

5. All the hazards and possible outcomes associated with a particular activity are not identified.

6. Employees with practical knowledge of the process or activity are not included in the assessment and consultants are used ineffectively.

7. Hazards are not linked with risk controls and results of risk assessment are not used.

2.3.3 Management Decision Making

Management decision making entails giving complete and correct information, as well as all available alternatives, to enable management to make intelligent, well-informed hazard control decisions (National Safety Council, 2001a-b [81] [82]). Such alternatives may include recommendations by considering the hierarchy of hazard control which comprises of Elimination, Substitution, Engineering Controls, Administrative Controls and use of Personal Protective Equipment (PPE) as depicted in **Figure 2.3** (Chinniah Y., 2015 [29]; NIOSH, 2020 [80]; OSHA, 2020 [85]).

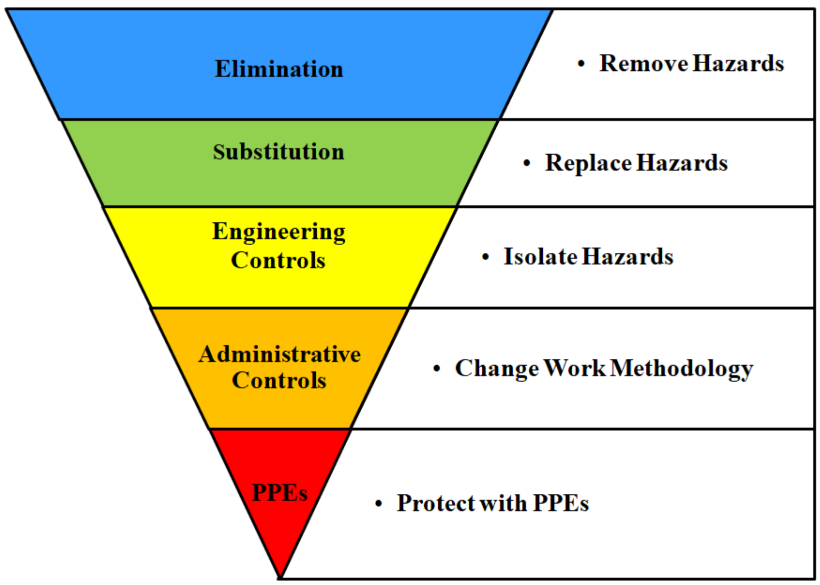

Figure 2.3: Hierarchy of Hazard Control
(Ref. Chinniah Y., 2015 [29]; NIOSH, 2020 [80]; OSHA, 2020 [85]

In this hierarchy, Elimination, Substitution and Engineering Controls assume the upper tiers, which consist of designing safe systems. Next in the hierarchy are Administrative Controls such as enforcement, training, job hazard analysis, safe work procedures, work permit system, access control, penalty etc. Use of Personal Protective Equipment (PPE) is the lowest in the hierarchy. PPE do not prevent accidents; however, it mitigates consequences of the accident (Lees, 2004 [71], Pisharody et al., 2018b [92]).

A study carried out on the cause of industrial accidents validates that about 50-60% of the root causes of the accidents are attributed to design and hence design improvement should be considered as one of the major strategies for accident prevention (Kinnersley and Roelen, 2007 [68]). Hazard control by design can be achieved by 'Safety through Design' in structures, systems, equipment, and components by judicious application of elimination, substitution, and engineering controls. Designing to remove or to avoid hazard should take precedence over controlling the hazard or protecting workers from hazard. Improving 'Safety through Design' is the most effective method for eliminating hazards and reducing risk.

During the planning and design phases, it is possible to remove hazards, which otherwise could appear in the field during a later stage while working. About 42% of 224 fatalities at construction sites are attributed to design deficiencies (Gambatese et al., 2008 [39]). Failures and accidents have occurred as a result of design flaws in equipment. Quite often this is attributed to lack of consideration for safety at the design stage (Haslam et al., 2005 [45]). Study of construction accidents in USA during the period from 1990 to 2008 indicates that fall of persons, fall of objects, struck-by objects, caught in or between and electric shock are the major causes of fatalities at construction sites (Wu et al., 2013 [122]).

Research by Haslam et al. (2005 [45]) indicates that although the design of scaffolding towers has received some attention in terms of ease of erection and usage, traditional scaffolding erection has not received the attention to human factors and ergonomics as it deserved. This could lead to the development of unsafe scaffoldings, thus it's an area where construction site accident prevention should be improved.

Fall of persons can be at the same level or from the height. Slips, trips, and falls can cause fall of persons at the same level. Unintentional or unexpected changes in the contact at the interface between footwear and the underfoot surface cause slips, trips, and falls (Noora Nenonen, 2013 [84]). Consequences of fall of persons at the same level in general may not be severe. However, falling from a height could have more severe consequences. Another independent analysis of fall-related deaths in the construction industry by Christopher (1998 [33]) and Dennerlein et al. (2009 [36]) indicates that more than half of the reported accidents in the construction industry are due to falls from ladders. Number of accidents while descending through the ladders was twice the number of accidents while ascending through the ladders. Overreaching, slipping on rungs, and missing steps or rungs were among the leading causes of ladder falls. Failure of the ladder structure, attempting to catch falling objects, applying excessive force, leaning the ladder against the structure, transitioning onto or off ladders, standing on the top rung, and unevenness or slipperiness of the surface were all mentioned as additional reasons.

Chi et al. (2005 [28]) in their analysis of work-related fatal falls during the period 1994-1997 in the Taiwan construction industry also found that deficient scaffoldings, ladders and platforms; unguarded floor and roof openings, use of defective personal protective equipment, wrong use or non-use of personal protective equipment, poor illumination, removal of fall protection barriers and lack of safety nets as the major causes of fatalities during climbing, waking or leaning against. Haslam et al. (2005 [45]) also reiterate that about 31% of the major injuries were due to falls of person from height. Christopher (1998 [33]) in his study on 'Fall-Related Deaths in the Construction Industry' also observed structural collapse, lack of fall protection harness, not anchoring fall protection harness to a firm structure, failure of fall protection systems such as guard rails, safety harness, covers of openings, improper working surfaces, unsafe use of scaffolding by the workers during erection or dismantling and fall from ladders while ascending or descending as causes for fall of persons from height.

Davies et al., (2003 [35]) in their study of 1504 work related injuries observed that 40% of the injuries were attributed to manual material handling. 80% of the manual material handling injuries had caused man days loss of about 1 month and 20% of these injuries have caused man days loss of more than one month. Sprains and strains have been connected with manual material handling, which includes lifting, carrying, supporting, putting down, and pulling or pushing with bodily force utilizing the hands, shoulder, back, or any other portion of the body. Manual material handling activities should be avoided whenever possible, and if it cannot be avoided, efforts should be made to reduce the risk as much as possible by wearing non-slip shoes, avoiding uneven, slippery, and contaminated flooring, and minimizing the risk of the foot becoming caught on protruding wrappings, binding tapes, and other objects. As far as possible material handling jobs should be carried out by mechanical means and system design should be made to reduce manual material handling.

Haslam et al. (2005 [45]) have accounted that a number of accidents were due to poor material condition of tools such as damage, wear and tear etc. As tools are used by multiple persons, wear and tear is bound to happen and hence periodic inspection and maintenance of tools are mandatory. They also noted that tools are typically chosen based on price and performance. Durability is sometimes a factor to consider as well. However, the usability and safety of tools are less considered while purchasing the tools.

'Safety through Design' incorporates hazard identification and risk assessment from the very beginning of the design process. It has an encompassing effect on the facilities and layout. Though initial investment for 'Safety through Design' could be relatively high, initial cost is comparable with subsequent costs involved in retrofitting efforts. At later stage, if safety related deficiencies are identified in the design, it may be impossible, impracticable, difficult or expensive to implement. Although, many accidents can be eliminated by following 'Safety through Design' principle, still there are more accidents. In such cases, Administrative Controls and PPE can supplement 'Safety through Design' and this involves management decisions (National Safety Council, 2001a-b [81] [82]; Haslam et al., 2005 [45]).

Management decisions on hazard control could have following alternatives:

1. Take no action due to financial constraints, crucial production schedules etc.
2. Modify workplace components, work methodology, administrative controls, personal protective equipment etc.
3. Redesign workplace components, work methodology, administrative controls and personal protective equipment etc
4. Discuss hazard and possible methods of elimination with affected workers and implement suitable hazard control methods to enhance safety.

Management decision making can be expedited by representing hazards and associated consequences in explicit manner with practical and cost-effective solutions.

2.3.4 Establishing Preventive and Corrective Measures:

After the hazards have been identified, ranked, and management decisions for corrective actions have been made, the next step is to apply hazard control measures at the 'Source,' 'Path,' or 'Receiver' as depicted in **Figure 2.4** (Pisharody et al., 2018-b [92]).

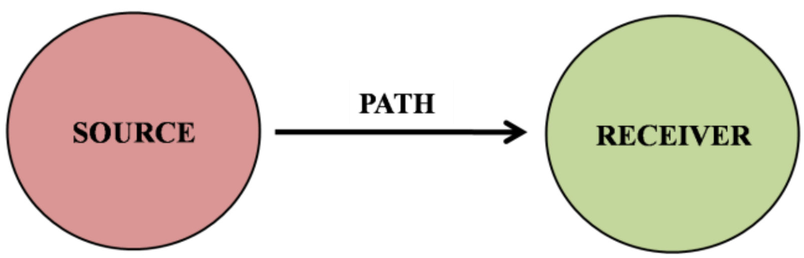

Figure 2.4: Hazard Control Alternatives
(Ref. Pisharody et al., 2018-b [92])

The most effective hazard control alternative is to contain the hazard at its ‘Source’. This can be accomplished through 'Safety through Design,' which involves either eliminating hazards during the design phase or substituting less hazardous processes and materials. The second alternative is to manage the hazard along its 'Path' by creating barriers between hazards and employees using engineering controls like machine guards, protective enclosures, and so on. This is also achieved through ‘Safety through Design’. The third alternative is application of hazard control efforts on the ‘Receiver’ i.e., the worker; by ‘Administrative Controls’ and use of ‘Personal Protective Equipment’. This is achieved by removing the worker from exposure to the hazard by automated or remote-control options, by adopting a system of job rotation or by providing Personal Protective Equipment. The third alternative is applied when the first two alternatives are not possible. Personal Protective Equipment is used only as a last resort if there is no other way to control the hazard immediately or if it is used as a temporary measure while more effective alternatives are being installed. However, Personal Protective Equipment has the following drawbacks:

1. It does not eliminate or reduce hazard.
2. If it fails, the worker is exposed to the full extent of hazard's damaging effects.
3. It could be inconvenient and interfere with worker's ability to complete the assignment. As a result, wearing of Personal Protective Equipment may exacerbate the condition.

The first and second alternatives of hazard control at ‘Source’ and ‘Path’ by ‘Safety through Design’ do not depend on human performance. Being immune to human errors, this is the most effective alternative. The third alternative of hazard control at ‘Receiver’ is a contingent action. Since it depends on human performance, it is less effective when compared with the first and second alternatives. Workplaces should be designed in such a way that highly stressful work practices are avoided, by considering human strengths and limitations. About 70% of the accidents are caused by worker’s actions and behavior. Therefore, human interaction errors should be included into the design, with the requirement of Personal Protective Equipment kept to a minimum. In fact, for successful hazard control, a multitier defense-in-depth approach with a combination of "Safety through Design," "Administrative Controls," and use of "Personal Protective Equipment" as shown in **Figure 2.5** should be used. To put it another way, "Administrative Controls" and "Personal Protective Equipment" should be used in addition to "Safety through Design" (National National Safety Council, 2001a-b [81] [82]; Lees, 2004 [71]; Haslam et al., 2005 [45]; Manuele, 2014 [75]; Pisharody et al., 2018b [92]).

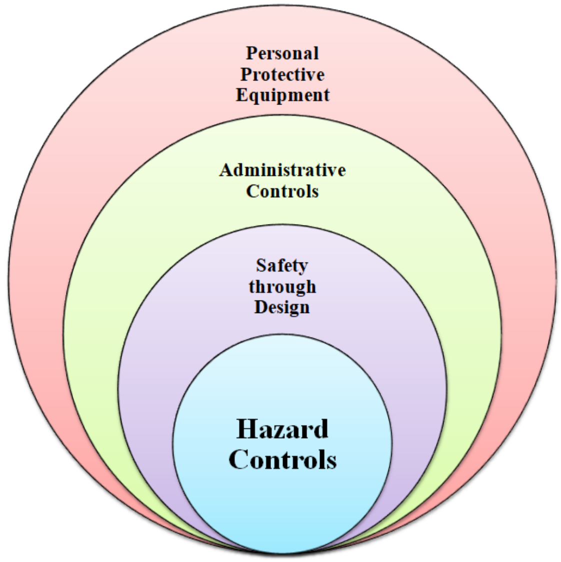

Figure 2.5: Defense in Depth in Hazard Control
(Ref. National National Safety Council, 2001a-b [81] [82]; Lees, 2004 [71]; Haslam et al., 2005 [45]; Manuele, 2014 [75]; Pisharody et al., 2018b [92])

2.3.5 Monitoring

Monitoring of implemented hazard control measures is essential:

1. To ensure that hazard control measures are working effectively to eliminate or reduce hazards.

2. To verify that modifications implemented for hazard controls have not altered the workplace hazards and made the existing hazard controls ineffective.

3. To ensure that the execution of hazard control measures does not result in the emergence of new hazards.

4. To identify previously undetected hazards if any.

Monitoring of hazard control measures can be carried out by plant safety inspection, safety audits, observation of jobs performed by the workers and by obtaining feedback from line managers, supervisors and workers.

2.3.6 Evaluating Program Effectiveness

Final process in hazard control process is evaluation of its effectiveness in terms of reduction of injuries and improvement of operational efficiency. This is achieved by trending of HFLS and LFHS accidents. Despite various measures for hazard control, effectiveness of hazard control program depends on organizational commitment, competence and cognizance to identify and remove potential hazards (Reason, 1991 [97]).

2.4 ACCIDENT CAUSATION

All accidents are caused. Therefore, it is necessary to identify causes of accidents to prevent recurrence. Structures, Systems and Components are well designed to provide automatic protection with minimum human intervention by 'Safety through Design'. These are further supplemented by 'Administrative Controls' and use of 'Personal Protective Equipment' as part of hazard control program. Despite these, there may be failures, leading to accidents and injuries due to shortfalls in implementation of hazard control and accident prevention program. In any group of failures, some failures might be recovered; others might fail in safe manner; and some others might fail in unsafe manner and escalate into minor or major accidents. Accident causation is described under following subheadings:

1. Evolution of Accident Cause Philosophy
2. Types of Failures and Cause of Accidents
3. Factors Contributing Accidents and Injuries
4. Accident Causation Theories

2.4.1 Evolution of Accident Cause Philosophy

It is difficult to design a safe system unless causes of accidents are anticipated and understood. Accident causation theories are developed for answering why and how do accidents occur (Al-shanini et al., 2014 [2]). Accident causation philosophy is evolved over five different ages as detailed below (Pillay M., 2015 [90]; Pisharody et al., 2018b [92]):

First age is closely associated with technological aspects, where accidents were attributed to mechanical and structural failures. These types of failures were prevented by developing and following technical standards and guidelines based on rules and regulations drawn from engineering and law disciplines.

Second age is related to human behaviors and human errors. Safety management initiatives in this age were based on behavior-based safety and human error management controls, consistent with sociology, psychology and industrial relations.

Third age is based on the premise that, if design of the system is human error prone, instead of human error reduction program, design modifications should be attempted first. Third age realizes that humans are not the sole cause of accidents as human performance depends on the complex interactions of socio-technical system in an organization. Therefore, design of structures, systems and components should be consistent with principles of ergonomics and human factors and engineering for an optimal man-machine fit in safety management system.

Fourth age postulated that poor organizational and cultural factors play key roles in occurrence of accidents. It is further argued that accidents are likely to occur in technologically advanced organizations where systems become more complex and tightly coupled. In this age, safety is managed through application of engineering, management, psychology and sociology, leadership, culture and collective mindfulness.

Fifth age is associated with complexity and uncertainty of safety and accidents; and justify that people play a key role in the proper functioning of modern technological systems due to their ability to adapt. Effective safety management in this age involved learning from failures and successes as people adapt themselves to ensure safety before failures.

2.4.2 Types of Failures and Cause of Accidents

HSE, UK (2002 [50]) in its study identified following eleven types of failures which could cause accidents:

1. **Hardware**, due to inadequate quality of materials and construction, ageing or unavailability of hardware.

2. **Design**, attributable to flaws in the layout or design of facilities, plant, equipment, or tools, which result in abuse or unsafe acts, as well as a greater risk of errors and violations.

3. **Maintenance management**, due to failures in maintaining technical integrity of systems, facilities, plant equipment, and tools during maintenance.

4. **Procedures**, where procedures are unclear, unavailable, erroneous, or with unsuitable task information so that the desired results are not achieved.

5. **Error-enforcing conditions**, due to time constraints, shifts in work patterns, or physical working circumstances of persons and workplaces that encourage unsafe acts, errors, or violations.

6. **Housekeeping**, where untidiness and cleanliness of facilities and work areas, as well as insufficient resources for cleaning and garbage removal, which raised likelihood of risky activities.

7. **Incompatible goals**, due to failure in managing conflicts between:

    (a) Safety and production objectives of the company.

    (b) Formal rules, such as written procedures established by the organization, and informal rules established by the work group, and

    (c) Individual requirements, tasks, and preoccupations or distractions.

8. **Communication**, due to failures in conveying information to recipients that is critical for the organization's safety and effective functioning, in a clear and unambiguous or understandable form. Transmission failures indicate that necessary communication channels do not exist or necessary information is not transmitted.

9. **Organization**, due to flaws in a company's organizational structure, the manner in which it performs its operations and; definition and implementation of safety responsibilities.

10. **Training**, due to deficiencies in providing awareness on hazardous conditions at the worksite and imparting knowledge or skill to individuals through formal courses and on-the-job coaching by work execution engineers and job supervisors.

11. **Defenses**, due to failures in systems, facilities, and equipment designed to control hazards and mitigate the effects of human or component failures. Detection, control, recovery, and protection are among them.

Failures can occur either at the workplace or in relation to the defenses. Failures occurring at the workplace are mainly 'active' and those which are associated with weaknesses in or absences of defenses are mainly 'latent'. Accident causation process is an interaction between latent and active failures. In order to avoid this interaction, proactive involvement of top management is essential. Active and latent failures are distinguished by the length of time taken to reveal the adverse effects. Active failures are immediate observable causes in an accident and those are easily identifiable. Active failures have direct impact upon the integrity of the system. In contrast, latent failures might be present in the system for many years, before getting revealed by active failures. Adverse consequences of latent failures may remain dormant within the system for a long time and become evident when combined with other factors to breach the defenses in system. Latent failures are difficult to detect and these are hidden in the organisation; examples are, poor design, gaps in supervision, lack of training etc. Active errors are caused by front-line performers, whereas latent errors are caused by those who are not involved in the direct control of the work such as designers, decision makers, managers etc. In general, safety programs are aimed at reducing active failures. However, organizations shall look into reducing latent failures also to achieve effective accident prevention and control program to get long term benefits (HSE, UK, 2002 [50]; Katsakiori et al., 2009 [66]).

2.4.3 Factors Contributing Accidents and Injuries

Accidents and injuries occur due to a series of events starting from hazards in work place. Injuries occur due to multiple reasons comprising of individual factors, job factors and organizational factors (Khanzode et al., 2012 [67]; Pisharody et al., 2018b [92]).

Individual Factors:

Individual factors are age, gender, work experience, living habits, use of personal protective equipment etc. Analysis of 621 fatal falls in Taiwan Construction Industry indicates that majority of victims were male (92.1%), between 25 and 44 years (51.4%), worked for companies with less than 30 workers (26.4%) and had less than 1 year of work experience (80.5%). Male workers were more susceptible to fatal falls as they were exposed to more hazardous working conditions in construction industry when compared to female workers. Injury risk is increased by inadequate work experience, advancing age, and unhealthy living habits. Injury risk rises and falls like a bath tub curve with age. Due to a lack of understanding and work experience, it is particularly high during the first a few years of employment. Young workers of less than 24 years old in Taiwan Construction Industry were vulnerable to fatal falls due to inexperience and carelessness. As the person gains job experience and becomes more aware of safety regulations, vulnerability to fatal falls decreases. As the age increases, workers gain experience and they are less susceptible to fatal falls, indicating that age or experience is beneficial to workers for a certain period of time. However, aging becomes less advantageous over a certain age. Fatal falls of workers of 55 and above age could be due to physiological weaknesses, reduced sensory capability such as decline of vision, hearing, reduced physical strength and flexibility; and mental inability to comprehend.

There is also another viewpoint that as people gain experience, they may get complacent and pay less attention to safe work procedures, thus increasing their risk for injury. This can be solved by assigning personnel with diverse levels of experience, ranging from inexperienced to highly experienced. Absenteeism, lack of emotional stability, risk-taking behavior, job unhappiness, and tendency for violations of established procedures and standards are all negative personality traits that can affect a person's relationships in work environment and contribute to accidents and injuries.

Accidents and injuries are also caused by living habits such as alcohol consumption and smoking. Risks of injury for each worker depends upon age, body mass index, hearing disorders, sleep disorders, and sporting activities. A worker who is young or overweight or having any hearing or sleep disorder and without sports activities has more risk for accidents than another worker without these risk factors. Workers with ‘risk accepting’ nature, who claim that ‘it won't happen to me!’ are more susceptible to accidents than workers without this attitude. Fatalities in smaller companies were found to be more. This could be due to their inability to afford safety management programs and as also these companies are less likely to be inspected by regulatory agencies (Antonio et al., 2012 [3]; Chi et al, 2005 [28]; Khanzode et al., 2012 [67]; Sawacha et al., 1999 [103]; US NRC, 2010 [116]).

Job Factors

Job factors are nature of hazards involved in the job. Injury risk is high while performing hazardous jobs. Since injury risk depends on the job factors, these are predictors of injury associated with job. As a result, job factors have a greater influence than individual factors. Due to changes in work and workplace factors, there are higher risks of getting injured when performing specific activities (Khanzode et al., 2012 [67]; Pisharody et al., 2018b [92]).

Hazardous jobs carried out in hazardous work environments without necessary safety precautions raise the risk of accidents and injury. Machines, for example, have a variety of risks that might cause injury or death if they are exposed to them. The following are the potential hazards:

1. **Structural Hazards** such as sharp edges, projections etc.
2. **Mechanical hazards** such as entanglement, crushing, cutting etc.
3. **Physical Hazards** such as electricity, pressurized content, noise, vibration, hot or cold temperatures etc.
4. **Ergonomic Hazards** such as repetitive actions, uncomfortable working situations, and manual handling etc.
5. **Slip, Trip or Fall Hazards** such as inadequate walkways, uneven floors, slippery floors and railings etc.
6. **Chemical Hazards** such as gases, vapors, liquids, and other substances
7. **End Use Condition Hazards** such as location, impact on workplace layout etc. and
8. **Biological Hazards** such as bacteria, mold, fungus etc.

Throughout its life cycle, which includes installation, commissioning, operation, maintenance, troubleshooting, repairs, adjustments, set up, handling production disturbances, cleaning, and dismantling, the ability of a machine to perform its intended function in safe manner, without causing any injury to the job performer should be considered. Workers are always exposed to the above-mentioned hazards as they work with machinery at all stages of its life cycle. Many major injuries and deaths have resulted from the moving parts of machinery. In the United States, 8505 persons died in machine-related accidents between 1980 and 1989, with an average annual death rate of 0.8 per 100,000 workers. Any area in or around a machine, which poses a risk to the worker's health and safety is referred to as a hazardous zone. Machines must be developed and built to keep hazardous zones out of reach of workers (Chinniah Y., 2015 [29]).

According to Chinniah Y. (2015 [29]) main causes of injuries due to machines are:

1. Working parts of machine are easily accessible;
2. Insufficient safeguarding;
3. Lockout procedures were not implemented;
4. Lack of experience workers;
5. Safeguards are bypassed;
6. Inadequate risk assessment;
7. Inadequate supervision;
8. Machines are poorly designed;
9. Unsafe Working practices;
10. Workers are not given clear instructions on how to intervene safely on machinery; and
11. Modifications to machinery and control systems without taking into account potential for new risks as a result of the changes.

Chinniah Y. (2015 [29]) further states that machine parts that could cause injury should be guarded, and the following are some general corrective measures:

1. Installing fixed guards;
2. Adding interlocking guards, including guards that previously allowed access to moving equipment parts;
3. Adding guard interlocking, i.e. a device that prevents the guard from opening as long as the moving parts of machines are not halted, for machinery with inertia-accumulating parts; and
4. Compliance to work permit system, guaranteed isolation from mechanical and electrical power and lock out and tag out system.

Manual material handling, which causes musculoskeletal diseases, strains, and sprains, is another common cause of job injury. Working on electrical systems without adequate electrical safety measures is yet another cause of work place injury. Other job-related factors that cause workplace injuries include poor housekeeping, insufficient work space, working in night shifts, high job stress, high job dissatisfaction, lack of job responsibility, and poor work execution (Khanzode et al., 2012 [67]).

Organization Factors:

According to Antonio et al. (Antonio et al., 2014 [3]), a large company is not always safer than a small company; experienced employees may not have the lowest accident rates. The authors identified following three types of underlying factors for fatal accidents and high-potential incidents:

1. **Macro Factors**, such as society, education, industry, and labour unions;
2. **Mezzo Factors**, such as project management, organisation, and procurement; and
3. **Micro Factors**, such as concerns relating to workers, workplaces, and supervisors.

Reason identified following seven organizational contributing factors to the accidents as shown in **Figure 2.6** (Reason, 1991 [97]; Pisharody et al., 2018b [92]):

1. **Pathological-Reactive:** In industry, safety practices are the bare minimum to meet regulatory requirements, with no commitment from management.
2. **Incipient-Reactive:** Safety practices are barely above regulatory requirements, and management appears to be concerned about safety.
3. **Worried-Reactive:** Management is concerned about the frequency of accidents.
4. **Repair-Routine-Reactive:** Accidents are treated with fair sensitivity by management, and takes corrective action.

5. **Conservative - Calculative - Reactive:** Auditing and workplace safety measures based on technological and human error issues are prioritized by management.

6. **Incipient-Proactive:** Management begins to recognize relevance of organizational factors and actively seeks engineering solutions to prevent and control accidents.

7. **Generative-Proactive:** Management is dedicated and proactive. Safety and corrective actions are examined and applied on regular basis across the organization.

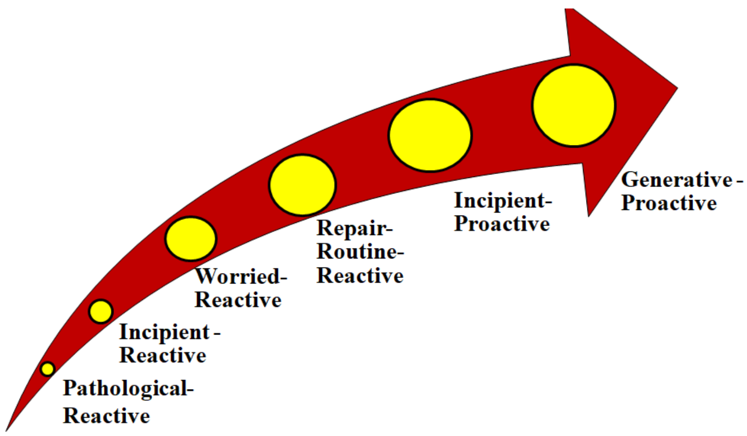

Figure 2.6: Organizational Factors Contributing Accidents
(Ref. Reason, 1991 [97]; Pisharody et al., 2018b [92])

Safety climate, workgroup size, management support, colleague support, supervisory support, workplace safety procedures, and management commitment to workplace safety are significant organizational factors that are taken into account for the occurrence of accidents. Safety climate is the summary of perceptions that employees share about their work environment. Higher the support and commitment of management, coworkers and supervisors towards safety, the less will be the accidents. Individual and job factors are influenced by organizational safety factors. Individual and job factors function as precursors to safe behavior. Safe workplace behavior lowers the risk of injury (Khanzode et al., 2012 [67]; Pisharody et al., 2018b [92]).

Patel and Jha, 2016 [88] in their evaluation of construction projects based on safe work behaviour of co-employees identified safety rules, procedures, personal appreciation of risk, supervisory environment, work pressure, employees' involvement, commitment, supportive environment, workers' involvement, communication, work pressure, competence, and appraisals of physical work environment and work hazard as significant organizational factors supporting safe behaviour of construction employees. The authors suggest that an effective and supportive environment may be developed by organizing social and safety awareness programs at construction projects with the objectives to motivate workers and to increase awareness of the safety issues.

Productivity, bonus compensation, and safety performance have a high correlation. Bonus incentives may entice staff to boost productivity even if it means adopting risky practices. This may result into accidents. Also, management attitude to increase productivity may increase work pressure on the workers, which may lead to increased accidents. Since good safety performance and high productivity are complimentary to each other, organizations may adopt safety bonus based on compliance to safety requirements while performing jobs, rather than production bonus (Sawacha et al., 1999 [103]).

Supervisors have a vital role in enforcement of safety measures. If supervisors demonstrate importance to safety, workers will follow them. Frequent interaction of supervisors with workers for enforcing safety through pre-job briefing, tool box talks, coaching and mentoring will reinforce compliance to safety measures among the workers and support accident prevention. Supervisors and workers with high level of knowledge, skills and attitude often support safety requirements (Sawacha et al., 1999 [103]).

Safety education and training has a key role in accident prevention. Providing safety kits and personal protective equipment to workers is not enough. They should be trained on correct use of safety kits and personal protective equipment. Management shall give due importance to safety education and safety training. Management participation, such as safety policies, worker relationships, safety representatives, safety talks etc.; has a good impact on safety performance. Managers shall make all efforts to ensure that safe working conditions are established at the design stage itself.

2.4.4 Accident Causation Theories

Injury due to accident occurs due to unplanned or unwanted release of energy or hazardous materials above the threshold limit of human structure. Severity of injury depends on the amount of energy or hazardous materials transferred and vulnerability of body tissue to get damaged. Accident causation theories are classified based on the themes ‘Person as Cause’, ‘System as Cause’, ‘Person and System as Cause’ and ‘System-Person Sequence as Cause’. Classification of accident causation theories is given in **Table-2.3** (Lees, 2004 [71]; Khanzode et al., 2012 [67]; Pisharody et al., 2018a-b [91] [92])).

Table-2.3

Classification of Accident Causation Theories (Ref. Lees, 2004 [71]; Khanzode et al., 2012 [67]; Pisharody et al., 2018a-b [91] [92])

Accident Theme	Accident Causation Theory
Person as Cause	1. Pure chance hypothesis 2. Accident proneness theory 3. Unconscious motivation theory 4. Adjustment stress theory 5. Goal freedom alertness theory
Person or System as Cause	1. Domino sequential theory
System as Cause	1. Swiss cheese theory 2. Epidemiological theory
System - Person Sequence as Cause	1. Systems theory 2. Houston theory

Person as Cause Theme:

‘Person as Cause’ theme highlights individual factors for accident causation and considers personality traits liable for accident or injury. The first generation of accident causation theories reflects this, as summarized below:

Pure Chance Hypothesis: According to this theory, everyone has an equal risk of being involved in an accident. Accidents do not follow any particular pattern, and they are seen as acts of God. This theory is founded on emotions.

Accident Proneness Theory: According to the findings, due to innate personality features known as accident proneness, certain groups within a population are more likely to be involved in accidents. Individuals' socio-psychological conduct and stress may contribute to their accident proneness. Individuals who have frequent injuries indicate presence of accident proneness. An individual’s accident proneness may change with age. High energy for taking risks can lead to accidents while one is young, but low energy for overcoming risks can lead to accidents when one becomes older. Individuals are blamed for accidents in these models, and behavioral adjustments are suggested to improve safety.

Unconscious Motivation Theory is grounded in psycho-analytic thought. Accidents, according to this theory, are induced by subconscious processes such as guilt, aggressiveness, anxiety, ambition, and conflict. The hypothesis focuses on an individual's personality attributes as well as their perspective of their work environment. It implies that negative feelings about one's employment and workplace, as well as withdrawal from work, can lead to workplace accidents. The theory suggests behavioral interventions for improving safety performance.

Adjustment-Stress Theory holds the view that, Individuals who are unable to adapt to their jobs and work environments are more likely to be involved in accidents than those who are able to do so. Physical and psychological pressures may cause inability to adjust.

Goal Freedom Alertness Theory says that due to a lack of attentiveness on the job and a lack of freedom to set job goals, some people are prone to accidents.

Person and System as Cause Theme:

‘Person and System as Cause’ theme considers that individual factors and system failures both contribute to accidents. Heinrich’s Domino Sequential Theory is based on Person and System as cause theme.

Domino Sequential Theory postulates that an injury occurs as a result of a series of circumstances indicated by falling of five dominoes consisting of ancestry and social environment, fault of persons, hazards, accident and injury as shown in **Figure 2.7** (Heinrich et al., 1980 [46]; Pisharody et al., 2018b [92]). It is a linear model in which one-by-one progression of events leads to an accident. Any one of the dominoes can be removed to stop the accident and avoid injuries. The first two dominos i.e., ancestry and social environment; and fault of persons are beyond organization's control; hence the third domino i.e., hazards due to unsafe conditions and unsafe acts, are controlled to prevent accidents. Ancestry, social environment and fault of persons and unsafe acts follow "Person as Cause” theme. The 'System as Cause' theme is used to explain why unsafe conditions exist. This theory adopts a 'Person and System as Cause’ theme for the accidents in combination. According to Heinrich, 88% of accidents are caused by unsafe acts, 10% by unsafe mechanical or physical conditions, and 2% are unavoidable.

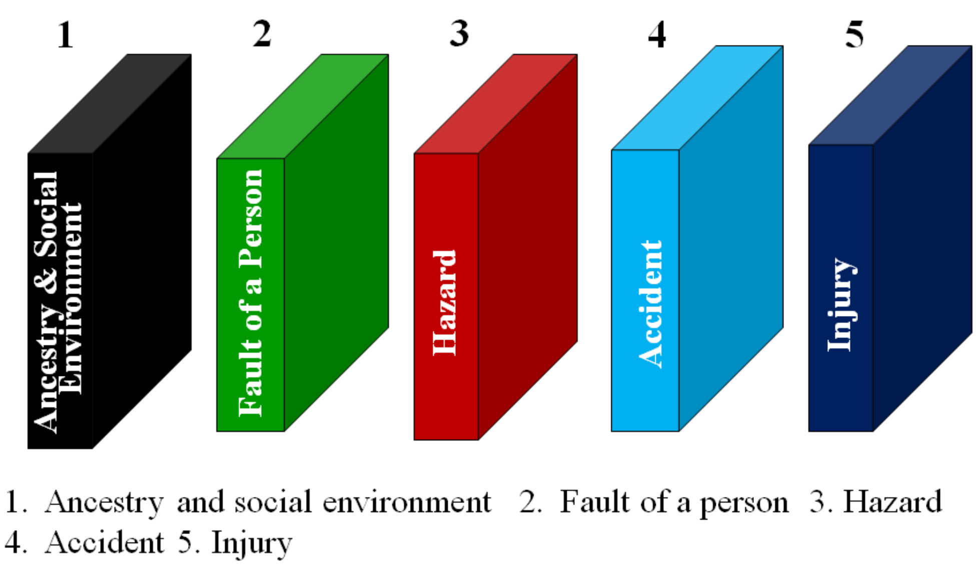

Figure 2.7: Heinrich’s Domino Theory of Accident Causation
(Ref. Heinrich et al., 1980 [46]; Pisharody et al., 2018b [92])

Bird and Loftus (Bird and Loftus, 1976 [9]) replaced Heinrich's first three dominoes with 'Lack of Control' due to poor management, 'Basic Causes' of individual and job factors, and 'Immediate Causes' of unsafe acts and unsafe conditions respectively. Accident causation is depicted in both Heinrich's and Bird's models as a one-dimensional sequence of events (Katsakiori et al., 2009 [66]).

According to Domino theories, the only causes of accidents are unsafe acts and unsafe conditions, leaving out other causes like organizational factors. Manuele (2011 [74]) argues that Heinrich's argument that unsafe acts cause 88% of the accidents is incorrect as evidence on data collecting, survey documents, information quality, and analytical methods applied by him are not available. Accidents, according to modern theories on accident causation, are caused by organizational factors rather than by worker's error. Overemphasizing unsafe acts and unsafe conditions as causes of accidents may diminish the importance of accident prevention based on organizational factors and may shift focus towards human errors for the causation of accidents (Manuele, 2014 [75]).

System as Cause Theme:

According to the ‘System as Cause’ theme, accidents occur as a result of system failures rather than individual errors. Swiss Cheese Model and Epidemiological theory are two themes of accident causation with System as Cause.

Swiss Cheese Model consists of a series of Swiss cheeses with holes cut at random and put in a series as illustrated in **Figure 2.8** (Pisharody et al., 2018b [92]).

Each slice represents a safety barrier, whereas each hole indicates a potential barrier failure condition. There will be an accident if a failure mechanism makes it through all the holes. There will be anomaly if there is a deviation from the sequence. Accidents can occur when an anomaly occurs in conjunction with favorable circumstances. Anomaly denotes a system failure, hence follows System as Cause theme (NASA, 2011[79]; OHS Body of Knowledge, 2012 [86]; Moura et al., 2016 [77]; Manuele, 2014 [75]).

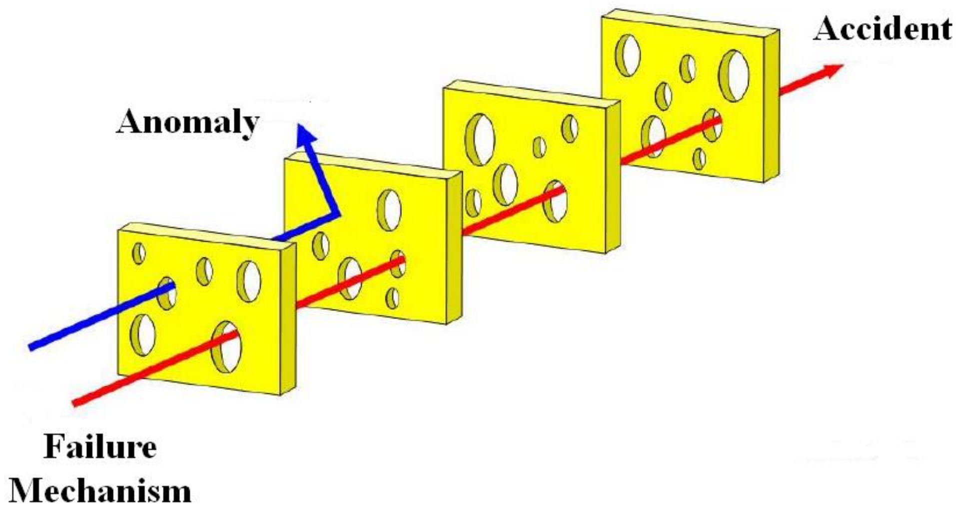

Figure 2.8: Swiss-Cheese Model of Accident Causation
(Ref. Pisharody et al., 2018b [92])

Epidemiological theory recognizes similarity between occurrence of accidents and diseases. In this theory, injury is compared to an agency which causes disease to the human body. While injuries do immediate damage to the human body, diseases take longer to do so. According to this theory, the number of pathogen latent failures, such as unsafe conditions within the systems, determines the probability of accidents. To describe the injury phenomena, injury epidemiology models consider three factors: 'Host,' 'Agent,' and 'Environment.' The injured individual is the 'Host', the energy that causes injury is the 'Agent', and 'Environment' is the physical, biological, and organizational factors. To sustain a healthy or injury-free state, epidemiological theory implies equilibrium between Host, Agent, and Environment. Any disruption to this equilibrium will render the host ill or injured (Gordon, 1949 [41]).

System - Person Sequence as Cause Theme:

'System-Person Sequence as Cause' theme proposes that accidents are caused by successive interactions between the system and the person. On this theme, the systems model of accident causation is developed.

Systems model of accident causation considers that in order to produce output, Worker, Equipment, and Environment interact with one another as shown in **Figure 2.9** (National Safety Council, 2001a-b [81] [82]; Pisharody et al., 2018b [92]). When a worker detects a hazard, he or she takes necessary control actions to return the system to a safe state. This process is interrupted by an accident. To ensure worker safety, equipment must be designed, maintained, and used correctly. Workers' health, safety, and comfort should be incorporated in the design of workplace environment. When the worker performs task on an equipment in unsafe environment, there could be accident. Accidents will be less likely and have less consequences, if interfaces between workers, equipment, and the environment are well managed.

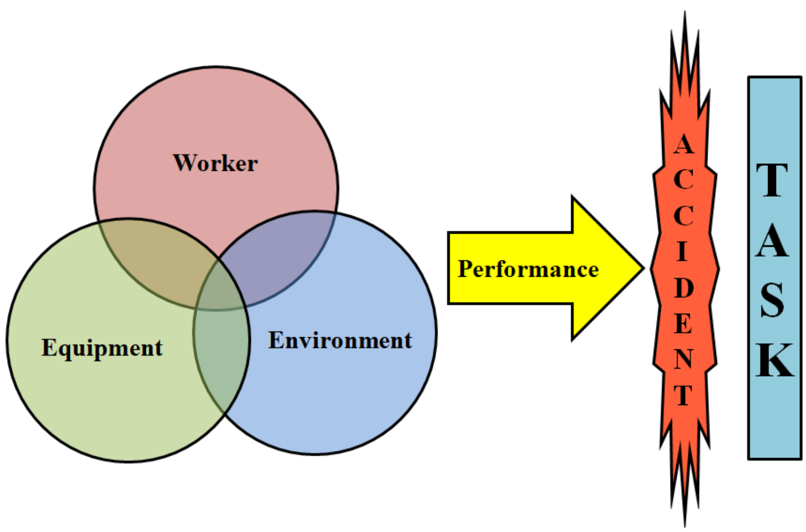

Figure 2.9: Systems Model of Accident Causation
(Ref. National Safety Council, 2001a-b [81] [82]; Pisharody et al., 2018b [92])

Houston's accident-process theory postulates that a series of interactions between the Target, Driving Force, and Trigger leads to an accident. Energy is the primary Driving Force. Target has threshold intensity, below which Driving Force has no impact. Triggers also have a threshold level, below which they do not work. Target is injured by the Driving Force as a result of Trigger. Accidents can be avoided by lowering energy of Driving Force or erecting barriers between the Driving Force and Target (Lees, 2004 [71]).

Safety hazards, safety climate, and production pressure significantly influence safety efficacy and casual attitude of employees. During peak production, the risk of an accident rises. Increased production pressure may compromise safety efficacy. Employees with a casual attitude are more likely to break safety rules and become risk takers (Brown et al., 2000 [24]). Accidents can also be caused by deficiencies in hardware, design, maintenance management, goals, housekeeping, communication, organization, training, safety measures, and introduction of error-prone situations (HSE UK, 2003a-e [51] [52] [53] [54] [55]).

There are three sorts of accident causation theories: linear, epidemiological, and systemic. Heinrich's Domino Theory is a linear model that describes an accident causation chain. The linear model is easy to understand. However, it may be misconstrued to mean that an accident can be prevented merely by removing one of the dominoes, such as unsafe worker behavior. Epidemical accident causation theory explains latent failures of an accident phenomenon and it is based on the premise that an accident is not due to sequential development; rather it is an outcome of a concurrent combination of factors. Isolating error-promoting conditions; and reinforcing barriers and safeguards are remedial efforts in epidemical accident causation theories. In systemic accident causation theory, accidents are considered as representations of performance at the level of a system as a whole, rather than a specific cause-effect mechanism. In this theory, accidents are considered as emergent phenomena in a system. Therefore, predicting the outcome of a specific initiating event could be is unrealistic (Shin, 2015 [106]).

2.5 ACCIDENT INVESTIGATION

Accident investigation provides meaningful information on the cause of accident as well as gives a profound insight for accident prevention (Moura et al., 2016 [77]). It helps to learn lessons and provides information on human, organizational and technical factors associated with accidents, and facilitates corrective actions. Depth of an accident investigation is a measure of transparency, safety culture, and management commitment to understand and correct accident causes. Accidents occur or can recur despite excellent safety performance, if organizations do not learn from their mistakes and do not address the root causes of accidents.

Management will be eager to find true causes of accidents in an organization with a positive safety culture. Accident investigations will be based on the facts, in such organizations. The success of an accident investigation is dependent on blame-free culture, absence of fear of retaliation, and the belief that the information gathered will be used for the benefit of all parties involved. In order to be impartial, accident investigation should be conducted by an independent team that is not associated with the area or job where the accident happened (Manuele, 2014 [75]).

According to Pisharody et al., (2018b [92]), a true accident investigation is hampered by the following barriers:

1. Investigating team's training and knowledge are insufficient.
2. When supervisors of the work in which the accident occurred investigate incidents, they may fail to point out flaws for which they themselves are personally accountable.
3. If management is unwilling to cooperate, a thorough investigation will be impossible.
4. Accident investigations may be prejudiced in organizations with a blaming culture, and corrective actions in such organizations may include reprimanding of individuals.

According to Heinrich et al., (1980 [46]), 88 % of accidents are caused by unsafe acts or human error. Accidents are caused by a variety of factors, including human error. However, human error is a symptom of systemic problem. A systemic accident model considers the entire system, including its design, development, operation, and maintenance, rather than just human errors. The first step in addressing human errors is to look at the workplace design and work procedures (Manuele, 2014 [75]; Pisharody et al., 2018b [92]). Safety should be imbibed in the design itself with the objective of avoidance of human errors.

According to Manuele (2014 [75]), following factors shall be taken into account in the design for safety:

1. Risk should be within the acceptable range.
2. Human errors should account for a small percentage of work system and procedure failures.
3. During operation and maintenance, hazards and risks should be kept to a bare minimum.
4. System should be designed in such a way that requirement of personal protective equipment is minimal while performing the job.
5. Design should conform to applicable codes and standards.

Many serious injuries and fatalities are low-probability events with multiple, complex contributing factors, such as poor design, supervision weaknesses, poorly developed procedures, undetected manufacturing defects, maintenance failures, insufficient training, insufficient tools or equipment, and other technical, operational, cultural, or administrative issues (Manuele, 2014 [75]).

According to Pisharody et al. (2018b [92]), following are the most common working conditions in which serious injuries and fatalities occur:

1. Out-of-the-ordinary tasks and plant transients.
2. Plant or equipment shutdowns, maintenance, and start-ups.
3. When working in close proximity to high-energy sources.
4. Construction and modification of plant structures, systems and components.

Depending up on the working conditions, methodology of accident investigation may vary. However, answering the questions involving five Ws and one H i.e. 'What happened?' ‘When did it happen?' ‘Where did it happen?’ ‘Why did it happen?’ 'Who is involved in it?’

and ‘How did it happen?' should be an integral part of accident investigation (Reason, 1991 [97]; Pisharody et al., 2018b [92]). The 'Why' and 'How' of these involve root cause analysis using the 'Five Why Technique,' which entails asking 'Why' at least five times to determine the underlying cause (Pisharody et al., 2018b [92]). Ideal accident investigation follows 'What You Find Is What You Fix' principle, which means that the causes of the accident should be identified first, and then remedial actions should be taken to address those causes. However, 'What You Find Is Not Always What You Fix,' despite the fact that most of the investigations follow 'What You Find Is What You Fix' approach. Several constraints influence identification and implementation of appropriate corrective actions. Thus, 'What You Find Is Not Always What You Fix' (Jonas et al., 2010 [64]). Experience and competency of investigators are some of the restrictions in achieving 'What You Find Is What You Fix’. In addition, resources, time, data availability, management support, acceptance of investigation results, and lack of a stop rule to determine scope of the investigation also influence accident investigation and implementation of corrective measures. Most of the accidents are caused by ineffective leadership, lack of supervisory control, and lack of organizational learning (Taylor et al., 2015 [113]). Results of accident investigation are sometimes too immature that remedial actions increase complexity. In fact, accident investigations should be conducted with the goals of preventing recurrence, assigning responsibility, and also developing accident models for theoretical understanding (Hale et al., 1991 [44]).

The investigation of an accident should be unbiased. Unfortunately, some sort of bias enters into accident investigations due to 'Author Bias,' i.e. a reluctance to accept the conclusions of other investigations; 'Confirmation Bias,' i.e. the propensity to confirm predetermined causes; 'Frequency Bias,' i.e. the tendency to classify causes into common categories; 'Political Bias,' when an individual's standing and position have undue influence; and 'Sponsor Bias,' where an organization's reputation may be jeopardized (Jonas et.al, 2010 [64]; Pisharody et al., 2018b [92]). Bias can be reduced in accident investigations by forming independent investigation panels of specialists from many fields who are relevant to the type of accident.

Accident data collection and analysis are critical for risk assessment and making risk-informed decisions for accident prevention. However, due to under-reporting or non-reporting, it is difficult to gather genuine and factual data with quality and in-depth information (Hale et al., 1991 [44]). Since only 40% of the injuries are reported, published accident data are only the tip of the iceberg (Haslam et al., 2005 [45]). Therefore, lessons from the accidents are still to be learned, as many accidents are not reported. Accidents of lesser severity are either under-reported or not reported at all due to media's lack of interest. In such cases, data will be made available only to meet regulatory requirements, if at all it is reported. This sometimes reduces accident investigations to a simple checklist filling, obviating the need to address underlying issues (Carol et al., 2002 [26]). In order to have an effective accident prevention and control program; all disruptions, anomalies, near misses and accidents, however small the severity may, shall be investigated to identify and address the causes to prevent recurrence.

2.6 HUMAN FACTORS, ORGANIZATIONAL SAFETY CULTURE AND SAFETY PERCEPTION

2.6.1 Human Factors

Accidents occur due to interface between human factors and organizational factors. Because human mind is effective in detecting and eliminating possible hazards. Human factors play a significant role in building a safety culture at the organizational grass roots. Employee behavior is influenced by human factors such as environmental, organizational, and job factors, all of which have a substantial impact on their health and safety (HSE UK, 2007 [56]). Mere adherence to the written down documents is not adequate. Individuals shall demonstrate high degree of safety culture while performing jobs. All jobs must be done appropriately with utmost vigilance, consideration for health and safety, complete information, solid judgment, and proper sense of accountability.

Human factors aim to create systems, jobs, and organizations that are adapted to human abilities and limitations. Depending on the type of technology, nature of human factors issues varies. Manual and automated systems, for example, will have different human factors considerations. According to Pisharody et al. (2018b [92]), following aspects should be well-thought-out in the design and development process, when considering human factors:

1. Most successful technique for controlling hazards and risks associated with human factors is to address them at the design stage itself and continuing it throughout the life cycle.

2. System should be designed to aid operators.

3. Human factors issues should not be treated as an afterthought.

4. Human factors activities must emerge in tandem with technology advances.

Pisharody et al. (2018b [92]) further states that, five essential human factors aspects to be included within the overall design process are:

1. **Plan human centered process**: Make sure that, relevant human factors activities are planned for and properly resourced.

2. **Understand and specify the context of use**: Determine who will be using the system and what they will do. Make sure that user attributes and duties are taken into account when designing.

3. **Specify user and organizational requirements**: Describe the system's qualities that affect users and the organization.

4. **Produce design solutions**: Apply human factors knowledge to come up with design solutions that fulfill user needs. Iterative design is a good way to go. Prototypes can be used to clarify needs.

5. **Evaluate design against user requirements**: Involve target users and human factors experts in testing requirements.

The majority of accidents are caused by human actions that could have been prevented if suitable actions had been taken at the right time. About 80% of the incidents attributed to human factors are caused by individual acts or omissions (HSE UK, 2007 [57]). Despite the fact that advanced controls, automated safety systems, and structured documentation systems can assist in the creation of safer operating environments, human intervention is essential in accident prevention and control. Therefore, the duty of human being for maintaining safety should not be disregarded (Rathnayaka et al., 2011a-b [95] [96]). Accident rates are lower when management is committed to safety. Poor decision-making is one of the most common causes of accidents. Decision-making errors might go undiscovered for years before they cause an accident. Benchmarking safety management strategy and climate across organizations at regular periods will help to create a safer work environment and improve safety climate (HSE UK, 2003a-e [51] [52] [53] [54] [55]).

Accident prevention relies heavily on safety education and training. Haslam et al. (2005 [45]) in their study on contributing factors of construction accidents found that construction workers are engaged in unsafe acts for the following reasons:

1. Due to enormous workloads and construction work priorities, safety is neglected;

2. To save time and effort, shortcuts are used;

3. Risk perception is inaccurate, leading to the belief that 'It Won't Happen to Me.'

Haslam et al. (2005 [45]) further argue that the foregoing behaviours are attributable to a lack of safety understanding as a result of ineffective safety education and training. Safety education offers high-level knowledge and abilities that may be applied in a variety of scenarios, whereas safety training is more context specific, addressing procedures or regulations for performing specific tasks or activities. Individuals with effective safety education are able to assess a situation and respond appropriately. Safety training, on the other hand, gives more specific instructions on how to do a task. It is necessary to have a combination of safety education and training. However, due to the safety trainers' lack of knowledge, skill, attitude, and understanding, the effectiveness of safety education and training may be compromised. If safety training fails to engage participants, they may develop damaging negative attitudes toward safety. When learning is based on 'On the Job,' with no health and safety instruction at the supervisory, managerial, or professional levels, the wrong attitude towards safety is likely to spread and be perpetuated. This ultimately will lead to unsafe human behaviour by the workers and increased accident rate.

Shin (2015 [106]), based on a study of 38 fatal accident cases involving tower cranes in Republic of Korea between 2001 and 2011 on 'Factors That Affect Safety of Tower Crane Installation or Dismantling in Construction Industry', found that tower crane installation or dismantling is one of the most dangerous tasks in the construction industry. Human factors such as human error, insufficient knowledge and skills of erectors and dismantlers; insufficient instructions on safe work procedures; noncompliance to procedures and manufacturer's instructions; deterioration of tower crane parts due to poor storage conditions; insufficient supervision at the work site and poor working conditions, such as time constraints and space constraints, as well as lack of safe work programme, etc. accounted for approximately 68.4 % of fatal accidents during the installation or dismantling of tower cranes.

2.6.2 Organizational Safety Culture

Organizational safety culture is that assembly of characteristics and attitudes in organizations and individuals; which establishes that, as an overriding priority, plant safety issues receive the attention warranted by their significance. In other words, it is an organizational culture that places a high level of importance on safety beliefs, values and attitudes and these are shared by the majority of people within the organization. It can also be characterized as 'The Way We Do Things around Here'. Organizational safety culture comprises of basic values, norms, perceptions and practices within the organization and among the individuals that, safety related issues are received the importance as warranted (IAEA, 1991[60]; Biggs et al, 2008 [8]; Manuele, 2014 [75]; Pisharody et al., 2021[93]).

This implies that safety culture in an organization is related to characteristics and attitudes of individuals as well as organization. It is not necessary that an organization with well documented procedures and regulations will have good safety culture; rather it depends on how well it is being practiced, even without any supervision.

Safety culture development is a management driven and worker supported activity. It consists of two components i.e., a frame work by means of organizational policy by the management and response of individuals to work within the frame work. Success of the safety culture frame work depends on the commitment by the management and compliance by the individuals. A positive safety culture will lead to improved workplace and organizational safety performance. It is permanent in nature; and management commitment and workers' support can bring continual improvement to it. Accidents and injuries are caused by a variety of systemic causes that are largely a reflection of organizational safety culture. Safety is given a high priority in organizations with strong management commitment. As a result, the number of accidents in such organizations will be less.

Key element of positive safety culture is an all-pervading safety thinking, which allows questioning attitude, prevention of complacency, commitment to excellence and fostering of both personal accountability and organizational self-regulation in safety related issues. Key characteristics of organizations with positive safety culture are (IAEA, 1991 [60]; HSE UK 2003a-e [51] [52] [53] [54] [55]):

1. Individual awareness on the necessity of safety is increased through trainings, instructions, and self-education to guarantee that safety measures are implemented consistently.

2. Individual motivation and leadership to increase safety through the formation of objectives, reward and reprimand systems, and self-generated attitudes.

3. All jobs are supervised, and supervisors are trained to be role models, with audit and review procedures in place, as well as the ability to respond to individuals' skeptical views.

4. Workers are educated and trained to ensure compliance to safety requirements, even without any supervision.

5. Delegation of authority and responsibility through effective personal communication, formal assignment and description of duties, and ensuring that persons understand them.

6. Active managerial participation and visible commitment by placing a high priority on safety and bringing everyone in the business together to achieve a common goal of safety.

Pisharody et al. (2021 [93]) states that five attitudes which may adversely affect organizational safety culture are:

1. Employees have the impression that their senior management is unconcerned about workplace safety.

2. Emphasizing only the importance of completing the tasks at hand.

3. Financial concerns are always prioritized before safety concerns.

4. Safety statements are not included in job descriptions as part of important job activities.

5. Ongoing programs, which are evidence of management commitment to health and safety, are lacking.

Supervisor or front-line manager is the key individual in accident prevention as they are in daily contact with staff. Supervisor or front-line manager gets opportunity to control unsafe conditions and acts leading to accidents. Important aspects of supervisory behaviour include attitudes and approaches to safety and training, nature and extent of interaction with employees, and thoroughness and willingness to learn from accident investigation (Haslam et al., 2005 [45]).

Many serious injuries are caused by insufficiently conservative decision-making and lack of organizational safety culture. Accidents and injuries may be caused by latent weaknesses such as unsafe design, insufficient supervision, inability to recognize and remedy unsafe conditions, insufficient training, and improper tools, in combination with a weak organizational safety culture. Top management's culture has an impact on organizational safety culture. Workplace hazards are easier to control than human minds. Therefore, top management must take lead in cultivating a strong positive safety culture within organization in order to address human factors. Since organizational safety culture is an assembly of both individual and organizational characteristics, the frame work for positive safety culture development should consist of human factors and organizational factors. The highest level of safety culture is achieved if the individuals and organization are aligned and dedicated towards a common goal of establishing strong positive safety culture (IAEA, 1991 [60]). Safety culture in an organization can be assessed by conducting a Safety Perception Survey.

2.6.3 Safety Perception

If safety performance is not measured, it is not managed. By not measuring safety performance, organization will miss the opportunity for future improvement. Safety performance in an organization can be measured by monitoring lagging and leading indicators (Taizer J. and Cheng T., 2015 [114]; Ryan D., 2019 [101]; Pisharody et al., 2021 [93]).

Lagging indicators are based on accident statistics such as Frequency Rate, Severity Rate, Man days Loss etc. Since lagging indicators are standardized, these are good for benchmarking safety performance of one organization against its peer organizations. These indicators give information to take corrective measures in reactive manner. Therefore, lagging indicators cannot be used to prevent the occurrence of an incident; however, these can be used to prevent recurrence of accidents. Leading indicators are based on proactive parameters such as near misses, safety audits, safety training, safety training effectiveness etc. Leading indicators can be used to improve future safety performance and to take measures to prevent accidents. Hinze et al. (2013 [47]) gives a comparison of leading and lagging indicators as given **Table 2.4** below:

Table-2.4

Comparison of Leading and Lagging Indicators (Ref. Hinze et al., 2013 [47])

Leading indicators	**Lagging indicators**
Upstream indicators	Downstream indicators
Predictive indicators	Historical indicators
Heading indicators	Trailing indicators
Positive indicators	Negative indicators

Since leading indicators are proactive in nature, they are used to make changes to the safety process in order to prevent injuries from occurring. Whereas being reactive in nature, lagging indicators are aimed at making changes to prevent recurrence of already occurred injuries (Hinze et al., 2013 [47]). Though measurement of safety performance by monitoring leading indicators is a proactive approach, in reality, an organization's safety performance is determined by a number of elements, including management support for safety, employee perceptions of safety, the effectiveness of corrective and preventative action programs, and consideration of human factors, among others. When incidents occur and repeat, despite all efforts, organizations are frequently perplexed. As a result, in addition to traditional methods for assessing safety performance using lagging and leading indicators, it is imperative to go above and beyond by soliciting direct input from employees who are getting injured in incidents. This information is gathered through safety perception surveys. Employees' collective expertise on accident prevention and control is obtained through safety perception surveys, which help organizations to gather their collective knowledge (Taizer J. and Cheng T., 2015 [114]; Ryan D., 2019 [101]; Pisharody et al., 2021 [93]).

According to Pisharody et al. (2021 [93]) safety perception surveys assist in identification of elements that influence safety culture and safe behavior. Once these elements have been identified, actions to attain safety excellence can be determined.

The following are the goals of safety perceptions surveys:

1. To conduct a quantitative evaluation of human factors and safety culture.

2. To determine how employees, feel about current safety performance evaluation methodologies.

3. To determine if there is a gap between employee and management perceptions on safety.

4. To determine how employees, feel about the effectiveness of organizational policies, documents, and management commitments in terms of safety.

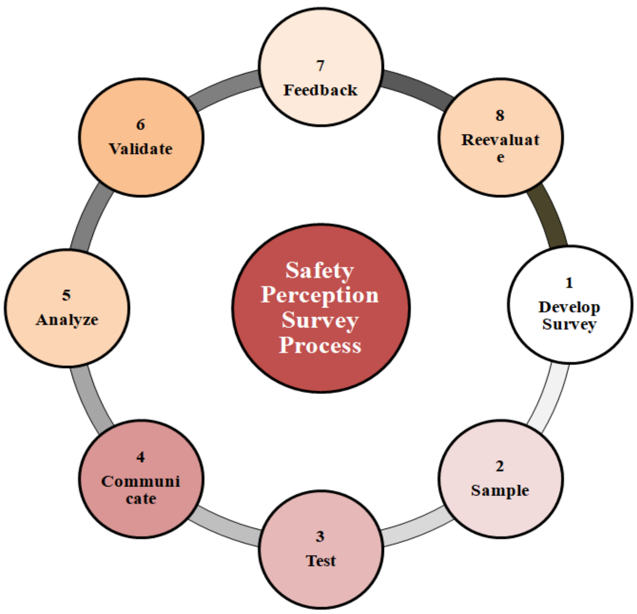

Figure 2.10: Safety Perception Survey Process
(Ref. Ryan D., 2009 [100]; Pisharody et al., 2021 [93]

The following steps as shown in **Figure 2.10** are involved in the safety perception survey process (Ryan D., 2009 [100]; Pisharody et al., 2021 [93]):

Step 1: Developing the Survey:

The first step for safety perception survey is development of survey questionnaire suitable to the organization. Survey questions should be understood by all respondents and should be clear to obtain desired information.

Following are considered for development of survey questions:

1. Limit each statement to one idea or concept.
2. Avoid using subjective adjectives such as good, fair and bad.
3. Avoid using terms such as ‘always’ and ‘never’.
4. If there is any chance that a term will be unclear to some respondents, provide clarification.
5. Avoid using leading questions.

Information on workplace safety should be requested in anonymous manner to acquire an informed assessment without any fear of reprisal. Each question should use a Likert scale to gather data. Each question may have many options based on Likert scale, with expected responses ranging from the most positive to the least positive, as shown below (Pisharody et al., 2021 [93]):

1. Strongly Agree
2. Agree
3. Do Not Know
4. Disagree
5. Strongly Disagree

The questions should be set up so as to choose one from the multiple options. With higher and lower levels of agreement, responses of 'Strongly Agree' and 'Agree' show the existence of a good safety culture. Similarly, the responses of 'Strongly Disagree' and 'Disagree' indicate larger and lesser degrees of disagreement, respectively, emphasising the need for improvement. Corrective steps are required for any attribute with less than 90% agreement across all samples.

Step 2: Select a Sample Size

It is preferable to include all employees in the survey so that everyone can voice his or her thoughts. This will make each employee feel like they are part of the team. The larger the sample size, the more reliable the study. However, in a large firm, conducting survey of large number of people is impracticable due to the time commitment. Due to the high amount of data, analysis will be tough. In such instances, doing a sampling survey is advantageous. Based on the required confidence level, the number of samples can be determined statistically. It will take less time to conduct a sampling survey and analyze the results.

Step 3: Test Survey

A sample test survey should be conducted with a small group of people to ensure that questions are clearly understood, interpreted appropriately, and are not sensitive to hurt respondents' emotions. The test survey results should be used to improve the questionnaire.

Step 4: Communication of Intentions

Employees should be informed of the plan and purpose of the questionnaire before it is sent to them to receive accurate feedback. In addition, following aspects should also be communicated:

1. Objectives of the survey.
2. Authority under which the survey is being carried out.
3. Importance and request for participation.
4. Confidentiality protection measures taken to ensure anonymity.
5. Outcome of the results of survey.

Step 5: Administration of the Survey

The survey can be administered in a number of ways, depending up on the preferences. Earlier days, hardcopy of the questionnaire used to be sent to the prospective respondents. However, this involved cumbersome process of sending and receiving, which used to take more time and regular follow-up for getting the response. Subsequently, questionnaires used to be sent by emails. This used to take less time, however, regular follow-up, will be required for getting responses. With the advent of internet and development of software applications; now days, survey links are sent to prospective respondents. Through regular follow-up is required in this method also, processing and analysis of filled questionnaire are faster.

Step 6: Analysis of Perception Survey Data

Once the survey has been completed, data should be sorted according to the relevance of the data filled. Data which are not relevant to the objectives of the survey can be excluded from the analysis. On questions with a positive response rate of less than 90%, corrective action should be taken.

Step 7: Validation of Safety Perception Survey Results

Validation of survey results can be accomplished by organizing a focus group of employees to discuss the survey findings. Outcome of such discussion can be used to further refine the results.

Step 8: Feedback

After finalizing survey result, it should be communicated to employees with corrective measures to improve safety performance on questions with less than 90% score. The attributes with more than 90% score should also be communicated to ensure that continual efforts are put in to improve safety performance on those attributes further.

Safety perception survey has following benefits:

1. Facilitates to obtain true picture of employees' perception on work place safety.
2. Provides a clearer understanding of what needs to be done to improve safety.
3. Information obtained through the survey will be unbiased as the survey is conducted in anonymous manner.
4. Supports an organization's efforts to gather its employees' knowledge in accident prevention and control.

2.7 ACCIDENT PREVENTION AND CONTROL

A process is always related to energy transmission in a controlled environment. If control is lost and energy is released more than the physiological threshold of the human body, it will result in accidents and injuries. Accident prevention and control is a multi-disciplinary subject comprising of wide spectrum of topics on administration, program implementation, engineering, and technology (National Safety Council, 2001a-b [81] [82]).

The first step for administration and implementation of safety program is identification of safety professionals with requisite qualifications and experience; and defining their role. Safety professionals facilitate establishment of a safety organization by development of safety and occupational health programs to meet statutory requirements as per the national laws to safeguard the safety, health and welfare of workers and to protect them from exploitation (GOI, 1987 [42]).

An organization shall establish an Occupational, Health Safety Management System (OHSMS) for the effective implementation of safety programs. At the outset, the top management shall issue an OHS policy, expressing their commitment on OHS responsibilities. Implementation of OHSMS in an organization is based on Plan-Do-Check-Act (PDCA) cycle. It involves review of existing OHS programs and establishment of programs for hazard identification, risk assessment, hazard control, accident prevention, accident reporting, accident investigation, surveillance of work environment, industrial hygiene, work place ergonomics, safety education, emergency preparedness, corrective and preventive action, development of safety culture, enforcement of safety legislation, maintenance of records, verification of system effectiveness through safety auditing and periodic management review for continual improvement (National Safety Council, 2001a-b [81] [82]; IS-14489, 2002 [12]; IS-15656, 2006 [11]; IS-18001, 2007 [14]; ISO-45001, 2018 [62]).

Despite all these efforts, there could be accidents and injuries due to shortfalls in program implementation. Therefore, it is essential to investigate each accident to identify causes and contributors, whether it is HFLS or LFHS accident. An accident is preceded by numerous incidents such as near misses, disruptions or anomalies from normal or intended operations. These relatively harmless occurrences serve as precursors or warning signs of impending accidents, signaling that "All is Not Well" within the organization in terms of safety. These are indications of unknown or insufficiently understood significant risks. Being more frequent events than accidents, near misses give useful information for safety management improvement. Near misses may lead to accidents under different circumstances. Therefore, all near misses shall be analyzed to identify potential safety risks, to take corrective measures and hence to prevent more severe accidents (Cambraia et al., 2010 [25]; Khanzode et al., 2012 [67]; Pisharody et al., 2018b [92]).

Organizations may adopt a 7-point protocol for identification of precursors to direct their resources to improve safety. It includes the followings:

1. Selection of area,
2. Identification of precursors,
3. Prioritization of precursors,
4. Identification of ineffective control processes,
5. Identification of latent conditions,
6. Identification of affected safety barriers, and
7. Derivation of conclusion.

Precursors and near misses may not evolve into serious accidents if they are maintained under control, either by preventive or controlling measures. In fact, investigation of precursors and near misses shall be an integral part of organizational safety management system. Recurrence of precursors indicates failure in accident prevention and control mechanisms. Under different circumstances, in the presence of specific immediate factors, precursors may escalate into accidents. Immediate factors are aggravating factors such as a breakdown in teamwork, a hazardous workplace, or inadequate equipment and resources. In the absence of Mitigating Factors, a Precursor combined with Immediate Factors will result in accidents, as illustrated below (Wu et al., 2010 [121]; Pisharody et al., 2018b [92]):

Accident = Precursor + Immediate Factors - Mitigating Factors

In the absence of mitigating factors, accidents will recur if corrective measures are not taken, as illustrated below (Wu et al., 2010 [121]; Pisharody et al., 2018b [92]):

Accident $_{(n+1)}$ = Accident $_{(n)}$ + No corrective measures + Time - Mitigating Factors.

The ability to stop an accident sequence from growing into a more serious accident can be achieved by identifying and correcting the causes of precursors. Accidents happen less frequently than precursors and immediate factors. As a result, addressing the causes of precursors and immediate factors will give more opportunities for accident prevention and hence to improve workplace safety. There should be a systematic mechanism to interrupt and prevent precursors and immediate factors (PaIFs) through real-time tracking of historical accident records. However, organizational and management factors such as weak safety culture and ineffective root cause analysis could lead to failure of accident prevention and control system. An accident reporting and investigation system should be based on blame free and forgiveness culture. Identification of human errors as causes for accidents should be based on man-machine interface and system induced errors (Lucas, 1991[73]; Lees, 2004 [71]; Jones et al., 1999 [65]; Phimister et al., 2003 [89]; Sonnemans and Korvers, 2006 [107]; Sonnemans et al., 2010 [108]; Wu et al., 2010 [121]; Wu et al., 2013 [122]; NASA, 2011 [79]; US Department of Energy, 2012 [115]; Saleh et al., 2013 [102]; Pisharody et al., 2018b [92]).

Heinrich et al. (1980 [46]) hypothesize that in a unit group of 330 same kinds of accidents involving the same person, there is a constant ratio of 1:29:300 between major injuries, minor injuries, and near misses, meaning that there should have been 29 minor injuries and 300 near misses owing to unsafe conditions and acts attributable to human, organisational, and technical factors prior to one major injury as shown in **Figure 2.11** (Heinrich et al., 1980 [46]; Jones et al., 1999 [65]; Pisharody et al., 2018b [92]). This implies that someone who has a major injury as a consequence of an unsafe act or condition had 329 reasonable chances of narrowly escaping major injury as a result of the same unsafe acts or conditions.

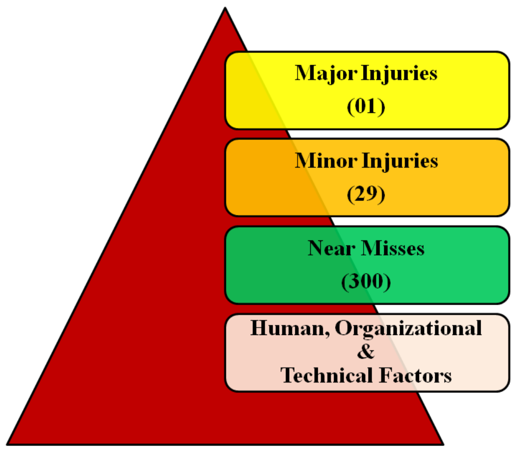

Figure 2.11: Heinrich's Triangle of Accidents
(Ref. Heinrich et al., 1980 [46]; Jones et al., 1999 [65]; Pisharody et al., 2018b [92])

The above postulation is also not free from controversy. Manuele (2011 [74]) refutes this theory under the premise that there is no consistency in the categorization of 330 accidents in different editions of Heinrich's book. 330 accidents were classified as having the "same" cause in the first edition. It was altered to ‘similar' in the second edition and was classified as 'of the same kind and involving the same person' in the third edition. Heinrich did not explain the above changes. According to Manuele (2011 [74]), if the data based on the first premise is correct, how can the conclusion of the same book be altered from edition to edition? However, other research works show that High Frequency and Low Severity (HFLS) accidents provide more opportunities to address accident causes, and hence support prevention of Low Frequency and High Severity (LFHS) accidents (Khanzode et al., 2012 [67]).

Major accidents are rarely the results of a single error; rather these are the cumulative effects of a series of insignificant errors and accidents. Therefore, it is essential to reduce even insignificant errors and incidents to prevent major accidents. This can be achieved by proactive measures, reactive measures, or both, through own experience or the experience of others; by identification and correction of shortfalls in accident prevention and control measures (Geoffrey, 1991 [40]).

In order to develop a solid accident prevention system, reporting of HFLS accidents and rectifying causes should be engrained in the organizational safety culture. According to studies, there were less LFHS accidents when line managers were more focused on reporting and fixing the causes of HFLS accidents. As HFLS accidents provide a comprehensive picture of the organization's risks, failing to include them in risk assessments can result in a considerable under estimation of 'true' risk. The continuous advancement of human, organizational, and technological systems towards a high-risk condition results in major injuries. HFLS accidents give signal on this movement, and hence corrective actions based on this movement can help in averting LFHS accidents. (Heinrich et al., 1980 [46]; Geoffrey, 1991 [40]; Taylor and Lucas, 1991[112]; Lucas, 1991 [73]; Masson, 1991 [76]; Van der Schaaf, 1991a-b [118] [119]; Van der Schaaf, 1995 [120]; Jones et al., 1999 [65]; Phimister et al., 2003 [89]; Sonnemans and Korvers, 2006 [107], Sonnemans et al., 2010 [108], NASA, 2011 [79]; Rathnayaka et al., 2011a-b [95] [96]; Khanzode et al., 2012 [67]; Pisharody et al., 2018a-b [91] [92]).

A dangerous situation with the potential for an accident is formed due to technical failure, human operator failure, and organizational failure. If adequate defenses are available, dangerous situation could return to normal, else it will develop into an incident. With adequate human recovery actions, the incident could be reduced to a near miss; else it may escalate to an accident. Hence human recovery has an important role in accident prevention as it reduces a possible accident into a mere near miss (Van der Schaaf, 1995 [120]).

Accidents are caused by both individual and organizational factors. Individual factors include an employee's educational level and organizational position. Organizational factors include organizational culture, support, job satisfaction, and workplace safety perceptions. Employees with higher levels of education are more likely to follow safety procedures and are less prone to accidents. Employees with high levels of job uncertainty and dissatisfaction, on the other hand, had weaker motivation, lower adherence to safety measures, and higher rates of injuries. Employees' safe conduct and their overall impressions of management's concern for their well-being are influenced by organizational characteristics such as safety climate, organizational support, and job satisfaction. The incidence of accidents is highly influenced by workers' perception of workplace safety. Human and work environment factors combine to cause workplace injuries. Accident frequency can be reduced through effective communication and information exchange. By paying attention to social structures at work, an effective organizational management can lower the incidence of accidents. Organizational and cultural precursors such as leadership, oversight and scrutiny; and organizational learning play critical roles in accident prevention (Seth et al., 2012 [104]; Taylor et al., 2015 [113]).

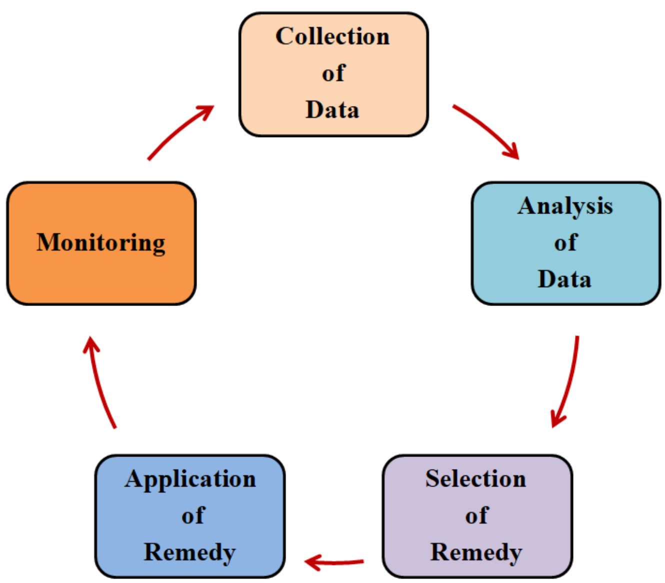

Figure 2.12: Accident Prevention and Control Model
(Ref. Heinrich et al., 1980 [46]; Pisharody et al., 2018b [92])

Accident prevention and control follows the Plan-Do-Check-Act (PDCA) management decision-making model with five steps consisting of data collection, data analysis, remedy selection, remedy application, and monitoring as shown in **Figure 2.12** (Heinrich et al., 1980 [46]; Pisharody et al., 2018b [92]). Effective corrective and preventive action program with management oversight is essential for a strong accident prevention and control.

Accident prevention and control techniques can be performed in a short term or long-term manner. The direct control of worker performance, equipment performance, and work environment is a short-term method. Enforcement and education are the long-term approaches. If an unsafe condition needs to be addressed in a fool proof manner, it should be done without any regard for the related unsafe act. An accident prevention strategy that is implemented successfully will interrupt the sequence of events leading to accidents and hence prevent accidents. Inadequate design specification and design implementation are responsible for about 50-60% of accidents (Kinnersley and Roelen, 2007 [68], HSE UK, 2003a-e [51] [52] [53] [54] [55]). Design not meeting established standards, failure of defense in depth in design due to insufficient back-up mechanisms, and operating outside the design envelope due to misunderstanding between designers and operators are some of the design-related cause factors. Accident prevention and control is a continual process and hence a multitier defense-in-depth approach, right from the design stage, by judicial application of the hierarchy of hazard controls could be an effective technique towards this.

The construction industry is inherently hazardous. A construction site is highly dynamic with respect to the working conditions, the floating nature of workers, the low education level of workers, and the hazards in the work environment when compared with normal factory conditions; where most of the working conditions are stable. Implementation of hazard control measures and complete elimination of injuries and accidents at construction sites is a tough task when compared with conventional factories. However, by the effective enforcement of safety precautions, accidental injuries at construction sites can be minimized and it will result in increased efficiency and reduced cost of construction. In all stages of construction, scaffoldings are essential for carrying out works which cannot be conveniently and easily carried out either from the ground floor or from any other floor of the building or even with the use of a ladder. Accidents attributed to scaffoldings are one of the major concerns in the construction industry. Scaffolding-related accidents are typically caused by the direct collapse of scaffolding, defects in scaffolding, unsafe workman actions, or due to any material falling from the top of the scaffold. As a result, extreme caution must be exercised in the erection, use, and disassembly of scaffoldings to guarantee a safe working environment and to avoid injuries (IS-3696 (Part-1), 2017 [20]). Steel tubular scaffolding is a popular choice since it is simple to erect, transport, and handle. It can be quickly dismantled and re-used, and it can be relied on to provide years of service and life. In order to prevent accidents, scaffoldings and platforms shall meet following requirements (GOI, 1996 [43]; AERB, 2011 [4]; IS-2750, 2016 [22]; IS-4014 (Part-2), 2018 [23]; IS 16809 (Part 2), 2018 [16]; Pisharody et al., 2018a-b [91] [92]):

1. For any work that cannot be done safely from the ground, scaffolding must be provided.

2. All scaffold members, such as planks, braces, vertical supports, and horizontal supports, must be of good material, structure, and strength, and must be well maintained.

3. Scaffolding shall not be erected, altered, or disassembled unless under the direct supervision of a qualified and authorized engineer and competent workmen with sufficient experience in such operations. All materials for scaffoldings shall be inspected by qualified and authorized engineer on each occasion before using.

4. No scaffolding, or portion of scaffolding, shall be partially removed and left in usable state unless it meets the design safety criteria. If the scaffolding or part thereof does not comply with design safety requirements, a prominent warning notice indicating that scaffolding or part thereof shall not be used, shall be affixed near by the scaffolding or parts liable to be approached for using.

5. Scaffoldings shall be inspected by qualified and authorized engineer before use and at regular period, till the works using scaffoldings are in progress.

6. Where a scaffolding or part of scaffolding is to be used by an agency other than the agency for which the scaffolding has been erected, the former shall ensure by inspection that the scaffolding is safe for use.

7. Guard rails of at least 1-meter height above the floor or platform must be installed on scaffolding that extends more than 3.5 meters above the ground floor.

8. Standard railing should have posts spaced not more than 2 meters apart and an intermediate rail halfway between the scaffolding's floor or platform and the top rail.

9. While working at height on unprotected scaffoldings, workers shall wear double lanyard full body harness and at least one of the lanyards shall be anchored to a firm structure or life line.

10. Scaffoldings placed along the passages must have side screens.

11. Suspended scaffolding platforms must be at least 45 cm wide, with suspension points not more than 3 meters apart.

12. Platform or scaffolding must have a secure and convenient means of access. A portable ladder, a fixed ladder, a ramp, or stairwells are all options for gaining access.

13. Un-insulated electric wire shall not exist within 3 meters of the scaffoldings and working platforms.

14. Scaffold toe boards should be at least 15 cm high to prevent materials from falling.

15. Minimum width of platforms shall be as given below:

    a. Where platform is not more than 2 m above the ground or solid floor:

(i)	For painters, decorators and similar workmen	-	30 cm.
(ii)	For other types for persons and tools	-	50 cm.

b. Where platform is more than 2 m above the ground or solid floor:

(i)	For men, tools and materials	-	120 cm.
(ii)	For men, tools, materials and wheel barrows	-	150 cm

Accidents caused by ladders are another cause of concern in construction industry. In the construction sector, ladders are used to gain access to floors and platforms that are more than 1.5 meters above or below ground level. Accidents might occur if not enough attention is paid to the use and selection of the right size and design of ladder for the work.

Causes of accidents attributed to ladders in general are:

1. Incorrect ascending or descending,
2. Failure to secure top and/or bottom of the ladder
3. Structural breakdown of ladders,
4. While ascending or descending, carrying objects in one's hand, and
5. Unsafe situations while placing ladders.

The likelihood of ladder-related accidents can be significantly decreased if due care is taken in selecting the proper size and design of a ladder for a work. In addition, it would bring confidence among the workers to work safely and prevent injures (IS-3696 (Part-2), 2017 [21]).

Ladders shall meet following requirements (GOI, 1996 [43]; AERB, 2011 [4]; IS 16809 (Part 1), 2018 [15]; IS 16809 (Part 3) [17], 2018; IS 16809 (Part 4), 2018 [18]; Pisharody et al., 2018a-b [91] [92]):

1. Every ladder must be well-built, made of sturdy materials, and strong enough.
2. Ladders should be anchored to the ground or positioned on sturdy platforms. An additional person should be hired to hold the ladder if it is not properly secured.

3. Ladder shall be extended at least one meter above the platform.
4. Ladder rungs must be parallel, level, and regularly spaced at 30 cm.
5. Ladders must be inspected on a regular basis and repaired as soon as possible if they are damaged. It is prohibited to use a ladder with broken or missing rungs.
6. Ladders made of wood must not be painted. To protect wood from degradation, use linseed oil or clear varnish.
7. Length of portable single ladders shall not be more than 9 m.
8. For access to a height of more than 4.5 m, no single portable ladder should be utilized. If the height of the work area exceeds 4.5 m, a prefabricated steel staircase should be used.
9. The width between styles (side bars) on ladders up to 3m in length should not be less than 300 mm. This width should be increased by at least 20 mm for each extra meter of ladder length for longer ladders.
10. Before utilizing a ladder, it must be kept in a safe position. The optimal angle for a ladder with the horizontal is 75 degrees, which means the ratio of length of the ladder to the base of the ladder from the wall should be 4:1.
11. While carrying materials in hands, ladders should not be used for ascending or descending. While using ladders, both the hands should be free and three-point contact theory shall be followed i.e. three out of two feet and two hands, shall always be in secured contact with ladder.
12. Two ladders should not be spliced together to the maximum extent practicable. They shall be connected together to ensure rigidity when it is unavoidable. At the point of splicing, more parallel members shall be added to each of the ladder's major members.
13. Splicing of two ladders together to gain access to a location higher than a single ladder is prohibited.

14. For working with electrical lines or in areas where ladders may come into contact with such wires, metal ladders with insulating rubber shoes must be used.

15. Man-guards must be put on any permanent vertical ladders over 3 meters in height.

Damage to underground cables during excavation is a frequent incident occurring at conventional industries and construction sites. If enough protective measures are not taken, this may lead to injuries due to exposure to electric current. While laying underground cables, following considerations should be given (IS-1255, 2016 [10]):

1. Cable route should be chosen with immediate and long-term use of cable as a component of transmission and distribution system in mind.

2. Parallel running gas, water, and telephone wires should be avoided along the cable route.

3. At an interval of not more than 200 meters and at the turning points of power cable routes, power cable route markers shall be provided.

4. To avoid putting a person's life in danger while excavating to repair a telecommunication cable fault, power cable should not be installed above it.

5. Cable should not be bent at a sharp angle. When bending is necessary, a larger bending radius should be chosen.

6. While laying cables directly in the ground, minimum depth of laying of cable shall be as per the following criteria

High Voltage Cables (22 kV to 33 kV)	-	1.05 meter
High Voltage Cables (3.3. kV to 11 kV)	-	0.90 meter
Low voltage and control cables	-	0.75 meter
Cables at road or railway crossings	-	1.00 meter

Cables in the earth in a trench should be laid over a 75 mm thick layer of riddled soil or sand at the bottom. The cables should then be covered with a minimum of 75 millimeters of riddled soil or sand and protected with tiles, bricks, or slabs.

Fall of persons and fall of objects though the floor or wall openings are another major type of accidents observed in construction industry and in conventional factories when large scale inspection and maintenance jobs are performed, where inbuilt structural members on the floors and wall are temporarily removed. All the floor and wall openings shall be guarded to prevent fall of persons and fall of objects (GOI, 1987 [42]; IS-4912, 2017 [19]).

2.8 ACCIDENT PREDICTION MODELS

Accident models are simplified representations of real-life accidents that are used to manage safety in both a reactive and proactive manner. Accident models influence how individuals think about safety and make things easier to undertake, like:

1. Recognizing accident cause.
2. Avoiding personal biases when determining accident cause.
3. Providing a broader choice of accident prevention options.
4. Assisting in data collection and accident analysis during accident investigation.
5. Examining the interrelationships among accident-causing factors and conditions.

Accident models based on theories of accident philosophy, accident sequence, and accident causation help to understand and analyze accidents and assist accident prevention. Cause-consequence models, descriptive models, and system models are the three types of accident models. All these approaches work in tandem and focus around the human, organizational, and technical aspects of risk management (Heinrich et al., 1980 [46]; Hovden et al., 2010 [48]).

Most of the accident models are based on chemical process industries. There were major accidents with fire and explosion in chemical process industries world over at hazardous material storage facilities, where large quantity of highly flammable and toxic substances is stored. When highly flammable Liquid Petroleum Gas (LPG) is stored under pressure, it involves the risk of explosion due to Boiling Liquid Expanding Vapor Explosion (BLEVE). Therefore, such tanks shall be installed at optimum safe distance such that in case of an event in one tank, it will not harm other thanks. Therefore, it is mandatory that chemical process industries are designed and operated by complying with requirements of applicable standards to prevent major accidents involving fire, explosion and toxic release (Tauseef et al., 2017 [110]). In a tank farm where highly flammable liquids are stored in two or more tanks and if one of the storage tanks meets with an accident and the gas leak leading to fire and explosion; adjacent tanks are also likely to fail due to heat. Inter-utility distances between hazardous facilities within the periphery of chemical process industry and risk of accidents can be minimized by using 'Risk and Distance Minimization in Process industry Units Siting' (RIDIMPUS) methodology (Basheer et al., 2019a [6]). The safe and optimum distance between two or more hazardous storage tanks in a tank farm can also be determined by accident models such as Point Source model, Shokri and Beyler's model, Mudan's model or Baldwin and Thomas model (Abbasi et al., 2017 [1]).

A template based quantitative risk assessment of hazardous material storage facilities to identify and reduce risks could prevent accidents in chemical process industries (Basheer et al, 2019b [7]). The Chemical Accident Simulation Tool (CAST) software can generate various scenarios of different types of accidental fires and explosions in chemical process industry with likely consequences in terms of area impacted and types of impacts. The CAST is developed with an integrated mapping tool to display damage zones around accident center; and it makes the application useful in decision making (Tauseef et al., 2018 [111])

The System Hazard Identification, Prediction and Prevention (SHIPP) model developed by Rathnayaka et al. use a combination of event tree and fault tree concepts based on precursor information to establish cause-consequence relationship (Rathnayaka et al., 2011a-b [95]

[96]). Similarly, Dynamic Sequential Accident Models (DSAMs) based on fault trees and event trees which utilizes precursor data such as near-misses, mishaps, incidents and accidents are also available to estimate posterior risk profile and support decision making (Ali Al-shanini et al., 2014 [2]).

Studies on occupational accident models, human factors and safety culture indicate that holistic quantitative models, capable of predicting accident frequencies in conventional industries are scarce (Attwood et al., 2006 [5]). Therefore, more research should be made in this direction. Accident models in conventional Industries can be developed based on Indian Standard IS-3786-2022. The standard establishes rules for accident classification based on seven major variables that contribute to accident causation: Agency, Unsafe Mechanical or Physical Condition, Unsafe Act, Unsafe Personal Factor, Type of Accident, Nature of Injury, and Injury Location (IS-3786, 2022 [13]).

Accident prediction is a science that involves extrapolating potential accidents based on available data and perceptions. The goal of accident prediction is to make accident prevention and control possible, before a serious injury or loss occurs. Accident prediction models have been developed to identify the key causes of accidents so that suitable corrective actions can be taken. Scenario Analysis, Regression Technique, Time-Series Method, Markov Chain Method, Grey Model, Neural Networks, and Bayesian Networks are a few of the most widely used accident prediction models (Zheng and Liu, 2009 [123]; Pisharody et al., 2018b [92]; Pisharody et al., 2022 [94]).

1. **Scenario Analysis** is a technique for analyzing prospective future events by considering multiple scenarios. Accidents are caused by the combination of human factors, situational job factors, and environmental factors, hence the accident scenario will be determined by how these components interact. Scenario analysis assists in the prediction of potential accident scenarios as well as the identification of circumstances that may have contributed to the occurrence of the accidents.

2. **Regression Model** is used to forecast accident scenarios based on previous accident data by transforming a dependent variable into a function of the independent variables. Regression models can be linear, non-linear exponential, logarithmic, or polynomial, depending on the research objectives. The regression model is commonly used to forecast events.

3. **Time-Series Methods** forecast future accidents by using historical time-series accident data. A time-series data set is made up of a series of observations made at different times.

4. **Markov Chain Model** uses stochastic processes to estimate transition probabilities between discrete states in observed systems. The Markov chain model is good for predicting occurrences with lot of randomness. It cannot, however, be used to track accident trends.

5. **Grey Models** for predicting accidents are based on the grey system theory. A white system has all of its information known, whereas a black system has no clear information. Between these two is the grey system. This model is used in accidents where there is insufficient information.

6. **Neural Networks** are used to fit complex non-linear input-output interactions. Trend prediction and causality prediction are two types of neural network applications for accident prediction. While time-series data is used for trend prediction, a set of influencing elements associated to accidents is used in Neural Networks for causality prediction. Patel and Jha (2016 [88]) explored Artificial Neural Networks (ANN) for evaluation of construction projects based on safe work behaviour of co-employees.

7. **Bayesian Networks** are probabilistic graphical models that quantify the cause-and-effect relationship between numerous accident variables. Bayesian networks assist in the prediction and identification of accident causes. Eftychia et.al (2012 [37]) used Bayesian Analysis to derive worker unavailability statistics and predict the time that workers will be recovering from accidents. They have used databases of occupational accidents such as total number of workdays, work days lost due to recovering from occupational accidents, and number of occupational accidents over a period of time.

Accident prediction models are chosen based on the nature of data, prediction accuracy, and required information. Depending upon the data, each approach has its own restrictions. Since a single approach may not be able to generate a realistic prediction, a combination of methods is used to get fair prediction accuracy.

Multiple linear regression with Analysis of Variance (ANOVA) is one of the approaches utilized to predict a dependent variable based on a set of independent variables. Multiple linear regression analysis is a statistical approach for evaluating relationships between variables and describing such relationships in the form of equations. It is used to estimate a dependent variable using independent variables. It is commonly used in prediction to figure out which of the independent variables have significant relationship with the dependent variable. At some limited conditions, regression analysis is used for inferring causal relationships between independent and dependent variables also. R Square and Adjusted R Square values, F-Test, T-Test, and p-values for a certain value of significance are used to determine the statistical significance of the model (Kothari, 1990 [69]; Levin and Rubin, 1996 [72]; Jenan et al., 2015 [63]).

In academics, multiple linear regression models are used to analyze student's final grade as a dependent variable; and measurement and evaluation, educational psychology, curriculum development, guidance, teaching methods, and student's test, quiz, and final examination scores as independent variables. Prediction capabilities of these models are adequate and results are statistically significant (Shakil, 2001 [105]; Uyanik and Guiler, 2013 [117]).

Multiple linear regression is extensively used to predict road accidents. However, its capability in prediction of occupational accidents is less explored. The dependent variable in road accident prediction models is the number of accidents, while independent variables include quantitative and qualitative parameters such as road cross-section dimensions, traffic volume, speed, road shoulder width, lighting conditions, traffic signs and signals, and so on. The coefficient of determination and a comparison of predicted and actual values are used to verify the validity of these models. The coefficient of determination demonstrates goodness of fit of these models (Mustakim et al., 2008 [78]; Rokade et al., 2010 [98]; Pisharody et al., 2022 [94]).

Multiple linear regressions are also not free from controversies. One common issue with multiple linear regressions is multicollinearity; as sometimes it may make interpretation of results difficult. However, Kraha et al. (2012 [70]) opines that multicollinearity may not cause unwarranted problems in accident prediction and significant factors. Levin and Rubin, 1996 [72] also argues that regression models with multicollinearity can very well use to predict dependent variable.

2.9 CONCLUSION

Research was conducted on industrial accidents that occurred in the Public Sector Power Company from 2006 to 2015, based on the information acquired through an exhaustive literature survey, with the following objectives:

1. **To study Near Misses and Industrial Accidents** occurred in the Public Sector Power Company during the period of 10 years from 2006 to 2015 to identify causes and contributors with reference to Agencies, Types of Accidents and Locations of Injuries as per Indian Standard IS-3786-2022.

2. **To analyze HFLS accidents based on Agencies, Types of Accidents and Locations of Injuries** as per Indian Standard IS-3786-2022 **to identify significant contributors of HFLS accidents.**

3. **To develop Accident Prediction Models on Agencies, Types of Accidents and Locations of Injuries of LFHS accidents** as per Indian Standard IS-3786-2022 **to identify significant Agencies, Types of Accidents and Locations of Injuries of LFHS accidents.**

4. **To analyze significant Agencies, Types of Accidents and Locations of Injuries derived from Accident Prediction Models** on LFHS accidents as per Indian Standard IS-3786-2022 and **to identify significant contributors of LFHS accidents.**

5. **To carry out Safety Perception Survey** on Accident Prevention & Control among the employees of the Public Sector Power Company **to identify significant organizational contributors of accidents.**

6. **To identify accident prevention and control measures by 'Safety through Design',** reinforcement of **'Administrative Controls'** and strengthening use of **'Personal Protective Equipment', hence to upgrade accident prevention and control program** in the Public Sector Power Company.

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CHAPTER-3

DATA COLLECTION, DATA CLASSIFICATION AND RATIONALE FOR SELECTION OF ACCIDENT PREDICTION MODEL

3.1 PREAMBLE

The current study is focused on an Indian public sector power company with 11 twin-unit operating stations and three twin-unit construction project sites. In India, the company is involved in power plant design, construction, commissioning, and operation. The company has a documented corporate guideline on 'reporting and investigation' of Industrial Accidents. According to Pisharody et al. (2018a-b [91] [92]) following types of accidents are reported and investigated in the company as per the corporate guideline:

1. Near Misses
2. First-Aid Injuries
3. Non-Reportable Injuries
4. Reportable Injuries
5. Fatalities

Near misses, First-Aid Injuries and Non-Reportable Injuries are considered as accidents of High Frequency and Low Severity (HFLS) type. HFLS accident is an accident that occurs at a frequency of more than 1 accident per year per Station or Project; but with a low severity, in which there is no injury attributed to the accident or the accident victim returns back to workplace within 48 hours of the event. Reportable Injuries and Fatalities are considered as accidents of Low Frequency and High Severity (LFHS) type. LFHS Accident is an accident which occurs at a frequency of less than or equal to 1 accident per year per Station or Project; but with a high severity, in which there is a fatality or the accident victim returns back to workplace only after 48 hours of the event. (Heinrich et al., 1980 [46]; Jones et al., 1999 [65]; Khanzode et al., 2012 [67]; Pisharody et al., 2018b [92]). Occurrence of 1 accident per year at Stations and Projects is considered as the rationale for deciding frequency of HFLS or LFHS accidents for this study.

As per the company's guidelines, all Industrial accidents occurring at Operating Stations and Construction Project sites are reported to all concerned agencies at respective sites, other Operating Stations and Construction Project sites and at the corporate office. All the accidents are then investigated and corrective measures are taken. Despite this, accidents occur and recur. This indicates that current approaches for accident prevention and control need to be improved. One of the major goals of this study is to improve the industry's accident prevention and control methods.

3.2 DATA COLLECTION

Data on Industrial accidents in the present work were collected from the reports on Near Misses, First-Aid Injuries, Non-Reportable Injuries, Reportable Injuries and Fatalities issued by the Operating Stations and Construction Project sites during the period of 10 years from 2006 to 2015 from the corporate office of the company. Confirmation and clarifications on the accident details were obtained through visits to Operating Stations and Construction Project sites; and discussions with concerned persons at respective Operating Stations and Construction Project sites. Wherever data were found to be suspicious or ambiguous, such data were not considered for the research work.

2179 accidents were reported to have occurred at 11 twin-unit Operating Stations and 3 twin-unit Construction Project sites in the company, during the period of 10 years from 2006 to 2015. The 2179 accidents comprised of 1539 Near Misses, 366 First-Aid Injuries, 161 Non-Reportable Injuries, 95 Reportable Injuries and 18 Fatalities, and are given in **Table 3.1 and Figure 3.1** (Pisharody et al., 2018a [91]).

Table 3.1 (Ref. Pisharody et al., 2018a [91]).

Number of Accidents in the Public Sector Power Company during 2006-2015

Year	Near Misses	First-aid Injuries	Non-Reportable Injuries	Reportable Injuries	Fatalities	Total
2006	39	0	0	7	3	49
2007	46	0	2	18	3	69
2008	69	15	6	12	1	103
2009	93	11	17	10	1	132
2010	103	27	27	11	2	170
2011	172	53	17	6	1	249
2012	188	48	25	14	1	276
2013	241	80	22	8	3	354
2014	282	54	18	4	2	360
2015	306	78	27	5	1	417
Total	**1539**	**366**	**161**	**95**	**18**	**2179**

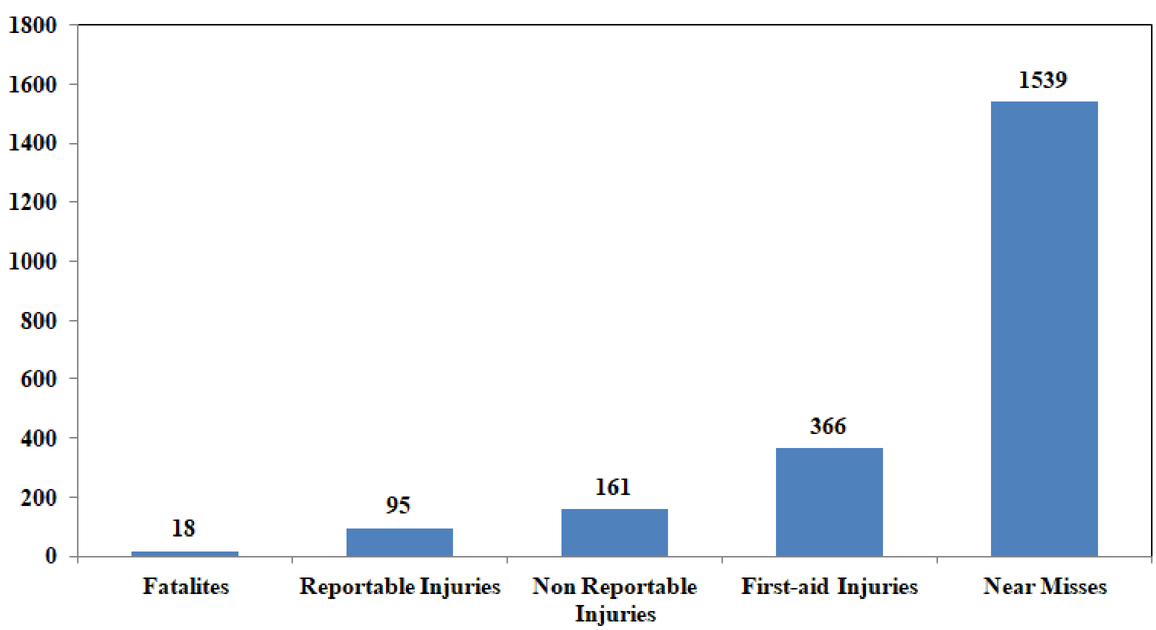

Figure 3.1: Number of accidents in the Public Sector Power Company during 2006-2015 (Ref. Pisharody et al., 2018a [91]).

3.3 DATA CLASSIFICATION

Data of the considered 2179 accidents were classified according to some principal identifiers, namely; 'Agencies', 'Types of Accidents' and 'Locations of Injuries' in reference to the Indian Standard IS-3786-2022 on 'Method for the Computation of Frequency and Severity Rates for Industrial Injuries and Classification of Industrial Accidents'.

3.3.1 Classification Accidents as per Agencies of Accidents

Industrial Accidents identified as caused due to 'Agencies', during the period of 2006 to 2015 were further classified as per the Indian Standard IS-3786-2022 into sub classes of 'Scaffolding', 'Others', 'Lifting Machines and Applications and Pressure Vessels', 'Electrical Installations' and 'Work Environment' (IS-3786, 2022 [13]). The details of which are displayed in **Table 3.2**. The number of HFLS accidents and the LFHS accidents were determined according to the **'Agencies of Accident**' involved, and are shown in **Table 3.3** and **Table 3.4** respectively.

Note

1. X11 to X15 of Table 3.2, Table 3.3 and Table 3.4 denote number of accidents based on B1 classification of IS-3786-2022.

2. YB1N of Table 3.3 and 3.4 denotes total number of X11 to X15 of accidents based on B1 classification of IS-3786-2022.

3. YB1MDL of Table 3.4 denotes Man-days lost on LFHS accidents under B1 classification of IS-3786-2022

4. Subscript 'H' of Table 3.3 denotes HFLS accidents and subscript 'L' of Table 3.4 denotes LFHS accidents

Table 3.2

Classification of Agencies of Accidents as per Indian Standard IS-3786

<table>
<tr><th colspan="2">Agencies of Accidents (B1) as per IS-3786 & Identification Numbers</th><th colspan="2">Codes of Agencies of Accidents (B1) as per IS-3786</th></tr>
<tr><td>Scaffolding</td><td>X11</td><td>228</td><td>Scaffolding</td></tr>
<tr><td rowspan="18">Others</td><td rowspan="18">X12</td><td>202</td><td>Transmission Machinery</td></tr>
<tr><td>203</td><td>Metal Working Machines</td></tr>
<tr><td>204</td><td>Wood and Associated Machines</td></tr>
<tr><td>205</td><td>Agricultural Machines</td></tr>
<tr><td>206</td><td>Mining Machinery</td></tr>
<tr><td>209</td><td>Other Machines</td></tr>
<tr><td>213</td><td>Other Wheeled Means of Transportation</td></tr>
<tr><td>219</td><td>Other Means of Transport</td></tr>
<tr><td>225</td><td>Electric Hand Tools</td></tr>
<tr><td>226</td><td>Tools Implementations and Applications</td></tr>
<tr><td>227</td><td>Ladders, mobile ramps</td></tr>
<tr><td>229</td><td>Other Equipment</td></tr>
<tr><td>231</td><td>Explosives</td></tr>
<tr><td>232</td><td>Dusts, Gases, Liquids and Chemicals</td></tr>
<tr><td>233</td><td>Flying Objects</td></tr>
<tr><td>239</td><td>Other materials</td></tr>
<tr><td>252</td><td>Open Cast Mining</td></tr>
<tr><td>261</td><td>Animals</td></tr>
<tr><td rowspan="2">Lifting Machines and Applications and Pressure Vessels</td><td rowspan="2">X13</td><td>211</td><td>Lifting Machines and Appliances</td></tr>
<tr><td>221</td><td>Pressure Vessels</td></tr>
<tr><td>Electrical Installations</td><td>X14</td><td>224</td><td>Electrical Installations</td></tr>
<tr><td rowspan="2">Work Environment</td><td rowspan="2">X15</td><td>241</td><td>Working Environment- Outdoor</td></tr>
<tr><td>242</td><td>Working environment- Indoor</td></tr>
</table>

Table 3.3

Agencies of HFLS Accidents (B1) and Number of HFLS Accidents during the Period from 2006 to 2015 as per IS-3786

Year	Scaffolding	Others	Lifting Machines and Applications and Pressure Vessels	Electrical Installations	Work Environment	Total Number of HFLS Accidents
	$X11_H$	$X12_H$	$X13_H$	$X14_H$	$X15_H$	$YB1N_H$
2006	4	5	15	3	12	39
2007	1	6	6	11	24	48
2008	1	30	14	10	35	90
2009	2	35	13	12	59	121
2010	5	32	14	28	78	157
2011	7	62	24	24	125	242
2012	2	68	21	32	138	261
2013	12	96	38	26	171	343
2014	9	95	31	28	191	354
2015	13	83	40	32	243	411
Total	**56**	**512**	**216**	**206**	**1076**	**2066**

Table 3.4

Agencies of LFHS Accidents (B1), Number of LFHS Accidents and Man days Loss during the Period from 2006 to 2015 as per IS-3786

Year	Scaffolding	Others	Lifting Machines and Applications and Pressure Vessels	Electrical Installations	Work Environment	Total Number of LFHS Accidents	Total Man Days Loss on LFHS Accidents
	$X11_L$	$X12_L$	$X13_L$	$X14_L$	$X15_L$	$YB1N_L$	$YB1MDL_L$
2006	2	3	0	1	4	10	18830
2007	2	8	1	1	9	21	18357
2008	1	3	1	3	5	13	6312
2009	0	2	3	2	4	11	7135
2010	3	3	0	1	6	13	12355
2011	0	2	0	1	4	7	6109
2012	1	8	0	2	4	15	8620
2013	1	4	1	1	4	11	18450
2014	0	0	3	1	2	6	18991
2015	1	2	0	1	2	6	10724
Total	**11**	**35**	**9**	**14**	**44**	**113**	**125883**

3.3.2 Classification of Accident as per Types of Accidents

Accidents identified according to ‘Types of Accidents’, and which occurred during the period of 2006 to 2015 were further classified as per the Indian Standard IS-3786-2022 into sub classes of ‘Fall of Objects’, ‘Exposure to or Contact with Electric Current’, Over Exertions’, ‘Wrong Movements’, ‘Exposure to or Contact with Harmful Substances’, ‘Exposure to or Contact with Extreme Temperature’, ‘Explosions’, ‘Fall of Persons from Height’, Fall of Persons on the Same Level’, ‘Stepping on, Striking Against or Struck by Object’ and ‘Caught in or Between Objects’ (IS-3786, 2022 [13]). The details of which are put in **Table 3.5**. The number of HFLS accidents and the LFHS accidents determined according to the ‘Types of Accidents’ are shown in **Table 3.6** and **Table 3.7** respectively.

Table 3.5

Classification of Types of Accidents (B5) as per Indian Standard IS-3786

Type of Accidents (B5) as per IS-3786 and Identification Numbers		Codes of Type of Accidents (B5) as per IS-3786	
Fall of Objects	X51	112	Slides of earth
		113	Subsidence of ground
		114	Collapse of piles of goods
		116	Falls of object during handling
Exposure to or Contact with Electric Current	X52	16	Exposure to or contact with electric current
Others 1. Over Exertion or Wrong Movement 2. Exposure to or Contact with Extreme Temperature 3. Exposure to or Contact with Harmful Substances 4. Explosions 5. Others	X53	141	Over exertion in lifting objects
		142	Over exertion in pushing or pulling objects
		144	Wrong Movement
		153	Contact with fire, hot substances or objects
		171	Contact by inhalation, ingestion or absorption of harmful substances including gases.
		172	Exposure to ionizing radiations

Type of Accidents (B5) as per IS-3786 and Identification Numbers		Codes of Type of Accidents (B5) as per IS-3786	
		182	Gas explosion
		191	Inundation and eruption
		192	Exposure to high noise
		193	Bursting and rupture of vessels
Fall of Persons	X54	101	Fall of persons from height or into depths
	X55	102	Fall of persons on the same level
Stepping on, Striking Against or Struck by Object	X56	121	Stepping on Objects
		122	Striking against stationary objects
		123	Striking against moving objects
		124	Struck by moving objects
Caught in or Between Objects	X57	131	Caught in an object
		132	Caught between a stationary object and a moving object
		133	Caught in between moving Objects

Note

1. X51 to X57of Table 3.5, Table 3.6 and Table 3.7 denote number of accidents based on B5 classification of IS-3786-2022.

2. YB5N of Table 3.6 and 3.7 denotes total number of X51 to X57 accidents based on B5 classification of IS-3786-2022.

3. YB5MDL of Table 3.7 denotes Man-days lost on LFHS accidents under B5 classification of IS-3786-2022.

4. Subscript ‘H’ of Table 3.6 denotes HFLS accidents and subscript ‘L’ of Table 3.7 denotes LFHS accidents.

Table 3.6

Types of HFLS Accidents (B5) and Number of HFLS Accidents during the Period from 2006 to 2015 as per IS-3786

Year	Fall of Objects	Exposure to or Contact with Electric Current	Others (Over Exertion or Wrong Movement, Exposure to or Contact with Harmful Substances, Exposure to or Contact with Extreme Temperature, Explosions and Others)	Fall of persons from Height	Fall of persons on the same level	Stepping on, Striking Against or Struck by Object	Caught in or Between Objects	Total Number of HFLS Accidents
	$X51_H$	$X52_H$	$X53_H$	$X54_H$	$X55_H$	$X56_H$	$X57_H$	$YB5N_H$
2006	29	2	1	1	3	2	1	39
2007	23	6	2	5	1	10	1	48
2008	26	3	8	12	15	23	3	90
2009	40	5	7	20	17	23	9	121
2010	41	14	13	16	18	43	12	157
2011	58	13	16	17	33	80	25	242
2012	61	14	22	26	47	74	17	261
2013	73	13	34	44	44	102	33	343
2014	93	13	25	48	53	101	21	354
2015	110	19	24	40	65	118	35	411
Total	**554**	**102**	**152**	**229**	**296**	**576**	**157**	**2066**

Table 3.7

Type of LFHS Accidents (B5), Number of LFHS Accidents and Man days Loss during the Period from 2006 to 2015 as per IS-3786

Year	Fall of Objects	Exposure to or Contact with Electric Current	Others (Over Exertion or Wrong Movement, Exposure to or Contact with Harmful Substances, Exposure to or Contact with Extreme Temperature, Explosions and Others)	Fall of persons from Height	Fall of persons on the same level	Stepping on Striking Against or Struck by Object	Caught in or Between Objects	Total Number of LFHS Accidents	Total Man Days Loss on LFHS Accidents
	$X51_L$	$X52_L$	$X53_L$	$X54_L$	$X55_L$	$X56_L$	$X57_L$	$YB5N_L$	$YB5MDL_L$
2006	2	0	0	4	0	2	2	10	18830
2007	4	1	0	9	0	4	3	21	18357
2008	0	2	0	8	0	3	0	13	6312
2009	1	2	0	4	0	1	3	11	7135
2010	0	1	0	7	1	3	1	13	12355
2011	3	1	0	1	1	1	0	7	6109
2012	0	1	0	7	1	4	2	15	8620
2013	1	1	2	3	0	1	3	11	18450
2014	0	1	1	2	1	0	1	6	18991
2015	0	1	0	2	1	1	1	6	10724
Total	**11**	**11**	**3**	**47**	**5**	**20**	**16**	**113**	**125883**

3.3.3 Classification of Accident as per Locations of Injuries

Accidents which occurred during the period of 2006 to 2015 and which were identified according to the 'Locations of Injuries' were further classified as per the Indian Standard IS-3786-2022 into sub classes of 'Head', 'Trunk', Upper Limb', 'Lower Limb', 'Multiple Locations', and 'General Injuries and Unspecified Location of Injuries' (IS-3786, 2022 [13]). The details of these are as shown in **Table 3.8**. Since there is no injury during near misses, in case of near misses, the potential locations of injuries are considered for the analysis. The number of HFLS accidents and LFHS accidents determined according to the 'Locations of Injury' are shown in **Table 3.9** and **Table 3.10** respectively.

Table 3.8

Classification of Locations of Injuries due to Accidents (B7) as per Indian Standard IS-3786

Location of Injuries due to Accidents (B7) as per IS-3786 and Identification Numbers		**Codes of Locations of Accidents (B7) as per IS-3786**	
Head	X71	411	Cranium Region (skull, brain, scalp)
		412	Eye
		413	Ear
		414	Mouth
		415	Nose
		416	Face
		418	Unspecified location
Trunk	X72	431	Back
		432	Chest
		433	Abdomen
		434	Pelvis
		439	Unspecified location

Location of Injuries due to Accidents (B7) as per IS-3786 and Identification Numbers		Codes of Locations of Accidents (B7) as per IS-3786	
Upper Limb	X73	441	Shoulder
		443	Elbow
		444	Forearm
		445	Wrist
		446	Hand
		447	Fingers
		449	Unspecified location
Lower Limb	X74	451	Hip
		452	Thigh
		453	Knee
		454	Leg
		455	Ankle
		456	Foot
		457	Toes
		458	Multiple locations
		459	Unspecified location
Multiple Locations	X75	461	Head and trunk, Head or one or more limbs
		462	Trunk, and one or more limbs
		463	One upper limb and one lower limb or more than two limbs
		465	Unspecified

Location of Injuries due to Accidents (B7) as per IS-3786 and Identification Numbers		Codes of Locations of Accidents (B7) as per IS-3786	
1. General Injuries 2. Unspecified Location of Injuries	X76	471	Circulatory system in general
		472	Respiratory system in general
		474	Nervous system in general
		476	Unspecified
		49	Unspecified location of injury

Note

1. X71 to X76 of Table 3.8, Table 3.9 and Table 3.10 denote number of accidents based on B7 classification of IS-3786-2022.
2. YB7N of Table 3.9 and 3.10 denotes total number of X71 to X76 accidents based on B7 classification of IS-3786-2022.
3. YB7MDL of Table 3.10 denotes Man-days lost on LFHS accidents under B7 classification of IS-3786-2022.
4. Subscript 'H' of Table 3.9 denotes HFLS accidents and subscript 'L' of Table 3.10 denotes LFHS accidents.

Table 3.9

Locations of Injuries due to HFLS Accidents (B7) and Number of HFLS Accidents during the Period from 2006 to 2015 as per IS-3786

Year	Head	Trunk	Upper Limb	Lower Limb	Multiple Locations	General Injuries and Unspecified Location of Injuries	Total Number of HFLS Accidents
	$X71_H$	$X72_H$	$X73_H$	$X74_H$	$X75_H$	$X76_H$	$YB7N_H$
2006	26	0	0	5	3	5	39
2007	20	1	3	3	14	7	48
2008	23	0	14	17	18	18	90
2009	41	1	13	23	21	22	121
2010	40	3	37	20	21	36	157
2011	60	1	48	50	38	45	242
2012	65	2	41	55	62	36	261
2013	80	3	76	61	59	64	343
2014	89	4	76	54	58	73	354
2015	111	7	94	61	56	82	411
Total	**555**	**22**	**402**	**349**	**350**	**388**	**2066**

Table 3.10

Locations of Injuries due to LFHS Accidents (B7), Number of LFHS Accidents and Man days Loss during the Period from 2006 to 2015 as per IS-3786

Year	Head	Trunk	Upper Limb	Lower Limb	Multiple Locations	General Injuries and Unspecified Location of Injuries	Total Number of LFHS Accidents	Total Man Days Loss on LFHS Accidents
	$X71_L$	$X72_L$	$X73_L$	$X74_L$	$X75_L$	$X76_L$	$YB7N_L$	$YB7MDL_L$
2006	3	3	2	2	0	0	10	18830
2007	6	4	7	2	2	0	21	18357
2008	1	1	3	6	2	0	13	6312
2009	0	0	5	3	1	2	11	7135
2010	5	0	1	3	3	1	13	12355
2011	0	1	3	2	0	1	7	6109
2012	3	0	7	3	1	1	15	8620
2013	5	1	3	1	0	1	11	18450
2014	2	1	1	0	2	0	6	18991
2015	1	0	1	2	2	0	6	10724
Total	**26**	**11**	**33**	**24**	**13**	**6**	**113**	**125883**

3.4 RATIONALE FOR SELECTION OF ACCIDENT PREDICTION MODEL

Accident prediction models are chosen based on the nature of data, prediction accuracy, required information, speed of processing and resource availability. Depending upon the data, each approach has its own restrictions. We have studied the suitability of generally used methodologies of Artificial Neural Networks, Bayesian Regression and Multiple Linear Regression for the development of accident prediction models. Study indicates that models based on Artificial Neural Networks (ANN) and Bayesian Regression, when compared with models based on Multiple Linear Regression, are computationally more intensive and take more time for processing and deriving inference. In addition, tools and aids to develop models based on Artificial Neural Networks (ANN) and Bayesian Regression are not easily available in many common scientific libraries, whereas tools for development of models based on Multiple Linear Regression are easily available (Christina Ellis, 2022 [30] [31] [32]; Ioannis et al., 2022[61]. Data analysis tools for Multiple Linear Regression is a standard package of Microsoft Excel available in all computers with MS Office. Therefore, considering the simplicity, reasonable predictability and easy availability, multiple linear regression is considered in our study for developing accident prediction models.

Literature survey indicates that multiple linear regression is extensively used to predict road accidents. However, its capability in prediction of occupational accidents is less explored. Therefore, Multiple Linear Regression Analysis with ANOVA is used in our study to predict a dependent variable based on a set of independent variables. Multiple linear regression analysis is a statistical approach for evaluating relationships between variables and describing such relationships in the form of equations. It is used to estimate a dependent variable using independent variables. It is commonly used in prediction to figure out which of the independent variables has a significant relationship with the dependent variable. R Square and Adjusted R Square values, F-Test, T-Test, and p-values for a certain value of significance are used to determine the statistical significance of the model (Kothari, 1990 [69]; Levin and Rubin, 1996 [72]; Shakil, 2001 [105]; Mustakim et al., 2008 [84]; Rokade et al., 2010 [98]; Uyanik and Guiler, 2013 [117]; Jenan et al., 2015 [63]; Pisharody et al., 2022 [94]).

3.5 FLOW CHART OF ACCIDENT PREDICTION MODEL

Multiple Linear Regression is used to develop accident prediction models on LFHS accidents in our study. **Figure 3.2** gives Flow Chart for Development of Accident Prediction Models.

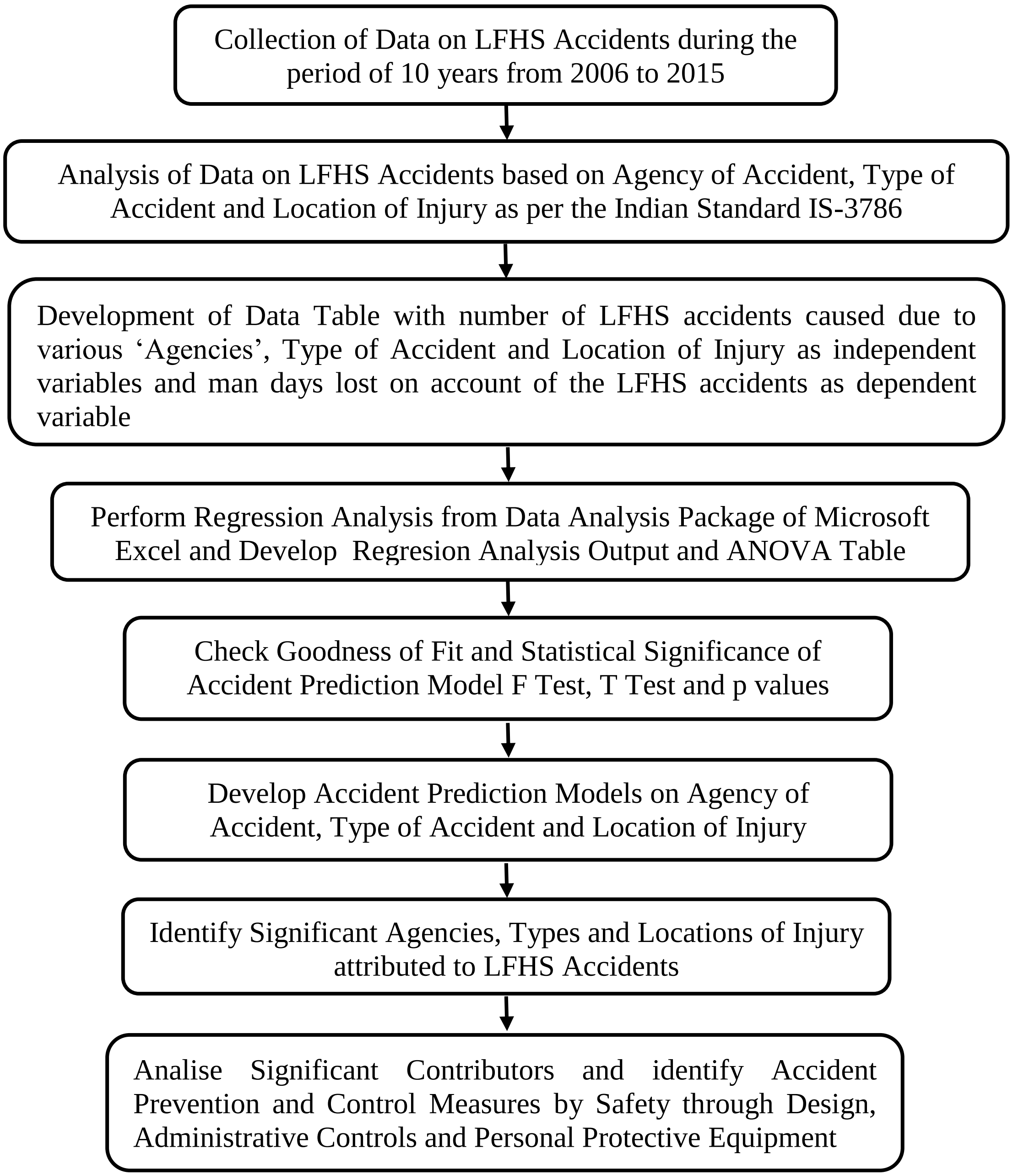

Figure 3.2: Flow Chart for Development of Accident Prediction Models

3.6 CONCLUSION

Accident data of 2179 accidents, which occurred at 11 twin unit Operating Stations and 3 twin unit Construction Project sites in the Public Sector Power Company during a period of 10 years (2006 - 2015) was considered in the present research work. This data was classified as per the principal identifiers of ‘Agencies’, ‘Types of Accidents’ and ‘Locations of Injuries’, in reference to the Indian Standard IS-3786-2022 ‘Method for the Computation of Frequency and Severity Rates for Industrial Injuries and Classification of Industrial Accidents’. Accidents have further been categorized into High Frequency and Low Severity (HFLS) accidents, and Low Frequency and High Severity (LFHS) accidents.

An HFLS accident is an accident which occurs at high frequency and has a low severity effect, such as those involved in Near Misses, First-Aid and Non-Reportable Injuries. A total of 2066 HFLS accidents, comprising of 1539 Near Misses, 366 First-Aid Injuries and 161 Non-Reportable Injuries were considered in the present work. Analysis of HFLS accidents has been carried out, as mentioned above, according to the principal identifiers of ‘Agencies’, ‘Types of Accidents’ and ‘Locations of Injuries’ in reference to Indian Standard IS-3786-2022. The details on the analysis of HFLS accidents are presented in **Chapter-4** of this thesis.

An LFHS accident is an accident which occurs with low frequency and has high severity effect, such as those involved in Reportable Injuries and Fatalities. 113 LFHS accidents, comprising of 95 Reportable Injuries and 18 Fatalities were considered for our research work. Analysis of LFHS accidents has also been carried out as per the principal identifiers of ‘Agencies’, ‘Types of Accidents’ and ‘Locations of Injuries’, in reference to the Indian Standard IS-3786-2022.

Analysis of significant contributors of LFHS accidents derived from accident prediction models of LFHS accidents has also been carried out by us according to the identifiers of ‘Agencies’, ‘Types of Accidents’ and ‘Locations of Injuries’, in reference to the Indian Standard IS-3786-2022. The details on development of accident prediction models on LFHS accidents and analysis of significant contributors of LFHS accidents derived from accident prediction models are provided in **Chapter-5** of this thesis.

Some of the independent variables of the models may have exponential relationship with the dependent variable. The exponential terms in a multiple linear regression model turn the model into non-linear. Since independent variables are the exponential terms and not the Beta coefficients; and the individual terms are added together, it still qualifies as a linear model.

Levin and Rubin, 1996 [72] caution following limitations for the regression analysis:

1. Regression model is valid only over the same range as the one from which the sample was taken initially.

2. Regression model may not be applicable if conditions and assumptions on which it was developed are changed.

3. Regression analysis cannot determine cause and effect. Rather, it can be used to identify statistical significance of independent variables in determining dependent variable.

Accident prediction models can be developed using Artificial Neural Networks (ANN), and Bayesian Regression approach as well Christina Ellis, 2022 [30] [31] [32]; Ioannis et al., 2022[61]. It suggested that this could a study subject for future research.

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CHAPTER-4

ANALYSIS OF HIGH FREQUENCY AND LOW SEVERITY (HFLS) ACCIDENTS

4.1 PREAMBLE

High Frequency and Low Severity (HFLS) Accidents, as the title suggests, are those accidents which occur with high frequency; but have relatively less severe effects, such as Near Misses, First-Aid Injuries and Non-Reportable Injuries. This thesis chapter deals with the analysis of 2066 HFLS accidents, comprising of 1539 Near Misses, 366 First-Aid Injuries and 161 Non-Reportable Injuries that occurred at the 11-twin unit Operating Stations and 3 twin unit Construction Project sites in the Public Sector Power Company under the study during the period of 10 years of 2006 to 2015. These accidents have been classified and analyzed according to the identifiers of 'Agencies', 'Types of Accidents' and 'Locations of Injuries', in reference to the Indian Standard IS-3786-2022 'Method for the Computation of Frequency and Severity Rates for Industrial Injuries and Classification of Industrial Accidents'.

4.2 ANALYSIS OF HFLS ACCIDENTS BASED ON 'AGENCIES'

Agency is an object or substance, most closely associated with causing an accident, and with respect to which adoption of a safety measure could prevent the accident from happening. Examples of an **Agency** are, machines, means of transportation, flying objects, scaffoldings, ladders, lifting machines, electrical conductors, electric hand tools, chemicals, gases, working environment, live animals etc.

The 'Agencies' for the HFLS accidents considered here are listed in **Table 4.1,** and their relative contributions are presented in **Figure 4.1** (Pisharody et al., 2018a [91]).

Table 4.1

Agencies of HFLS Accidents (B1) and Number of HFLS Accidents during the Period from 2006 to 2015 as per IS-3786

Year	**Scaffolding**	**Others**	**Lifting Machines and Applications and Pressure Vessels**	**Electrical Installations**	**Work Environment**	**Total Number of HFLS Accidents**
	$X11_H$	$X12_H$	$X13_H$	$X14_H$	$X15_H$	$YB1N_H$
2006	4	5	15	3	12	39
2007	1	6	6	11	24	48
2008	1	30	14	10	35	90
2009	2	35	13	12	59	121
2010	5	32	14	28	78	157
2011	7	62	24	24	125	242
2012	2	68	21	32	138	261
2013	12	96	38	26	171	343
2014	9	95	31	28	191	354
2015	13	83	40	32	243	411
Total	**56**	**512**	**216**	**206**	**1076**	**2066**

X11 to X15 of Table 4.1 denote number of HFLS accidents based on B1 classification of IS-3786-2022.
YB1N of Table 4.1 denotes total number of X11 to X15 HFLS accidents based on B1 classification of IS-3786-2022.
Subscript 'H' of Table 4.1 denotes HFLS accidents.

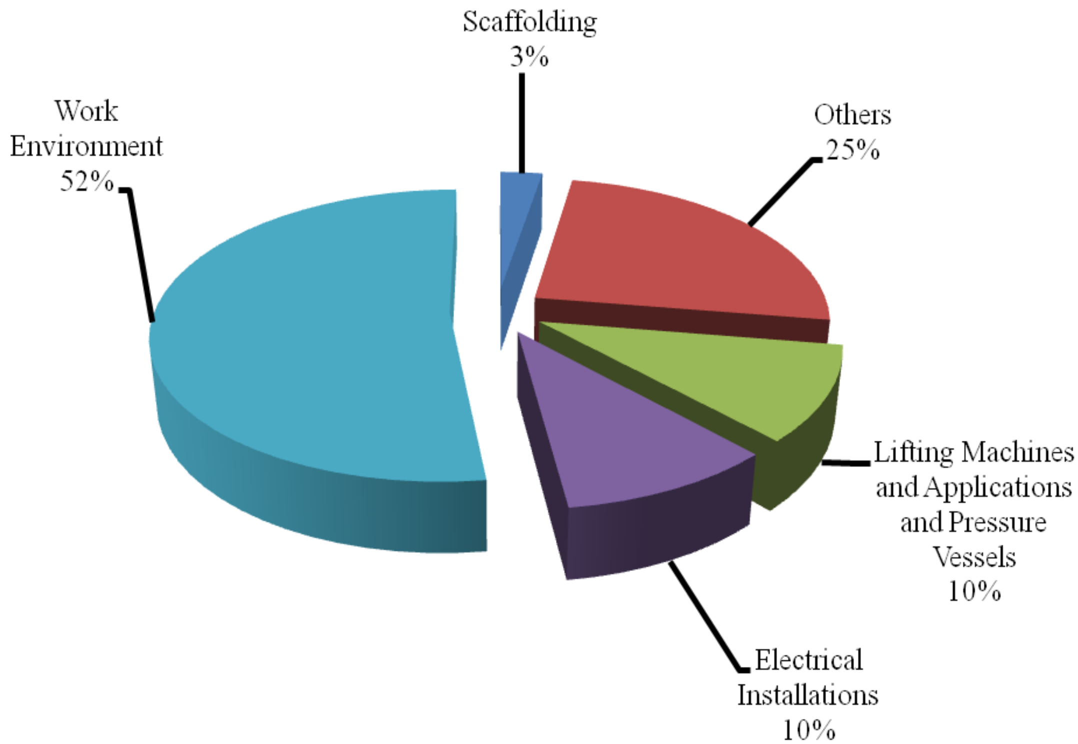

Figure 4.1: Agencies of HFLS Accidents during the period 2006-2015
(Ref. Pisharody et al., 2018a [91]).

52% of the HFLS accidents were due to unsafe conditions and unsafe acts while working in indoor and outdoor **'Working Environment'.** Floors, confined quarters, stairs, traffic and working surfaces, floor openings and wall openings, environmental factors such as lighting, ventilation, temperature, noise; water, fire, or other unsafe conditions in structures, systems, and components within the plant buildings are among the agencies in the indoor 'Working Environment' (44%). Weather, traffic and working surfaces, water, fire, or other unsafe conditions in structures, systems, and components outside the plant buildings account for 8% of the outdoor 'Working Environment.' This shall be addressed through machine guarding and fencing or barricading of hazardous work locations, covering or barricading of pits, floor, openings, wall openings and manholes, preventive maintenance and surveillance of structures, systems and components, periodic plant safety inspection and prompt correction of deficiencies, employee training and pre-job briefing, effective job supervision and housekeeping and workplace upkeep.

10% of the HFLS accidents were due to unsafe conditions and unsafe acts while working on '**Electrical Installations'** such as rotating machines, switchgears, circuit breakers, cables and lighting circuits or lamps. This shall be corrected by ensuring electrical safety as per the provisions of statutory and regulatory requirements and verifying compliance by periodic surveillance. ELCBs shall be provided on electrical circuits.

10% of the HFLS accidents were due to deficiencies in '**Lifting Machines and Appliances and Pressure Vessels'. '**Lifting Machines and Appliances' (6%) include Electrical Overhead Travelling (EOT) cranes, mobile cranes, tower cranes, forklifts, elevators, slings or other lifting tools and tackles. 'Pressure Vessels' (4%) include pressurized containers, gas cylinders, pressurized piping and accessories. These deficiencies shall be corrected by deploying authorized persons for working on Lifting Machines and Appliances and by enforcing periodic surveillance on Lifting Machines and Appliances and Pressure Vessels.

3% of the HFLS accidents were due to deficiencies in '**Scaffoldings',** such as loosely placed working platforms, hand railings and absence of toe boards or mid railings etc. Scaffolding shall be certified for safe use by the authorized agency.

25% of the HFLS accidents were attributed to deficiencies in '**Other Agencies',** which comprise of miscellaneous equipment such as 'Wheeled Means of Transportation' (4.5%), 'Tools, Implements and Appliances' (3.3%), 'Dusts, Gases, Liquids and Chemicals' (2.5%), 'Ladders and Mobile Ramps' (1.7%), 'Metal Working Machines' (1.3%), 'Living Animals' (1.0%), 'Transmission Machinery' (0.6%), 'Flying Objects' (0.7%) and 'Other Miscellaneous Equipment' (9.4%). This shall be addressed through enforcing speed limit on vehicle movement in plant premises. Securing tools while working at height or enforcing use of tool bags. Deficiencies in other agencies shall be addressed by periodic surveillance and prompt correction of deficiencies.

4.3 ANALYSIS OF HFLS ACCIDENTS BASED ON 'TYPES OF ACCIDENTS'

The class of **Type of accident** is created by considering the manner in which an object or substance causing an injury comes into contact with a person, or from the movement of a person which results into an injury. Examples from this class are, fall of objects, fall of person, stepping or striking against or struck by object, caught or in between the objects, over exertion or wrong movements, exposure or contact with extreme temperature or electric current or harmful substances, explosions etc.

The different '**Types**' of HFLS accidents listed in **Table 4.2,** and **Figure 4.2** give their relative contributions (Pisharody et al., 2018a [91]).

Table 4.2

Type of HFLS Accidents (B5) and Number of HFLS Accidents during the Period from 2006 to 2015 as per IS-3786

Year	Fall of Objects	Exposure to or Contact with Electric Current	Others (Over Exertions, or Wrong Movements, Exposure to or Contact with Harmful Substances, Exposure to or Contact with Extreme Temperature, Explosions and Others)	Fall of persons from Height	Fall of persons on the same level	Stepping on Striking Against or Struck by Object	Caught in or Between Objects	Total Number of HFLS Accidents
	$X51_H$	$X52_H$	$X53_H$	$X54_H$	$X55_H$	$X56_H$	$X57_H$	$YB5N_H$
2006	29	2	1	1	3	2	1	39
2007	23	6	2	5	1	10	1	48
2008	26	3	8	12	15	23	3	90
2009	40	5	7	20	17	23	9	121
2010	41	14	13	16	18	43	12	157
2011	58	13	16	17	33	80	25	242
2012	61	14	22	26	47	74	17	261
2013	73	13	34	44	44	102	33	343
2014	93	13	25	48	53	101	21	354
2015	110	19	24	40	65	118	35	411
Total	**554**	**102**	**152**	**229**	**296**	**576**	**157**	**2066**

X51 to X57of Table 4.2 denote number of HFLS accidents based on B5 classification of IS-3786-2022.

YB5N of Table 4.2 denotes total number of X51 to X57 HFLS accidents based on B5 classification of IS-3786-2022.

Subscript ‘H’ of Table 4.2 denotes HFLS accidents.

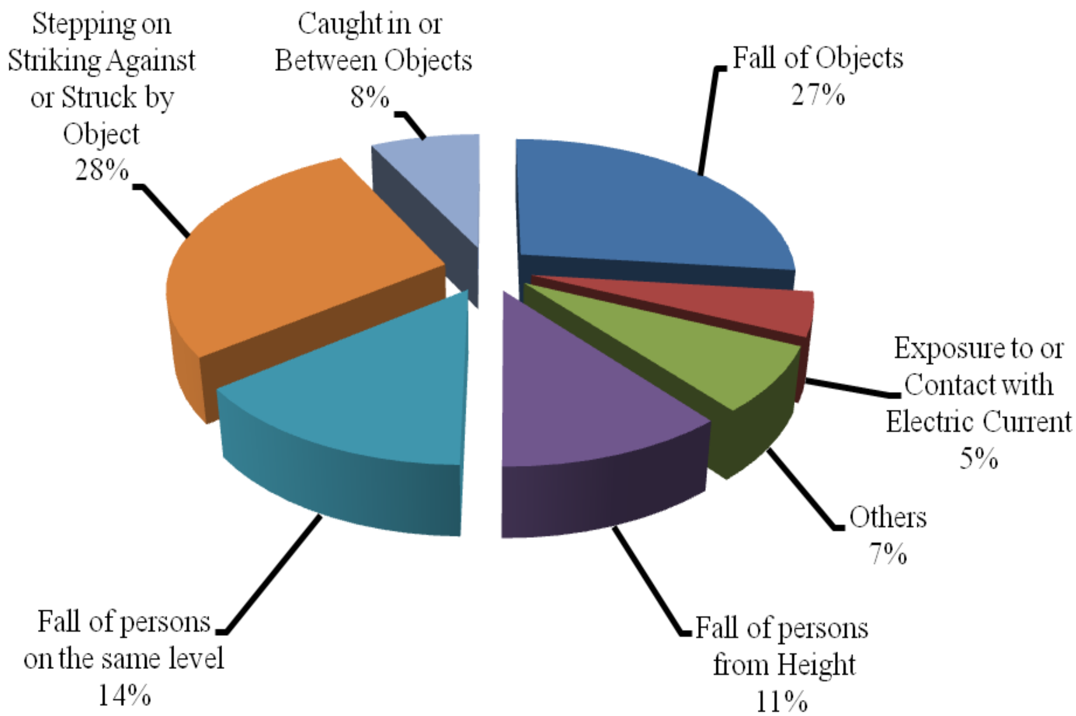

Figure 4.2: Types of HFLS Accidents during the period 2006-2015
(Ref. Pisharody et al., 2018a [91]).

28% of the HFLS accidents were attributed to **'Stepping on or Striking Against or Struck by Objects'** due to deficiencies in material condition, design, layout and ageing of structures, systems and components, tripping hazards, poor housekeeping, placing materials in unsecured manner, lack of caution signage or warning, ineffective communication, non-use of correct tools, non-use of personal protective equipment and lack of supervision. Periodic surveillance of structures, systems and components shall be carried out and slip, trip, bump and fall hazards should be promptly corrected. Work supervisors shall ensure use of correct type of tools and enforce personal protective equipment. Work place housekeeping shall be ensured and all unwanted materials shall be safely disposed of and specific locations shall be identified for all required materials.

27% of the HFLS accidents were due to **'Fall of Objects'** from structures, systems and components due to deficiencies in material condition or ageing, unsafe procedures, poor housekeeping and placing materials at height in unsecured manner. Periodic surveillance of structures, systems and components shall be carried out and all degraded components shall be repaired or replaced. Loose materials at height shall be removed through periodic housekeeping, toe boards shall be ensured to the platforms at height and safety nets shall be provided while works are in progress at height.

14% of the HFLS accidents were due to **'Fall of Persons on the Same Level'** due to deficiencies in material condition, design, layout or ageing of structures, systems and components, slipping on the floor due to spillage of materials or biological growth, tripping hazards, use of unsafe personal protective equipment, taking unsafe posture by the workers, unsafe procedures, unsafe acts by the workers, poor housekeeping, lack of caution signage or warning, and low illumination. Slip, trip and fall hazards in the work place shall be removed through periodic surveillance and corrective measures. Where ever there is difference in floor elevations, those locations shall be made even by either constructing a ramp or steps. Work supervisors shall ensure use of safety shoes by the persons working under them and supervisors shall coach the workers to refrain from unsafe acts.

11% of the HFLS accidents were due to **'Fall of Persons from Height'** due to unsafe scaffolding, platforms and ladders; lack of safe access for working at height, lack of hard barricading and caution signage at height, uncovered openings or openings covered with soft materials, unsafe design and layout, tripping hazards at height, deficiencies in staircases, deficiencies in material condition, aging, not securing ladders, low illumination, unsafe acts by the workers, non-use of personal protective equipment or fall protection measures, use of unsafe personal protective equipment, unsafe procedures, non-adherence to procedures and work permit system, slipping on the floor due to spillage of materials, poor housekeeping and ineffective supervision and communication. Work supervisors shall ensure compliance to requirements for works at height, work permit system, work procedures and enforce use of personal protective equipment, all floor and wall openings shall be covered or barricaded, scaffoldings and platforms shall be certified for safe use by the authorized agency, Periodic inspection of ladders shall be carried out and defective ladders shall be repaired or removed from work location. area illumination shall meet the statuary requirements. Plant safety inspection shall include inspection of staircases and housekeeping of plant area with timebound corrective action program.

8% of the HFLS accidents were due to **'Caught in or Between the Objects'** attributed to shortfalls in identification of hazards and implementing risk control measures, lack of hard barricading or guarding with caution signage, uncovered openings or pits, unsafe storage of materials during transportation, ineffective supervision and communication, unsafe design and layout, lack of procedures, unsafe procedures, non-adherence to procedures and work permit system; uncovered openings, unsafe acts by the workers, placing materials in unsecured manner, unsafe platform, non-use of personal protective equipment or use of unsafe personal protective equipment, lack of safe access for working and low illumination. Access to hazardous work locations shall be prohibited by guarding or barricading and caution signage. Work supervisors shall ensure compliance to the procedures, work permit system and enforce use of personal protective equipment.

5% of the HFLS accidents were due to **'Exposure to or Contact with Electrical Current'** attributed to ageing of cables, wrong identification and tagging of equipment, design deficiencies in the equipment, lack of guaranteed electrical isolation, lack of procedures, unsafe procedures, non-adherence to procedures and work permit system, ineffective supervision and communication, weakness in self checking and peer checking of equipment before the job, exposed live contactors of equipment and cable terminals, unsafe design and layout, non-use of personal protective equipment, lack of caution signage and markers for underground cables, use of cables with joints, lack of Earth Leakage Circuit Breakers (ELCBs) in electrical circuits, lack of hard barricading and caution signage to restrict approach, low illumination and unsafe acts by the employees. While working on electrical system, guaranteed electrical isolation; and compliance to procedures and work permit system shall be ensured. Design shall ensure that there are no exposed live electrical conductors and all electrical conductors which are susceptible for human interaction shall be insulated. Earthing shall be provided on all electrical equipment as per the statutory requirements and ELCBs shall be provided on electrical circuits.

7% of the HFLS accidents were due to '**Other Types of Accidents'** which comprise of the followings:

1. 'Exposure to or Contact with Extreme Temperature' (3%) attributed to heating or sparks due to non-adherence to procedures and work permit system during hot works, unsafe procedures, sparks from damaged electrical cable by rodent attack or ageing, lack of arrangement for collecting welding and cutting spatters, ageing of equipment and components, storage of incompatible chemicals, use of cables with joints, un-insulated hot components of systems, lack of barricading and caution signage to restrict approach to hot components of the system and environment, water leakage on electrical systems, non-use of personal protective equipment, use of personal protective equipment in incorrect manner, lack of supervision, shortfalls in design and layout, storage of flammable materials or oil leak at work places, overloading of electrical cables, lack of attention of workers to hazards in workplace or shortfalls in identification of hazards and implementing risk control measures. All hot surfaces of systems and equipment shall be insulated or approach to such surfaces shall be barricaded. Work supervisor shall ensure compliance to requirements of hot work permit system. Joints in cables shall be avoided. Surveillance program shall be made to identify hotspots in cable joints, if any and corrective measures shall be taken.

2. 'Exposure to or Contact with Harmful Substances' (3%) due to deficiencies in material condition, design, layout and ageing of structures, systems and components; unsafe acts by the workers, ineffective supervision and communication, lack of procedures, unsafe procedures, non-adherence to procedures and work permit system, shortfalls in identification of hazards and implementing risk control measures, use of incorrect tools, non-use of personal protective equipment, use of incorrect personal protective equipment or lack of labels on chemical containers. While performing jobs involving hazardous chemicals, compliance to procedures and work permit system shall be ensured and use of personal protective equipment shall be enforced. Periodic inspection of structurers, systems and components shall be carried out and degradation shall be addressed.

3. Remaining 1% of the HFLS accidents were attributed to 'Over Exertions or Wrong Movements' (0.4%), 'Explosions' (0.2%), and 'Others which are not classified elsewhere' (0.4%). Workers shall be coached to avoid over exertions or wrong movements.

4.4 ANALYSIS OF HFLS ACCIDENTS BASED ON 'LOCATIONS OF INJURIES'

Accidents are also identified by **'Location of Injury',** where the 'Location of Injury' is that part of the injured person's body which is directly affected by the injury. However, since there are no injuries to persons in case of near misses, potential locations for injuries are considered for classification of near misses. Some typical examples are head, trunk, upper limb; lower limb etc.

Table 4.3 gives 'Locations of Injuries' due to HFLS accidents and **Figure 4.3** gives the relative proportion of those 'Locations of Injuries' (Pisharody et al., 2018a [91]).

Table 4.3

Locations of Injuries due to HFLS Accidents (B7) and Number of HFLS Accidents during the Period from 2006 to 2015 as per IS-3786

Year	Head	Trunk	Upper Limb	Lower Limb	Multiple Locations	General Injuries and Unspecified Location of Injuries	Total Number of HFLS Accidents
	$X71_H$	$X72_H$	$X73_H$	$X74_H$	$X75_H$	$X76_H$	$YB7N_H$
2006	26	0	0	5	3	5	39
2007	20	1	3	3	14	7	48
2008	23	0	14	17	18	18	90
2009	41	1	13	23	21	22	121
2010	40	3	37	20	21	36	157
2011	60	1	48	50	38	45	242
2012	65	2	41	55	62	36	261
2013	80	3	76	61	59	64	343
2014	89	4	76	54	58	73	354
2015	111	7	94	61	56	82	411
Total	**555**	**22**	**402**	**349**	**350**	**388**	**2066**

X71 to X76 of Table 4.3 denote number of accidents based on B7 classification of IS-3786-2022.

YB7N of Table 4.3 denotes total number of X71 to X76 based on B7 classification of IS-3786-2022.

Subscript ‘H’ of Table 4.3 denotes HFLS accidents.

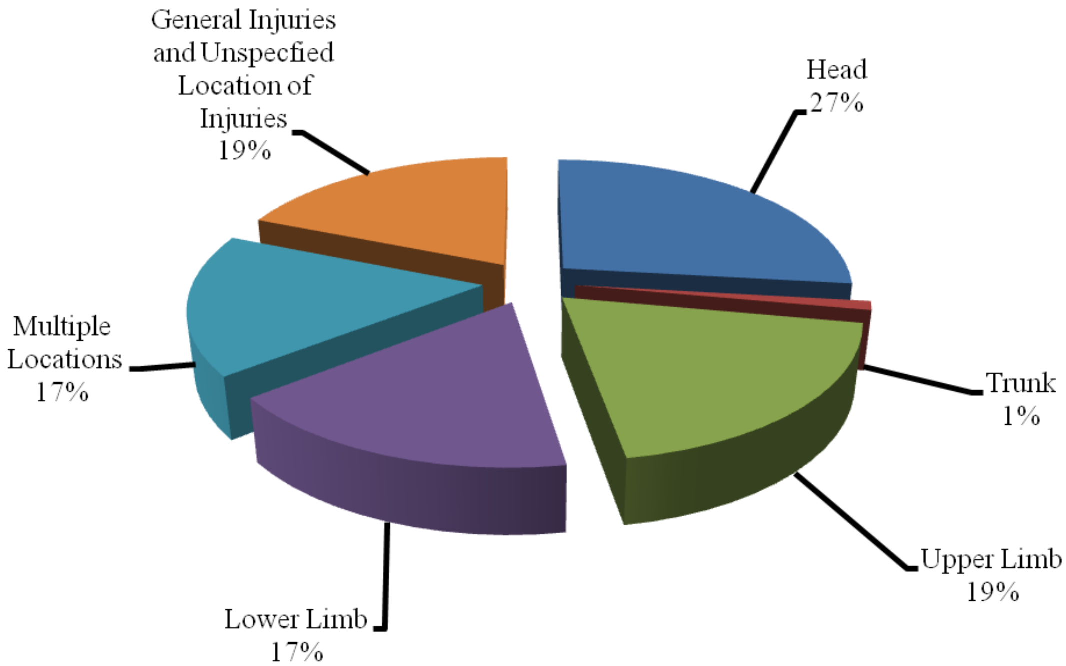

Figure 4.3: Locations of Injuries due to HFLS Accidents during the period 2006-2015 (Ref. Pisharody et al., 2018a [91]).

27% of injuries due to HFLS accidents considered in our present study were on **'Head'** at different parts of head such as cranium region, eye, ear, mouth, nose, face and other unspecified locations of head due to fall of objects, fall of persons, stepping on or striking against or struck by objects, caught in or between the objects and exposure to or contact with extreme temperatures. Work supervisors shall ensure compliance to the requirements for works at height and enforce use of helmets and safety shoes by persons working under them. Fall of objects shall be addressed by avoiding loose materials at height, periodic housekeeping, ensuring toe boards to the platforms at height and by providing safety nets while works are in progress at height. Slip, trip and fall hazards in the work place shall be removed. All floor and wall openings shall be covered or barricaded, scaffoldings and platforms shall be certified for safe use by the authorized agency, area illumination shall meet the statuary requirements.

19% of injuries due to those HFLS accidents were on **'Upper Limb'** at different parts of upper limb such as shoulder, elbow, forearm, wrist, hand, fingers and other unspecified locations of upper limb due to fall of objects, fall of persons, stepping on, striking against or struck by objects, caught in or between the objects, over exertions or wrong movements, exposure to or contact with electrical current, extreme temperature or harmful substances and bursting of pressured equipment. Work supervisors shall ensure precautions to prevent deficiencies which can lead to these types of accidents as explained earlier.

19% of injuries due to the HFLS accidents were **'General Injuries' or on 'Unspecified Locations of Injury'**, such as at various internal systems and other unspecified locations of human body due to fall of objects, fall of persons, stepping on or striking against or struck by objects, caught in or between the objects, over exertions or wrong movements, exposure to or contact with electrical current, extreme temperature or harmful substances, gas explosions, inundations and bursting of pressured equipment. Supervisory oversight shall be enhanced to prevent these types of accidents as already explained.

17% of injuries due to the HFLS accidents were on **'Lower Limb'** at different parts of lower limb such as hip, thigh, knee, leg, ankle, foot, toes and other unspecified locations of lower limb due to fall of objects, fall of persons, stepping on or striking against or struck by objects, caught in or between the objects, wrong movements and exposure to or contact with extreme temperature or harmful substances. Work supervisors shall ensure compliance to safety requirements to prevent these types of accidents as explained earlier.

17% of injuries due to HFLS accidents were on **'Multiple Locations'** such as head, trunk, one or more limbs and other unspecified locations of human body due to fall of objects, fall of persons, stepping on or striking against or struck by objects, caught in or between the objects, exposure to or contact with electrical current, exposure to or contact with extreme temperature, exposure to or contact with harmful substances and bursting of pressured equipment. Work supervisors shall coach persons working with them to prevent these types of accidents as explained earlier.

1% of injuries due to HFLS accidents were on **'Trunk'**; at different parts of trunk such as back, chest, abdomen, pelvis and other unspecified locations of trunk due to fall of objects, fall of persons, stepping on or striking against or struck by objects and caught in or between the objects. Supervisory effectiveness shall be enhanced to prevent these types of accidents as already explained.

4.5 DISCUSSION & RECOMMENDATIONS

Analysis of 2066 HFLS accidents that occurred at 11 twin unit Operating Stations and 3 twin unit Construction Project sites in the Public Sector Power Company during the period of 10 years from 2006 to 2015 were classified according to 'Agencies of Accidents', 'Types of Accidents', and 'Locations of Injuries' and analyzed as per the Indian Standard IS-3786-2022. The analysis indicates that the accidents have occurred due to shortfalls in design, administrative controls and use of personal protective equipment either to prevent accidents from happening or to reduce the severity of accidents. These shortcomings can be addressed through implementation of 'Safety through Design', enforcement of 'Administrative Controls' and use of 'Personal Protective Equipment'. The following recommendations are made, based on our study, to prevent HFLS accidents from occurring:

4.5.1 Safety Through Design

Machine Guarding and Fencing or Barricading of Hazardous Work Locations

1. A comprehensive survey of systems, equipment and components shall be carried out to identify machine guarding related deficiencies and guards shall be provided to prevent approach of workers to hazardous components of systems, equipment and components. In case of new equipment, requirement of machine guarding as per Indian Standard IS 16809 (IS 16809 Part 1-4, 2018 [15] [16] [17] [18]) shall be included in the purchase specifications.

Covering of Pits, Floor Openings, Wall Openings and Manholes

2. Fencing, railing or hard barricading of at least 1 m height with caution signage and mid rail shall be provided around pits, floor openings, wall openings, manholes and other work locations with fall potential to prevent fall of persons, complying with the requirements of Indian Standard IS 4912 (IS 4912-2017 [19]).

3. Pits, floor openings, wall openings, and manholes must be covered with materials of sufficient strength to prevent persons and objects from falling, complying with the requirements of Indian Standard IS 4912 (IS 4912-2017 [19]).

Ensuring Scaffolding Safety

4. All scaffolding members, such as planks, braces, vertical supports, and horizontal supports, must be of sound material, well-constructed, and of sufficient strength.

5. Safe access shall be ensured at work places at height by safe scaffoldings and platforms with provisions for hooking of safety harness.

6. Safety nets shall be provided below the locations of works at height and wrapped on all sides of the scaffoldings; and firmly secured to prevent fall of persons and materials.

7. Design of scaffoldings and platforms shall meet safety requirements complying with Indian Standard IS-3696 on "Scaffolds and Ladders – Code of Safety" (IS-3696 Part-1 and Part-2, 2017 [20] [21]).

8. Platforms of following minimum width shall be provided for various types of works as indicated below (GOI, 1996 [43]):

    i) Where platform is not more than 2 m above the ground or solid floor:

        a) For painters, decorators and similar workmen - 30 cm.

        b) For other types (Men and tools) - 50 cm.

ii) Where platform is more than 2 m above the ground or solid floor:

a) For men, tools and materials - 120 cm.

b) For men, tools, materials and vehicles such as wheel barrows - 150cm.

9. Open sides of the platforms shall be provided with toe-boards of 15 cm height, hand rails of 1 m height and mid rails.

10. Platform gratings shall be locked in secured manner. Alternatively press locking platform gratings shall be provided.

Ensuring Ladder Safety (GOI, 1996 [43]; AERB, 2011 [4])

11. Every ladder must be well-built, made of sturdy materials, and of sufficient strength.

12. For work places at a height of 4.5 meters or more, prefabricated steel staircase must be used.

13. Step/rung spacing of ladders should be uniform and should not exceed 30 cm.

14. Man-guards must be installed on all vertical ladders over 3 meters in height that are permanently installed.

15. The width between the styles (side bars) on ladders up to 3m in length must not be less than 30 cm. This width must be increased by at least 2 cm for each extra meter of ladder length.

16. Ladders must be fixed to the ground or rigid platforms and top end of the ladder shall be secured to a firm structure.

17. In area where frequent entry is required, permanent ladders shall be provided instead of temporary ladders.

18. Ladders must be kept in a safe position before use. The optimal angle for a ladder with the horizontal is 75 degrees, which means the length of the ladder to the base of the ladder from the wall must be in the ratio of 4:1.

Electrical Safety (GOI, 1996 [43])

19. Exposed power terminals of electrical equipment shall be insulated.

20. Joints in cables shall be avoided. If joints cannot be avoided, cables should be joined using standard electrical connectors.

21. Earth Leakage Circuit Breakers (ELCBs) shall be provided with electrical circuits.

22. Approach to charged electrical equipment shall be restricted by hard barricading with caution signage.

23. Visible double earthing shall be provided on tube light fixtures and electrical equipment.

24. Underground cables shall be provided with visible cable markers at surface level.

25. Barriers on both sides of overhead electrical transmission and distribution lines must be installed on the access path to prevent mobile cranes with extended booms from entering area below the transmission and distribution lines.

26. Cable trays must be constructed with a 40-50 % capacity excess to accommodate additional cables in the case of future field modifications. Cable trays must not be filled more than 40% of the tray's interior area or the maximum weight allowed by the cable tray's specifications. If cables in cable trays are expected to exceed this limit, the cable trays' capacity must be increased through engineering changes or cable rerouting through less loaded cable trays (NFPA 70E, 2021 [83]).

27. Openings in electrical equipment must be sealed to prevent rodent ingress, and cables in electrical circuits must have sheathing that is resistant to rodent attack.

4.5.2 Administrative Controls

System Isolation and Work Permit System

1. Before taking up works, ensure positive isolation of process systems through work permit system. Pressurized systems shall be depressurized and drained.

2. For effective control of floor openings, wall openings, and manholes, a work permit system must be implemented. Removal of grills or covers of these openings up to normalization shall be controlled through work permit system.

3. Compliance to hot work permit requirements shall be ensured during the hot works such as cutting, welding and grinding operations. Arrangement for collection of hot spatters shall be made during the hot works to prevent fire incidents due to fall of hot spatters at locations below the hot works.

Hazard Identification and Control Measures

4. Job Hazard Analysis (JHA) is required for all normal and non-routine jobs in order to identify hazards and risks. Before starting the job, a JHA checklist comprising of hazard control measures shall be developed and incorporated in the work procedure. The job shall be performed by using approved work procedure and JHA checklist. Hazard control measures recommended in JHA shall be implemented while performing the jobs. Engineer in charge responsible for the job shall monitor effective implementation of hazard control measures during the job.

5. To prevent burn injuries to workers who come into touch with or are exposed to high-temperature fluids, insulated protection covers must be provided over the system components.

Preventive Maintenance and Surveillance

6. Periodic inspection, preventative maintenance, and testing of structures, systems, and components for material condition and ageing must be carried out, and deficiencies must be corrected.

7. Periodic illumination surveys of work places must be conducted, and shortcomings must be corrected, in order to ensure adequate illumination at workplaces in accordance with legislative standards.

8. At fire points, the required quantity and type of fire extinguishers must be provided, and the availability of fire extinguishers must be ensured during periodic inspection and maintenance.

9. Periodic preventive maintenance and testing of vehicles shall be carried out and road-worthy vehicles shall only be deployed for use.

Employee Training and Pre-job Briefing

10. Blood pressure, epilepsy, flat feet, frequent headaches or spinning sensations, mental depression, limping stride, and acrophobia must be checked among those who work at a height of 2.5 meters or more. The persons medically fit for working at height shall undergo physical fitness on height work simulator by walking over a beam of 30 cm width at 2.5 m height by wearing safety harness without any ill effect. The persons successfully completing medical and physical test for working at height of 2.5 m and above shall be imparted with training on safety precautions to be taken and use of fall protection measures and personal protective equipment while working at height; and issued with height pass after examination. Validity of height pass shall be 1 year. Persons with valid height pass shall only be deployed for working at height (AERB, 2011 [4]).

11. Employees must be instructed on how to use the appropriate equipment and tools for the job and the work supervisor must ensure that the appropriate equipment and tools are used.

12. During the safety induction training, pre-job briefing, and tool box talks, work supervisors should highlight compliance with safety measures, procedures, work permit system, and job specific hazard controls, and enforce compliance during job execution.

13. Drivers must get defensive driving training on a regular basis, and work supervisors must verify that drivers adhere to set speed restrictions while operating vehicles.

14. Employees with requisite qualifications as per the Central Electricity Authority (CEA) Regulations shall only be designated for working on electrical systems. Employees must receive site-specific training on electrical systems and the measures to be followed while working on electrical systems before being deployed for electrical system work.

15. Employees who install and dismantle scaffolds and platforms must get skill-based scaffolding erection and dismantling training.

16. During Industrial Safety training programs, pre-job briefings, and tool box talks, requirements for compliance with correct use of personal protective equipment such as double lanyard full body harness, helmets, safety goggles, face shields, earmuffs, ear plugs, arc rated suit, acid and alkali resistant suits, and so on, shall be covered.

17. Mobile crane operators shall be given training on safe loading of materials and stability of mobile cranes during material handling.

18. Material handling jobs shall be carried out by trained and authorized crane operators, riggers and signalmen.

Job Supervision

19. Work supervisors must ensure that all jobs are completed under their supervision, in accordance with established procedures and appropriate work permits. They shall ensure that line managers, work supervisors, and employees communicate and coordinate effectively.

20. Work supervisors must insist on the usage of mechanical rather than manual material handling equipment.

21. Work supervisors shall ensure that cylinder valve caps or guards are in place while shifting gas cylinders.

22. While carrying out material handling operations using mobile cranes, work supervisors shall ensure stability of mobile crane by uniform loading of cranes and placing of mobile cranes on out riggers at even surfaces.

23. Employees engaged in jobs at high temperature environment shall be given rest based on Wet Bulb Globe Temperature (WBGT) Index as per the Work-Rest Regimen given in **Table 4.4** below. WBGT values in Degree Celsius are given in the table against workload and work rest regimen. Work and rest based on workload and WBGT shall be selected such that the prescribed limit of WBGT is not exceeded (GOI, 1996 [43]).

Table 4.4
Work-Rest Regimen based on Permissible WBGT Index in Degree Celsius

Work-Rest Regimen in each hour	Light Work Load	Moderate Work Load	Heavy Work Load
Continuous Work	30.0	26.7	25.0
75% Work - 25% Rest	30.6	28.0	25.9
50% Work - 50% Rest	31.4	29.4	27.9
25% Work - 75% Rest	32.2	31.1	30.0

Light Work Load	-	Up to 200 K Cal/hr
Moderate Work Load	-	200 to 350 K Cal/hr
Heavy Work Load	-	350 to 500 K Cal/hr

WBGT for Outdoors with Solar load = 0.7NWBT + 0.2GT + 0.1DBT

WBGT for Indoor or Outdoor without Solar load = 0.7 NWBT + 0.3GT

Where

NWBT	-	Natural Wet Bulb Temperature,
GT	-	Globe Thermometer Temperature
DBT	-	Dry Bulb Temperature

Scaffolding Safety

24. Before use, scaffoldings, platforms, ladders, walkways and access paths shall be inspected, certified and tagged for safe use by the authorized agency with the expiry dates displayed appropriately.

25. Inspection and certification of scaffoldings shall be carried out with approved checklist considering safety requirements, which also should include fixing of working platforms, width of working platforms, adequate ‘earthing’, handrails, mid rails, toe boards, life line for hooking safety harness, safe access path, safety net and provision for lifting and lowering materials etc.

26. Green tags must be placed on scaffoldings that have been certified as safe to use, whereas "Red" tags must be placed on scaffoldings that are being erected or being dismantled or unsafe to use. Supervisors shall ensure that works are performed using scaffoldings with green tags only and shall prohibit workers from using scaffoldings with red tag.

27. Unsafe scaffoldings or scaffoldings with surpassed expiry dates shall be red tagged and shall not be used. Before using scaffolding with expired usage date, it shall be re-inspected and recertified by the authorized agency for safe use.

28. Scaffolding shall be periodically inspected to ensure that no parts are disturbed or damaged. If there is any disturbance or damage to the scaffolding parts, defects must be remedied and scaffolding must be re-inspected and recertified by the authorized agency for continuing use.

29. Scaffolding shall not be dismantled with persons standing on it. Dismantling of scaffolding shall be carried out in sequential manner and load-bearing members shall be removed only after all other members are removed.

Ladder Safety

30. Ladders shall be periodically inspected and certified for safe use. Deficiencies in ladders shall be corrected promptly. If deficiencies cannot be corrected, unsafe ladders shall be segregated and prohibited from use by tagging them. Ladders certified for safe use shall only be deployed for use.

31. Before utilizing a ladder, it must be kept in a secure posture. The optimal angle for a ladder with the horizontal is 75 degrees, which means the length of the ladder to the base of the ladder from the wall must be in the ratio of 4:1.

Electrical Safety

32. Complete isolation from power supply shall be ensured before working on electrical systems and equipment.

33. Before working on electrical systems and equipment, equipment that can possibly start automatically on process parameters shall be blocked and controlled through work permit system. Such blocks shall be normalized after the job.

34. Before execution of jobs on electrical systems, self-checking and peer checking shall be carried out for guaranteed isolation and identification of tagging and labeling of equipment.

35. Before carrying out any excavation works, clearance from all concerned agencies with respect to presence of underground facilities such as electrical cables, communication cables, process piping etc. shall be obtained.

36. Periodic inspection and testing of cables shall be carried out with respect to ageing and damaged cables. Cables that have reached the end of their service life and damaged cables must be replaced. Electrical cables that have been discarded must be de-energized and tagged.

37. Arc Flash Hazard Analysis of the Switchgears shall be performed to determine the arc flash incident energy and arc flash protection boundary for determining the required arc flash protection suit and arc rated PPEs for use while working on electrical switchgears within arc flash protection boundaries. Arc Flash Protection Boundary within which arc resistant cloths should be marked in front of the panel (IEEE 1584, 2022 [59]; NFPA 70E, 2021 [83]).

Chemical Safety

38. Protective covers shall be provided over flanges and valves of systems carrying hazardous chemicals to prevent injury due to splash of chemicals over persons in the vicinity caused by failure of gaskets or piping components.

39. Hazardous and flammable materials shall be labeled during storage with Material Safety Data Sheets (MSDS) displayed at the storage locations. Chemicals with incompatible properties shall be segregated to prevent accidents during storage and handling. Self-checking and peer checking shall be carried out during identification, tagging or labeling of materials.

40. Gas cylinders shall be chained in secured manner with cylinder valve caps or guards in place during transportation and storage.

41. Quantity of flammable and hazardous materials stored shall be limited below the threshold quantities stipulated by the national laws or regulatory authorities.

42. The temporary storage of flammable and hazardous materials at work must be regulated by a permit system. The amount of flammable and hazardous materials stored at workplace must adhere to the established limitations and precautions prescribed in temporary storage permits.

Housekeeping and Workplace Upkeep

43. Work supervisor shall ensure that tools, equipment and other materials at work locations are kept in secured manner and are prevented from falling.

44. Periodic housekeeping of work locations shall be carried out and unwanted materials shall be disposed off safely.

4.5.3 Personal Protective Equipment

Fall Protection

1. While working or moving at height or on fragile surfaces, helmet and double lanyard safety harness shall be used. One of the lanyards shall always be anchored to a life-line or a firm structure. Chinstraps shall be tied while using helmets. While working on fragile roof, roof top ladder shall be used.

Fall of Objects and Striking Hazards

2. While performing jobs at locations with potential for head injury due to fall of objects and/or striking hazards, workers shall wear helmets with chin-straps.

Eye Protection

3. While performing welding, cutting and grinding operations, workers and other supporting persons associated with the job shall wear goggles and face shields.

Ear Protection

4. While performing jobs in high noise area with noise level of 85 dB and above, workers shall use ear-muffs or ear plugs.

5. At the entrance to the high-noise area, a warning notice with instructions for using ear-muffs or ear plugs must be shown.

4.6 CONCLUSION

Our present study on HFLS accidents yields that causes for most of those accidents are repetitive and multi-disciplinary in nature. This could possibly be due to shortfalls in the identification of root causes of accidents and the enforcement of foolproof corrective measures for them. Accident prevention and control is a challenging task, and continuous efforts are required to control or reduce the probability and severity of accidents.

Our research emphasizes the importance of thoroughly investigating all accidents, as this provides insight into the causes of accidents as well as vital information for accident prevention. It is required that accident investigations be unbiased. It is proposed that accident investigation be carried out by a completely different team that is not associated to the site or job where the accident has occurred.

In most cases, accident investigations entail answering five Ws and one H, namely; What happened? When did it happen? Where did it happen? Why did it happen? Who are involved in it? and How did it happen? The 'Why' and 'How' of these are the most important, as these involve determining root causes of the accidents. A root cause of an accident can be identified by various methods. Cause and Effect chart or the ‘Five Why Technique’ can be used for identification of a root cause. In the Cause-Effect chart, causes for the effects are determined by ‘top-to-bottom’ approach being applied in a sequential manner to arrive at the root cause. In the 'Five Why Technique', 'Why' on the scenario of the accident is questioned at least five times to identify the root cause.

HFLS accidents are generally precursors or warning signals to LFHS accidents, and hence, identification of root causes and correction of causes of HFLS accidents should help in prevention of LFHS accidents. Since number of HFLS accidents is normally bigger, as compared to that of the LFHS accidents, HFLS accidents statistically provide more opportunity for correction of causes of accidents, which in turn will prevent or reduce occurrence of LFHS accidents.

In order to decrease the inherent risks to acceptable levels, we propose that accident prevention and control measures be incorporated into the design and subsequent operations. As a result, risk control should require judicial application of 'Safety through Design,' enforcement of 'Administrative Controls,' and usage of 'Personal Protective Equipment,' in that order of effectiveness hierarchy. The effective implementation of these measures will prevent accidents and help the organization to achieve its goal of **Zero Harm**.

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CHAPTER-5

DEVELOPMENT OF ACCIDENT PREDICTION MODELS ON LOW FREQUENCY HIGH SEVERITY (LFHS) ACCIDENTS

5.1 PREAMBLE

Accident prediction models are developed to identify major contributors to accidents and implement appropriate corrective actions. Scenario Analysis, Regression Method, Time-Series Method, Markov Chain Method, Grey Model, Neural Networks, and Bayesian Networks are some of the most commonly used methods for accident prediction. Sometimes, combinations of different methods are also used to generate a realistic prediction model. The multiple linear regression method has been used for accident prediction models in the present research work. Some of the independent variables of the models have exponential relationship with the dependent variable. The exponential terms in a multiple linear regression model turn the model into non-linear. Since independent variables are the exponential terms and not the Beta coefficients; and the individual terms are added together, it still qualifies as a linear model (Kothari, 1990 [69]; Levin and Rubin, 1996 [72]; Mustakim et al., 2008 [78]; Zheng and Liu, 2009 [123]; Rokade et al., 2010 [98]; Uyanik and Guiler, 2013 [117]; Jenan et al., 2015 [63]; Pisharody et al., 2022 [94]).

This thesis chapter deals with the development of accident prediction models in our research work. The accident prediction models were developed by **Multiple Linear Regression Analysis** and **ANOVA** of 113 LFHS accidents, comprising of 95 Reportable Injuries and 18 Fatalities occurred at the 11-twin unit Operating Stations and 3 twin unit Construction Project sites of the Public Sector Power Company under study, during the period of 10 years from 2006 to 2015. The significant contributors derived from the accident prediction models were analyzed to identify causes of LFHS accidents in the company (Pisharody et al., 2022 [94]).

The analysis and the development of models have been carried out by considering the principal factors of ‘Agencies’, ‘Types of Accidents’ and ‘Locations of Injuries’, in reference to Indian Standard IS-3786-2022 ‘Method for the Computation of Frequency and Severity Rates for Industrial Injuries and Classification of Industrial Accidents’ to identify significant contributors of accidents (IS-3786, 2022 [13]).

Goodness of Fit of Models

Goodness of fit of multiple linear regression models is determined from the coefficients of multiple determination; R Square and Adjusted R Square values. R Square is a goodness-of-fit measure for linear regression models. It measures how well the regression models fit. On a scale of 0-100 %, R Square indicates how strong the association between independent variables and dependent variable is. The higher R Square indicates the better fit for the model. The Adjusted R Square is a modified version of R Square that has been adjusted for the number of independent variables in the model. Adding more number of independent variables to a regression model, irrespective of the fact that additional variables make any sense, increase the R Square value. It may tempt the developers of the model to add even more variables. R Square is adjusted for the number of variables in the model using Adjusted R Square. Adjusted R Square increases only when the additional variable really improves goodness of fit of the model more than the predicted, and decreases when the additional variables reduce goodness of fit of the model less than the expected (Kothari, 1990 [69]; Levin and Rubin, 1996 [72]; Mustakim et al., 2008 [78]; Zheng and Liu, 2009 [123]; Rokade et al., 2010 [98]; Uyanik and Guiler, 2013 [117]; Jenan et al., 2015 [63]; Pisharody et al., 2022 [94]).

Statistical Significance

Statistical significance of the model is assessed with reference to F-Test, T-Test, p-values and α-Value.

F-Test:

F-Test is a statistical test which demonstrates that at least one independent variable will give significant information for the prediction of dependent variable. F-Test is conducted by comparing values of F-Stat with F-Critical. F-Stat is the ratio of the mean regression sum of squares to the mean error sum of squares. It will have a value ranging from zero to an arbitrary large number. F-Critical is a specific value to compare with F-Stat. Value of F-Stat is obtained from the ANOVA table. In order to determine that the results of F-test are statistically significant, F-Stat is compared to F-Critical. If F-Stat is greater than F-Critical, results of the test are statistically significant (Kothari, 1990 [69]; Levin and Rubin, 1996 [72]; Mustakim et al., 2008 [78]; Zheng and Liu, 2009 [123]; Rokade et al., 2010 [98]; Uyanik and Guiler, 2013 [117]; Jenan et al., 2015 [63]; Pisharody et al., 2022 [94]).

p-Value and α-Value

p-Value is a measure of the probability of an observation. P-Value is also known as significance F. The statistical significance of the observed value increases as the p-value decreases. α-Value, which is also known as significance, is a threshold value used to judge whether a test statistic is statistically significant. The result is statistically significant if the p-value is less than α-Value and it also indicates that at least one of the regression coefficients is not zero (Kothari, 1990 [69]; Levin and Rubin, 1996 [72]; Mustakim et al., 2008 [78]; Zheng and Liu, 2009 [123]; Rokade et al., 2010 [98]; Uyanik and Guiler, 2013 [117]; Jenan et al., 2015 [63]; Pisharody et al., 2022 [94]).

T-Test:

T-Test is a statistical test which demonstrates whether independent variables are significantly related to the dependent variable. T-Test is conducted by comparing values of T-Stat with T-Critical. At a specific α-Value, if T-Stat of an independent variable is more than T-Critical, then that independent variable is related to the dependent variable in a significant manner (Kothari, 1990 [69]; Levin and Rubin, 1996 [72]; Mustakim et al., 2008 [78]; Zheng and Liu, 2009 [123]; Rokade et al., 2010 [98]; Uyanik and Guiler, 2013 [117]; Jenan et al., 2015 [63]; Pisharody et al., 2022 [94]).

5.2 DEVELOPMENT OF ACCIDENT PREDICTION MODEL BASED ON 'AGENCIES' CAUSED LFHS ACCIDENTS

Agency is the object or substance, which is most closely associated with an accident causing injury and with respect to which adoption of a safety measure could have prevented the accident. Some typical examples are machines, means of transportation, flying objects, scaffoldings, ladders, lifting machines, electrical conductors, electric hand tools, chemicals, gases, working environment, live animals etc. (IS-3786, 2022 [13]).

An accident prediction model was developed using **Multiple Linear Regression Analysis and ANOVA** of data on 113 LFHS accidents based on 'Agencies' as per the Indian Standard IS-3786-2022 (Pisharody et al., 2022 [94]). Microsoft Excel was used for carrying out the regression analysis. The number of LFHS accidents caused due to various 'Agencies', were considered as the independent variables, while the man days lost on account of the LFHS accidents was the dependent variable in the model. Thus, the Independent and Dependent Variables of the model were:

<u>Independent Variables</u>

Number of LFHS accidents attributed to various Agencies given below:

$X11_L$ - Scaffolding

$X12_L$ - Others

$X13_L$ - Lifting Machines and Applications and Pressure Vessels

$X14_L$ - Electrical Installations

$X15_L$ - Work Environment

(**Table 3.2** gives details on the above classification of 'Agencies' of Accidents as per Indian Standard IS-3786-2022.)

Dependent Variable

$YB1MDLE_L$ - Estimated man days loss on account of LFHS accidents

Table 5.1 gives number of LFHS accidents during the period from 2006 to 2015 based on Agency, observed man days loss and estimated man days loss derived from the model. **Table 5.2** gives details of Regression Analysis and Analysis of Variance (ANOVA) of LFHS accidents based on Agencies. The results of **Table-5.2** are derived from 'Data Analysis' package of Microsoft Excel by running 'Regression' module. The results are generated automatically by the software by feeding relevant data given in **Table 5.1**.

Table 5.1

Number of LFHS Accidents during the Period from 2006 to 2015 based on Agencies (B1) as per IS-3786, Observed Man days Loss and Estimated Man days Loss derived from the Model

Year	Scaffolding	Others	Lifting Machines and Applications and Pressure Vessels	Electrical Installations	Work Environment	Total Number of LFHS Accidents	Observed Man Days Loss on LFHS Accidents	Estimated Man Days Loss on LFHS Accidents
	$X11_L$	$X12_L$	$X13_L$	$X14_L$	$X15_L$	$YB1N_L$	$YB1MDL_L$	$YB1MDLE_L$
2006	2	3	0	1	4	10	18830	14550
2007	2	8	1	1	9	21	18357	18497
2008	1	3	1	3	5	13	6312	5649
2009	0	2	3	2	4	11	7135	7856
2010	3	3	0	1	6	13	12355	14306
2011	0	2	0	1	4	7	6109	5834
2012	1	8	0	2	4	15	8620	8598
2013	1	4	1	1	4	11	18450	18910
2014	0	0	3	1	2	6	18991	18307
2015	1	2	0	1	2	6	10724	13377
Total	**11**	**35**	**9**	**14**	**44**	**113**	**125883**	**125884**

$X11_L$ to $X15_L$ of Tables 5.1 and 5.2 denote number of LFHS accidents based on B1 classification of IS-3786-2022.

$YB1N_L$ of Tables 5.1 and 5.2 denotes total number of $X11_L$ to $X15_L$ LFHS accidents based on B1 classification of IS-3786-2022.

$YB1MDL_L$ of Tables 5.1and 5.2 denotes Observed Man-days lost on LFHS accidents under B1 classification of IS-3786-2022

$YB1MDLE_L$ of Table 5.1and 5.2 denotes Estimated Man-days lost on LFHS accidents under B1 classification of IS-3786-2022

Table-5.2

Output of Regression Analysis of LFHS Accidents during the period from 2006 to 2015 based Agencies as per IS-3786

SUMMARY OUTPUT

Regression Statistics

Multiple R	0.9428
R Squared	0.8889
Adjusted R Squared	0.7499
Standard Error	2779.0744
Observations	10

ANOVA

	Df	**SS**	**MS**	**F Stat**	**Significance F**	
Regression	5	247086994.17	49417398.83	6.40	0.048	
Residual	4	30893017.93	7723254.48			
Total	9	277980012.10				
	Coefficients	**Standard Error**	**t Stat**	**P-value**	**Lower 95%**	**Upper 95%**
Intercept	765.74	3029.43	0.25	0.81	-7645.30	9176.79
$X11_L$	3649.11	1480.82	2.46	0.07	-462.30	7760.52
$X12_L$	1417.96	556.43	2.55	0.06	-126.94	2962.86
$(X13_L)^{0.5}$	**6590.49**	**1719.12**	**3.83**	**0.02**	**1817.44**	**11363.55**
$(X14_L)^{-4.0}$	**10019.63**	**2333.48**	**4.29**	**0.01**	**3540.86**	**16498.40**
$X15_L$	-1946.78	815.45	-2.39	0.08	-4210.83	317.27

The Accident Prediction model developed by the above-mentioned analysis gave the following numeric expression:

$$\mathbf{YB1MDLE_L = 765.74 + 3649.11\,(X11_L) + 1417.96\,(X12_L) + 6590.49\,(X13_L)^{0.5} + 10019.63\,(X14_L)^{-4.0} - 1946.78\,(X15_L)} \text{ - } \textbf{Equation (1)}$$

Some of the independent variables of the models have exponential relationship with the dependent variable. The exponential terms in a multiple linear regression model turn the model into non-linear. Since independent variables are the exponential terms and not the Beta coefficient; and the individual terms are added together, it still qualifies as a linear model.

Goodness of Fit and Statistical Significance of Accident Prediction Model

Goodness of Fit

R Square and Adjusted R Square values of the model were found to be 0.8889 and 0.7499 respectively. R Square indicates that 88.89% of the total variation in the Dependent Variable is explainable in terms of the variations in the Independent Variables. Adjusted R Square indicates that 74.99% of the total variation in the Dependent Variable is explainable by the variation in Independent Variables. The values of R Square and Adjusted R Square indicate that goodness of fit of the model is satisfactory and at least one Independent Variable will contribute to the information for the prediction of Dependent Variable.

Statistical Significance

Statistical significance of the model is assessed with reference to F-Test, T- Test and p-values.

F-Test:

F-Stat is 6.40 and F-Critical for the model is 6.26. Since F-Stat of the model is more than the F-Critical, the model is statistically significant and at least one independent variable will give significant information for the prediction of dependent variable.

p-Values and α-Value:

Overall p-value (Significance - F) of the model is 0.048 and it is less than the α-value of 0.05. This implies that the model is statistically significant at an α-value of 0.05 and at least one of the regression coefficients is not zero.

The p-values for the estimated coefficients of $X13_L$ and $X14_L$ are 0.02 and 0.01 respectively. These values are less than the α-value of 0.05, which indicates that $X13_L$ and $X14_L$ are significantly related to $YB1MDLE_L$ at the α-value of 0.05.

The p-values for $X11_L$, $X12_L$ and $X15_L$ are 0.07, 0.06 and 0.08 respectively. These values are more than the α-value of 0.05. This indicates that $X11_L$, $X12_L$ and $X15_L$ are not significantly related to $YB1MDLE_L$ at the α-value of 0.05.

T-Test:

Absolute T-Stat values for the estimated coefficients of $X11_L$, $X12_L$, $X13_L$, $X14_L$ and $X15_L$ are 2.46, 2.55, 3.83, 4.29 and 2.39 respectively. T-Critical value for model at the α-value of 0.05 is 2.78.

T-Stat values of $X13_L$ and $X14_L$ are more than T-Critical. This indicates that $X13_L$ and $X14_L$ are significantly related to $YB1MDLE_L$ at the α-value of 0.05.

The T-Stat values for $X11_L$, $X12_L$ and $X15_L$ are less than T-Critical value. This indicates that $X11_L$, $X12_L$ and $X15_L$ are not significantly related to $YB1MDLE_L$ at the α-value of 0.05.

<u>Significant Agencies Caused LFHS Accidents</u>

The model developed in the present study identified '**Lifting Machines and Applications and Pressure Vessels' ($X13_L$); and** '**Electrical Installations' ($X14_L$)** as the significant 'Agencies' that caused the LFHS accidents.

Validation of Accident Prediction Model

The model thus developed was validated using an independent data. While, the model was developed on the data available for the period of 2006 – 2015, it was validated with independent data on LFHS accidents for the year 2018. Values of Independent Variables and Dependent Variable (man-days lost on account of LFHS accidents) for the year 2018 are given below:

<u>Independent Variables:</u>

$X11_L = 1$, $X12_L = 1$, $X13_L = 0$, $X14_L = 1$, $X15_L = 5$

<u>Dependent Variable:</u>

$YB1MDL_L = 18764$

<u>Estimated value of Dependent Variable:</u>

$YB1MDLE_L = 6119$

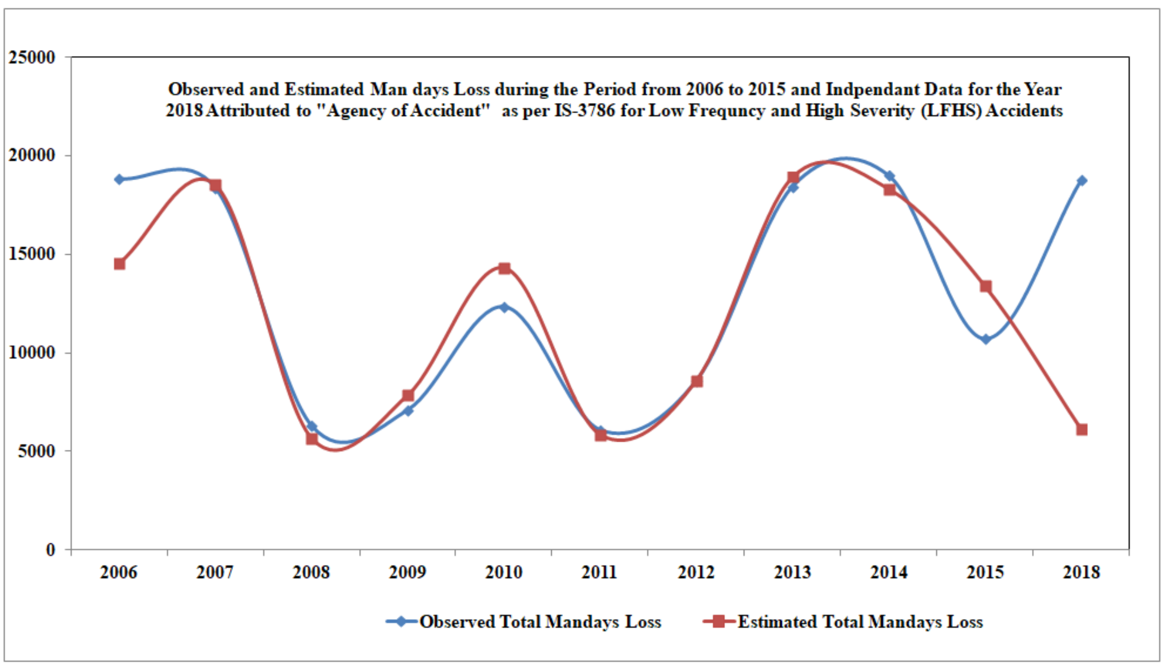

Figure-5.1: Observed and Estimated Man-days Loss on Account of LFHS Accidents as per Agencies of Accidents

Figure-5.1 shows comparison of observed and estimated man-days lost on account of LFHS accidents during the period from the year 2006 to 2015 and for the year 2018. The figure indicates that estimated man-days lost during the period from 2006 to 2015 are in agreement with the observed man-days loss.

The estimated 'man-days loss' using independent data (for the year 2018) is within 67% of the actual observed 'man-days loss'. The prediction capability of the model thus comes to about 33%. The probable reason for less value of prediction capability could be multicollinearity between one or more independent variables. However, Kraha et al. (2012 [70]) opines that multicollinearity will not cause unwarranted problems in accident prediction and identification of significant contributors. Levin and Rubin (1996 [72]) also argues that regression models with multicollinearity can very well be used to predict dependent variable. Thus, the model is helpful in identifying 'significant agencies' which contribute to the occurrence of LFHS accidents. The significant 'Agencies', as determined from our model, which caused LFHS accidents are:

1. Lifting Machines and Applications
2. Pressure Vessels
3. Electrical Installations

5.3 DEVELOPMENT OF ACCIDENT PREDICTION MODEL BASED ON 'TYPES' OF LFHS ACCIDENTS

Just like for the case of **'Agencies'** described above, analysis and development of accident prediction model was also done for the factor of **'Types of Accident'**. The 'Types of Accident' is classified by the manner in which the object or substance causing the injury comes into contact with the person, or by the movement of the injured person which resulted in the injury. Some of the examples for this class are; fall of objects, fall of person, stepping or striking against or struck by object, caught or in between the objects, over exertion or wrong movements, exposure or contact with extreme temperature or electric current or harmful substances, explosions etc. (IS-3786, 2022 [13]).

Accident prediction model for the class of 'Types of Accidents' was also developed using **Multiple Linear Regression Analysis and ANOVA** of 113 LFHS accidents considered, as per Indian Standard IS-3786-2022 (Pisharody et al., 2022 [94]). Microsoft Excel was used for carrying out the regression analysis. The Independent Variables considered in the model were the number of LFHS accidents based on 'Types of Accidents' and the Dependent Variable was again the 'mandays loss' on account of LFHS accidents. Thus, the Independent and Dependent Variables of the model were:

Independent Variables

$X51_L$ - Fall of objects

$X52_L$ - Exposure to or contact with electric current

$X53_L$ - Others (Over exertions or wrong movements, exposure to or contact with harmful substances or exposure to or contact with extreme temperature, explosions and others)

$X54_L$ - Fall of persons from height

$X55_L$ - Fall of persons on the same level

$X56_L$ - Stepping on striking against or struck by object

$X57_L$ - Caught in or between objects

(Table 3.5 gives details on above classification of 'Types of Accidents' as per Indian Standard IS-3786-2022.)

Dependent Variable

$YB5MDLE_L$ - Estimated man days loss on account of LFHS accidents

The **Table 5.3** gives the number of LFHS accidents that occurred during the period from 2006 to 2015, based on 'Type of Accidents', observed 'man days loss' and the estimated 'man-days loss' as determined from our model. While, the **Table-5.4** gives details of Regression Analysis and Analysis of Variance (ANOVA) of LFHS accidents based on Type of Accidents.

Table-5.3

Number of LFHS Accidents during the Period from 2006 to 2015 based on Type of Accidents (B5) as per IS-3786, Observed Man days Loss and Estimated Man days Loss Derived the from the Model

Year	Fall of Objects	Exposure to or Contact with Electric Current	Over Exertions or Wrong Movements, Exposure to or Contact with Harmful Substances, Extreme Temperature, Explosions and Others	Fall of Persons from Height	Fall of Persons on the Same Level	Stepping on, Striking Against or Struck by Object	Caught in or Between Objects	Observed Number of LFHS Accidents	Observed Man Days Loss on LFHS Accidents	Estimated Man Days Loss on LFHS Accidents
	$X51_L$	**$X52_L$**	**$X53_L$**	**$X54_L$**	**$X55_L$**	**$X56_L$**	**$X57_L$**	**$YB5N_L$**	**$YB5MD_L$**	**$YB5MDLE_L$**
2006	2	0	0	4	0	2	2	10	18830	18981
2007	4	1	0	9	0	4	3	21	18357	17886
2008	0	2	0	8	0	3	0	13	6312	6045
2009	1	2	0	4	0	1	3	11	7135	7553
2010	0	1	0	7	1	3	1	13	12355	13560
2011	3	1	0	1	1	1	0	7	6109	6441
2012	0	1	0	7	1	4	2	15	8620	8303
2013	1	1	2	3	0	1	3	11	18450	18619
2014	0	1	1	2	1	0	1	6	18991	18654
2015	0	1	0	2	1	1	1	6	10724	9841
Total	**11**	**11**	**3**	**47**	**5**	**20**	**16**	**113**	**125883**	**125883**

$X51_L$ to $X57_L$ of Tables 5.3 and 5.4 denote number of LFHS accidents based on B5 classification of IS-3786-2022.

$YB5N_L$ of Tables 5.3 and 5.4 denotes total number of $X51_L$ to $X57_L$ LFHS accidents based on B5 classification of IS-3786-2022.

$YB5MDL_L$ of Tables 5.3 and 5.4 denotes Observed Man-days lost on LFHS accidents under B5 classification of IS-3786-2022

$YB5MDLE_L$ of Tables 5.3 and 5.4 denotes Estimated Man-days lost on LFHS accidents under B5 classification of IS-3786-2022

Table-5.4

Output of Regression Analysis of LFHS Accidents during from 2006 to 2015 based on Type of Accidents as per IS-3786

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.9945
R Square	0.9889
Adjusted R Square	0.9502
Standard Error	1240.2657
Observations	10

ANOVA

	Df	**SS**	**MS**	**F-Stat**	**Significance F**	
Regression	7	274903493.98	39271927.71	25.53	0.038	
Residual	2	3076518.12	1538259.06			
Total	9	277980012.10				
	Coefficients	**Standard Error**	**t Stat**	**P-value**	**Lower 95%**	**Upper 95%**
Intercept	20886.47	2063.56	10.12	0.010	12007.70	29765.25
$X51_L$	-19.41	349.59	-0.06	0.961	-1523.60	1484.78
$X52_L$	**-9718.00**	**995.85**	**-9.76**	**0.010**	**-14002.79**	**-5433.21**
$X53_L$	2189.44	822.53	2.66	0.117	-1349.64	5728.51
$X54_L$ ^1.5	**1081.17**	**158.69**	**6.81**	**0.021**	**398.39**	**1763.96**
$X55_L$	872.58	1139.09	0.77	0.524	-4028.52	5773.69
$X56_L$	**-6623.14**	**1052.24**	**-6.29**	**0.024**	**-11150.55**	**-2095.74**
$X57_L$	1365.29	466.62	2.93	0.100	-642.40	3372.98

The numeric expression generated from the Accident Prediction model developed by the analysis is as given below:

$$\mathbf{YB5MDLE_L = 20886.47 - 19.41\,(X51_L) - 9718.00\,(X52_L) + 2189.44\,(X53_L) + 1081.17\,(X54_L)^{1.5} + 872.58\,(X55_L) - 6623.14\,(X56_L) + 1365.29\,(X5\,7_L)}$$ **– Equation (2)**

Some of the independent variables of the models have exponential relationship with the dependent variable. The exponential terms in a multiple linear regression model turn the model into non-linear. Since independent variables are the exponential terms and not the Beta coefficient; and the individual terms are added together, it still qualifies as a linear model.

Goodness of Fit and Statistical Significance of Accident Prediction Model

Goodness of Fit

The goodness of the model can be estimated from the ‘Goodness’ of the fit of multiple regression model, which in turn is determined from the coefficients of multiple determination; R Square and Adjusted R Square. The R Square and Adjusted R Square values as obtained from the model are 0.9889 and 0.9502 respectively. R Square indicates that 98.89% of the total variation of the Dependent Variable is explainable by the variation of Independent Variables. Adjusted R Square indicates that 95.02% of the total variation of Dependent Variable can be explained from the variation in Independent Variables. The values of R Square and Adjusted R Square indicate that goodness of fit of the model is satisfactory and at least one Independent Variable will contribute to the information for the prediction of Dependent Variable.

Statistical Significance

Statistical significance of the model is assessed with reference to F-Test, T- Test and p-values.

F-Test:

F-Stat value was determined to be 25.53 and the F-Critical value for the model was found to be 19.35. Since F-Stat value of the model is more than the F-Critical value, the model is statistically significant and at least one Independent Variable will give significant information for the prediction of Dependent Variable.

p-Values and α-Value:

Overall p-value (Significance - F) of the model was found to be 0.038 and it is less than the α-value of 0.05. This implies that the model is significant at an α-value of 0.05 and at least one of the regression coefficients is not zero.

The p-values for the estimated coefficients of $X52_L$, $X54_L$ and $X56_L$ were found to be 0.010, 0.021 and 0.024 respectively. These values are less than the α-value of 0.05, which indicates that these variables are significantly related to $YB5MDLE_L$ at the α-value of 0.05.

The p-values for $X51_L$, $X53_L$, $X55_L$ and $X57_L$ were obtained as 0.961, 0.117, 0.524 and 0.100 respectively. These values are more than the α-value of 0.05. This indicates that these variables are not significantly related to $YB5MDLE_L$ at the α-value of 0.05.

T-Test:

Absolute T-Stat values for the estimated coefficients of $X51_L$, $X52_L$, $X53_L$, $X54_L$, $X55_L$, $X56_L$ and $X57_L$ were determined to be 0.06, 9.76, 2.66, 6.81, 0.77, 6.29 and 2.93 respectively. T-Critical value for model at the α-value of 0.05 was found to be 4.30.

T-Stat values of $X52_L$, $X54_L$ and $X56_L$ are more than that of T-Critical. This indicates that these variables are significantly related to $YB5MDLE_L$ at the α-value of 0.05.

The T-Stat values for $X51_L$, $X53_L$, $X55_L$ and $X57_L$ were found to be less than T-Critical value. This indicates that these variables are not significantly related to $YB5MDLE_L$ at the α-value of 0.05.

Validation of Accident Prediction Model

Validation of this model also was carried out with the independent data for the year 2018. The values of Independent Variables according to the 'Type of Accidents' and the Dependent Variable (man-days loss) on account of LFHS accidents for the year 2018 are as given below:

Independent Variables:

$X51_L = 0$, $X52_L = 1$, $X53_L = 0$, $X54_L = 4$, $X55_L = 1$, $X56_L = 0$, $X57_L = 2$

Dependent Variable:

$YB5MDL_L = 18764$

Estimated value of Dependent Variable:

$YB5MDLE_L = 23421$

Figure 5.2 shows the comparison of the observed and estimated 'man-days loss' on account of LFHS accidents during the period from the year 2006 to 2015, and for the year 2018. It is clear from the figure that the 'man-days loss' estimated by our model for the period from 2006 to 2015 is in agreement with the observed 'man-days loss'.

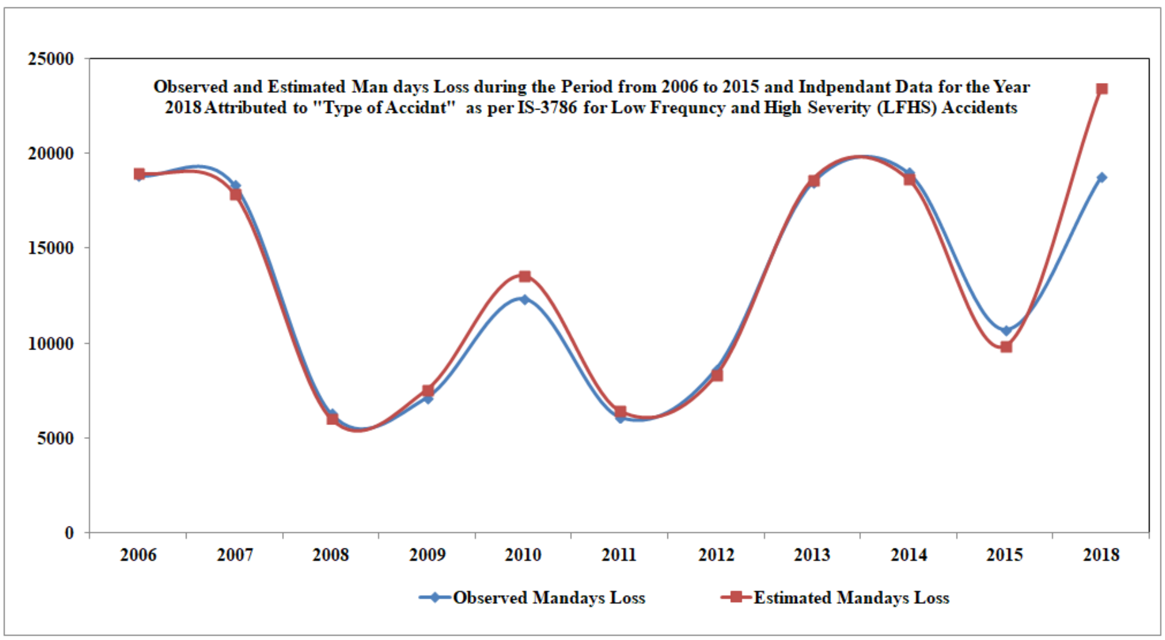

Figure-5.2: Observed and Estimated Man-days Loss on Account of LFHS Accidents as per Types of Accidents

The ‘man-days loss’ estimated by our model for the independent data, for the year 2018, was found to be within 25% of the actual observed ‘man-days loss’. Thus, the prediction capability of the model was about 75%. This is a fairly good result. The significant ‘Types’ of LFHS accidents, as put out by our model, were as follows:

1. Exposure to or Contact with Electric Current
2. Fall of Persons from Height
3. Stepping on Striking against or Struck by Object.

5.4 DEVELOPMENT OF ACCIDENT PREDICTION MODEL BASED ON ‘LOCATIONS OF INJURIES’ DUE TO LFHS ACCIDENTS

Similar to the two above-mentioned cases, analysis and development of accident prediction model was also done for the factor of ‘Location of Injury’. ‘**Location of Injury’** is the part of the injured person’s body directly affected by the injury. The examples of this are head, trunk, upper limb; lower limb etc. (IS-3786, 2022).

In this case too, the accident prediction model was developed by **Multiple Linear Regression Analysis and ANOVA** of the considered 113 LFHS accidents based on the class of ‘Location of Injury’, due to accidents as per the Indian Standard IS-3786-2022 (Pisharody et al., 2022 [94]). Microsoft Excel was used for carrying out the regression analysis. The Independent Variables considered in the model were the number of LFHS accidents that were considered according to the ‘Location of Injuries’ and the Dependent Variable was, in this case too, the ‘mandays loss’ on account of the LFHS accidents. Thus, the Dependent and Independent Variables of the model were:

Independent Variables

$X71_L$ - Head

$X72_L$ - Trunk

$X73_L$ - Upper Limb

$X74_L$ - Lower Limb

$X75_L$ - Multiple Locations

$X76_L$ - General Injuries and Unspecified Location of Injuries

(Table 3.8 gives details on above classification of 'Location of Injuries' due to accidents as per Indian Standard IS-3786.)

<u>Dependent Variable</u>

$YB7MDLE_L$ - Estimated man days loss on account of LFHS accidents

Table 5.5 gives number of LFHS accidents that occurred in the class of 'Locations of Injuries' during the period from 2006 to 2015, the observed 'man days loss' and the estimated 'man-days loss' derived from our model. **Table-5.6** gives the details of the Regression Analysis and Analysis of Variance (ANOVA).

Table-5.5

Number of LFHS Accidents during the Period from 2006 to 2015 based on Locations of Injuries (B7) as per IS-3786, Observed Man days Loss and Estimated Man days Loss Derived from the Model

Year	Head	Trunk	Upper Limb	Lower Limb	Multiple Locations	General Injuries and Unspecified Location of Injuries	Observed Number of LFHS Accidents	Observed Number of LFHS Accidents	Estimated Man Days Loss on LFHS Accidents
	$X71_L$	$X72_L$	$X73_L$	$X74_L$	$X75_L$	$X76_L$	$YB7N_L$	$YB7MDL_L$	$YB7MDLE_L$
2006	3	3	2	2	0	0	10	18830	18469
2007	6	4	7	2	2	0	21	18357	18787
2008	1	1	3	6	2	0	13	6312	5427
2009	0	0	5	3	1	2	11	7135	5300
2010	5	0	1	3	3	1	13	12355	13754
2011	0	1	3	2	0	1	7	6109	8308
2012	3	0	7	3	1	1	15	8620	9208
2013	5	1	3	1	0	1	11	18450	17935
2014	2	1	1	0	2	0	6	18991	17555
2015	1	0	1	2	2	0	6	10724	11140
Total	**26**	**11**	**33**	**24**	**13**	**6**	**113**	**125883**	**125883**

$X71_L$ to $X76_L$ of Tables 5.5 and 5.6 denote number of LFHS accidents based on B7 classification of IS-3786-2022.$YB7N_L$ of Tables 5.5 and 5.6 denotes total number of $X71_L$ to $X76_L$ LFHS accidents based on B7 classification of IS-3786-2022.

$YB7MDL_L$ of Tables 5.5 and 5.6 denotes Observed Man-days lost on LFHS accidents under B7 classification of IS-3786-2022

$YB7MDLE_L$ of Tables 5.5 and 5.6 denotes Estimated Man-days lost on LFHS accidents under B7 classification of IS-3786-2022

Table-5.6

Output of Regression Analysis of LFHS Accidents during from 2006 to 2015 based on Locations of Injuries as per IS-3786

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.9743
R Square	0.9493
Adjusted R Square	0.8478
Standard Error	2168.22
Observations	10

ANOVA

	df	**SS**	**MS**	**F-Stat**	**Significance F**	
Regression	6	263876530.18	43979421.70	9.36	0.047	
Residual	3	14103481.92	4701160.64			
Total	9	277980012.10				
	Coefficients	**Standard Error**	**t Stat**	**P-value**	**Lower 95%**	**Upper 95%**
Intercept	9235.40	2977.11	3.10	0.053	-239.10	18709.90
(X71)^0.2	**5764.42**	**1745.86**	**3.30**	**0.046**	**208.33**	**11320.52**
X72	2208.70	820.51	2.69	0.074	-402.52	4819.92
X73	-612.14	415.46	-1.47	0.237	-1934.30	710.03
X74	**-1674.33**	**521.33**	**-3.21**	**0.049**	**-3333.44**	**-15.23**
X75	50.65	836.06	0.06	0.956	-2610.07	2711.36
X76	2048.62	1752.43	1.17	0.327	-3528.38	7625.63

The numeric expression for the Accident Prediction model developed by the analysis is as given below:

$$\mathbf{YB7MDLE_L = 9235.40 + 5764.42\,(X71_L)^{0.2} + 2208.70\,(X72_L) - 612.14\,(X73_L) - 1674.33\,(X74_L) + 50.65\,(X75_L) + 2048.62\,(X76_L)}$$ **– Equation (3).**

Some of the independent variables of the models have exponential relationship with the dependent variable. The exponential terms in a multiple linear regression model turn the model into non-linear. Since independent variables are the exponential terms and not the Beta coefficient; and the individual terms are added together, it still qualifies as a linear model.

Goodness of Fit and Statistical Significance of Accident Prediction Model

Goodness of Fit

The Goodness of fit of our model is determined from the coefficients of multiple determination; R Square and Adjusted R Square. R Square and Adjusted R Square values of the model were obtained as 0.9493 and 0.8478 respectively. R Square indicates that 94.93% of the total variation of Dependent Variable is explained by the Independent Variables. Adjusted R Square indicates that 84.78% of the total variation of Dependent Variable is explained by the Independent Variables. Values of R Square and Adjusted R Square indicate goodness of fit of the model is satisfactory and at least one Independent Variable will contribute to the information for the prediction of Dependent Variable.

Statistical Significance

The statistical significance of the model is normally assessed with reference to the F-Test, T- Test and p-values.

F-Test:

The F-Stat value and the F-Critical value obtained for our model is 9.36 and 8.94, respectively. Since F-Stat value of the model is more than the F-Critical value, the model is statistically significant, and hence, at least one independent variable will give significant information for the prediction of dependent variable.

p-Values and α-Value:

The overall p-value (Significance - F) of the model was obtained as 0.047, and it is less than the α-value of 0.05. This implies that the model is significant at the α-value of 0.05 and at least one of the regression coefficients is not zero.

The p-values obtained for the estimated coefficients of $X71_L$ and $X74_L$ are 0.046 and 0.049 respectively. These values are less than the α-value of 0.05, which indicates that these variables are significantly related to $YB7MDLE_L$ at the α-value of 0.05.

The p-values for $X72_L$, $X73_L$, $X75_L$ and $X76_L$ were obtained as 0.074, 0.237, 0.956 and 0.327 respectively. These values are more than the α-value of 0.05. This indicates that these variables are not significantly related to $YB7MDLE_L$ at the α-value of 0.05.

T-Test:

The Absolute T-Stat values for the estimated coefficients of $X71_L$, $X72_L$, $X73_L$, $X74_L$, $X75_L$ and $X76_L$ were obtained as 3.30, 2.69, 1.47, 3.21, 0.06 and 1.17 respectively. The T-Critical value for model at the α-value of 0.05 was 3.18.

T-Stat values of $X71_L$ and $X74_L$ are more than the T-Critical value. This indicates that these variables are significantly related to $YB7MDLE_L$ at the α-value of 0.05.

The T-Stat values for $X72_L$, $X73_L$, $X75_L$ and $X76_L$ were obtained to be less than the T-Critical value. This indicates that these variables are not significantly related to $YB5MDLE_L$ at the α-value of 0.05.

Validation of Accident Prediction Model

Validation of our model was performed with the independent data for the year 2018. The values of Independent variables and the dependent variable (man-days loss on account of LFHS accidents for the year 2018) were obtained as given below:

Independent Variables:

$X71_L = 1$, $X72_L = 0$, $X73_L = 2$, $X74_L = 1$, $X75_L = 4$, $X76_L = 0$

Dependent Variable:

YB7MDL= 18764

Estimated value of Dependent Variable:

$YB7MDLE_L = 12304$

Figure 5.3 shows comparison between the observed and the estimated, from our model, 'man-days loss' on account of LFHS accidents during the period of 2006 to 2015, and for the year 2018. The figure shows clearly that the 'man-days loss' estimated by our model for the period of 2006 to 2015 is in agreement with the observed man-days loss.

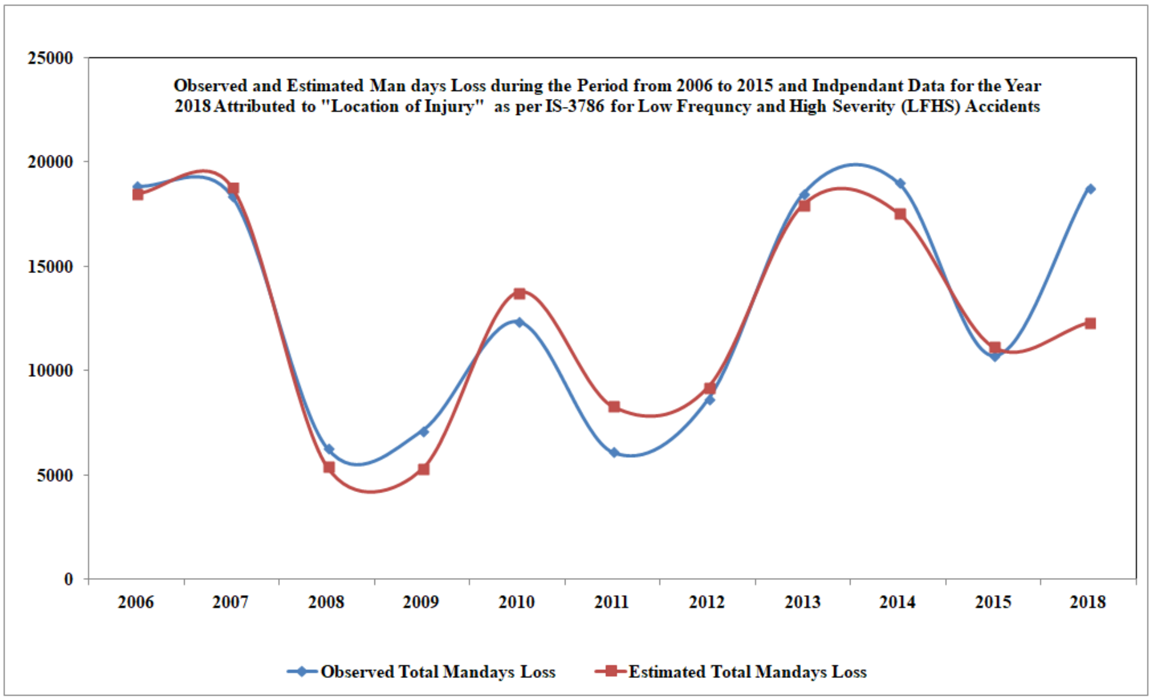

Figure-5.3: Observed and Estimated Man-days Loss on Account of LFHS Accidents as per Locations of Injuries

The 'man-days loss' in the independent data (for the year 2018), estimated by our model is within 34% of the actual observed 'man-days loss'. This is a good result. Thus, the Prediction capability of the model comes to about 66%. The probable reason for minor deviation of prediction capability could be multicollinearity between one or more independent variables. However, Kraha et al. (2012 [70]) opines that multicollinearity will not cause unwarranted problems in accident prediction and identification of significant contributors. Levin and Rubin, 1996 [72] also argues that regression models with multicollinearity can very well use to predict dependent variable. Thus, the model is helpful in identifying 'significant agencies' which contribute to the occurrence of LFHS accidents. The significant 'Locations of Injury' for the LFHS accidents, according to our model are:

1. Head

2. Lower Limb

5.5 DISCUSSION AND RECOMMENDATIONS

5.5.1 ANALYSIS OF LFHS ACCIDENTS BASED ON ACCIDENT PREDICTION MODELS

Accident Prediction models of LFHS accidents have been developed by us using the multiple linear regression analysis and ANOVA on 113 LFHS accidents, comprising of 95 reportable injuries and 18 fatalities that occurred as mentioned earlier, in the Public Sector Power Company under study, during the period of 2006 to 2015. The accident prediction models have been developed for the 'Agencies' of LFHS accidents, 'Types' of LFHS accidents, and 'Locations of Injuries', in accordance with the Indian Standard IS-3786-2022. **Table 5.7** shows the significant contributors for each of the three principal factors of LFHS accidents, as derived from the accident prediction models.

Table 5.7

Principal Factors and Significant Contributors of LFHS Accidents

Principal Factors as per IS 3786	Significant Contributors
Agency	1. Lifting Machines and Applications 2. Pressure Vessels 3. Electrical Installations
Type of Accidents	1. Exposure to or Contact with Electric Current 2. Fall of Persons from Height 3. Stepping on Striking against or Struck by Object
Location of Injury	1. Head 2. Lower Limb

Our analysis of 113 LFHS accidents of the three principal factors, and the eight significant contributors for them, given in **Table 5.7,** show that 99 out of 113 LFHS accidents are responsible for significant injuries and also the consequent 'man-days loss'. The detailed analysis is provided below.

5.5.1.1 Analysis of LFHS Accidents Based on 'Agencies'

The significant 'Agencies', **according to our analysis and the accident prediction models,** that caused LFHS accidents during the period of 2006 to 2015, considering all the eight significant contributors**,** as given in **Table 5.7,** are listed in **Table 5.8.** The **Figure 5.4** shows the relative proportion for these 'Agencies'. It needs to be mentioned that in addition to 'Lifting Machines and Applications', 'Pressure Vessels' and 'Electrical Installations'; 'Agencies' which caused 'Exposure to or Contact with Electric Current', 'Fall of Persons from Height' and 'Stepping on Striking against or Struck by Object'; and 'Agencies' which caused injury to 'Head' and 'Lower Limb' were also considered for the analysis.

Table 5.8

Significant Agencies Caused LFHS Accidents during the Period from 2006 to 2015 Based on Significant Contributors derived from Accident Prediction Models

Significant Agencies caused LFHS Accidents	**Number of LFHS Accidents**
Working Environment	37
Electrical Installations	14
Scaffolding	11
Ladders, Mobile Ramps	10
Lifting Machines and Appliances	5
Pressure Vessels	4
Wheeled Means of Transportation	3
Tools, Implements and Appliances	3
Other Agencies 1. Other Equipment (9) 2. Dusts, Gases, Liquids and Chemicals (2) 3. Metal Working Machines (1)	12
Total	**99**

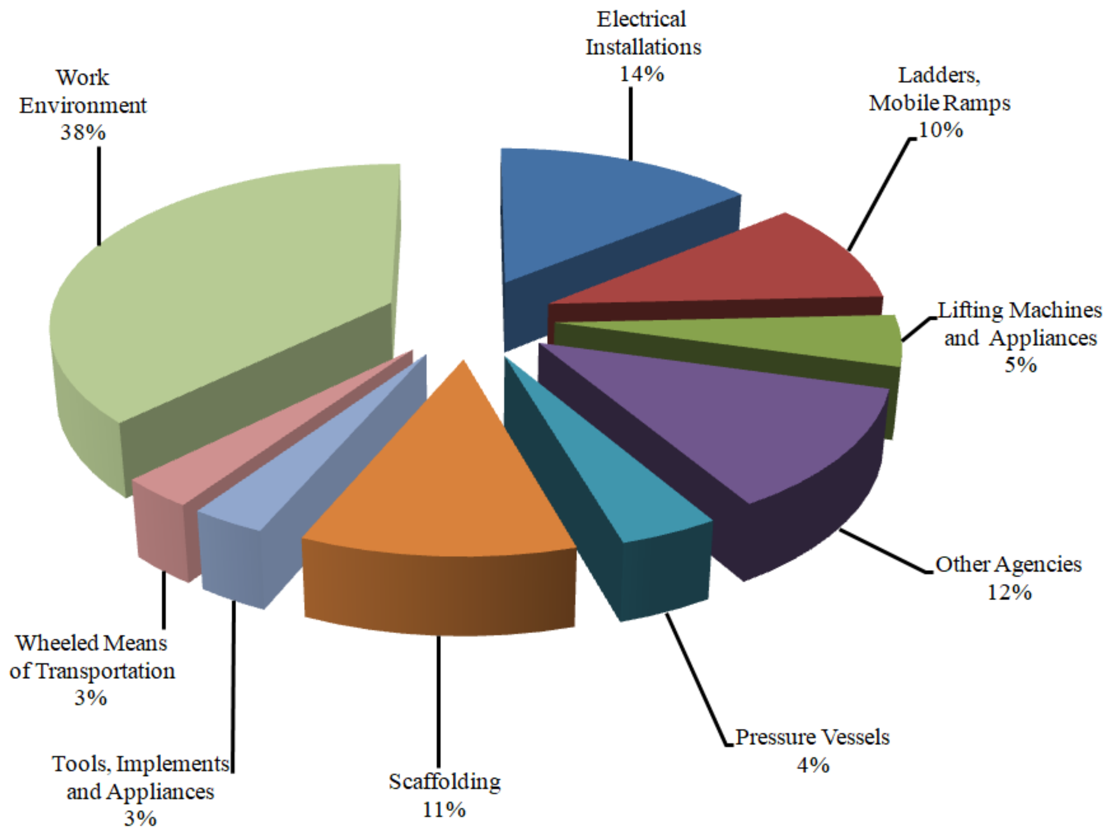

Figure 5.4: Significant 'Agencies' caused LFHS Accidents

38% of LFHS Accidents were attributed to **'Working Environments'** such as floors, confined quarters, stairs, traffic and working surfaces, floor openings, wall openings and fire. This shall be corrected by machine guarding, fencing or barricading of hazardous work locations, pits, floor, openings, wall openings and manholes, use of roof top ladders while working on fragile roofs, regular plant safety inspection to identify and correct slip, trip and fall hazards, regular Preventive Maintenance and Surveillance of structures, systems and components, ensuring illumination level at work places as per the statutory requirements, employee training and pre-job briefing, effective work supervision, use of mechanical means of material handling, instead of manual material handling and ensuring compliance to requirements of work permit system, job hazard analysis, work procedures and use of personal protective equipment.

14% of LFHS Accidents were due to unsafe conditions and unsafe acts while working on '**Electrical Installations'** such as rotating machines, switchgears, circuit breakers or electrical cables, circuits and conductors. This can be corrected by insulation of live electrical components, provision of system for monitoring overheating of electrical equipment, designing systems for arc flash protection, conducting arc flash hazard analysis and taking safety precautions while working within arc flash protection boundaries, effective supervision of works on electrical systems, provision of earthing and ELCBs as per the regulatory requirements.

11% of LFHS Accidents were due to unsafe conditions and unsafe acts while working on '**Scaffoldings'**. This can be addressed by designing scaffolding and platforms to meet safety requirements, inspection and certification of scaffoldings by authorized agencies and by ensuring compliance to work permit system during erection and dismantling of scaffolding.

10% of LFHS Accidents were due to unsafe conditions and unsafe acts while using '**Ladders, Mobile Ramps**'. This should be corrected by designing ladders to meet safety requirements, periodic inspection of ladders and segregation of unsafe ladders with tagging to prevent use of defective ladders.

5% of LFHS Accidents were due to unsafe conditions and unsafe acts while working on '**Lifting Machines and Appliances'** such as Electrical Overhead Travelling (EOT) cranes, mobile cranes, tower cranes, forklifts, elevators, slings or other lifting tools and tackles. This can be prevented by ensuring erection, modification, repair and dismantling of lifting machines as per manufacturer's instructions by authorized agencies, periodic maintenance and surveillance of lifting machines and appliances and providing facilities for safe material handling at work places.

4% of the LFHS Accidents were due to unsafe conditions and unsafe acts while working on '**Pressure Vessels'** such as pressurized containers, gas cylinders, pressurized piping and accessories. This can be addressed by periodic maintenance, surveillance safe storage of pressure vessels.

3% of the LFHS Accidents were due to unsafe conditions and unsafe acts while working on **'Wheeled Means of Transportation'** such as dumpers, light motor vehicle and tractors. This can be addressed by periodic maintenance and surveillance of transportation vehicles.

3% of the LFHS Accidents were due to unsafe conditions and unsafe acts while working on **'Tools, Implements and Appliances'.** This can be addressed by periodic maintenance and surveillance of tools and provision of tool bags while carrying tools for works at height.

12% of the LFHS Accidents were to unsafe conditions and unsafe acts while working on '**Other Agencies'** such as **'Dusts, Gases, Liquids and Chemicals' (2%), 'Metal Working Machines' (1%) and 'Other Miscellaneous Equipment' (9%)** such as cement silo dust collector cartage, metallic plates, metal sheets, wooden planks, process pipelines, pipe pieces, shoe cover and pump impeller. This can be addressed by ensuring compliance to work permit systems, use of required personal protective equipment, effective work supervision and training of workers.

5.5.1.2 Analysis of LFHS Accidents Based on 'Types of Accidents'

Similarly, the class of significant 'Types of LFHS Accidents', according to our analysis and the accident prediction model, that caused the LFHS accidents are shown in **Table 5.9,** and **Figure 5.5** gives the relative proportion of these significant 'Types of LFHS Accidents'. Here too it needs to be mentioned that in addition to 'Exposure to or Contact with Electric Current', 'Fall of Persons from Height' and 'Stepping on Striking against or Struck by Object', 'Types of LFHS Accidents' attributed to 'Lifting Machines and Applications', 'Pressure Vessels' and 'Electrical Installations'; and 'Types of LFHS Accidents' which caused injury to 'Head' and 'Lower Limb' were also considered for the analysis.

Table 5.9

Significant Types of LFHS Accidents during the Period from 2006 to 2015 Based on Significant Contributors derived from Accident Prediction Models

Significant Types of LFHS Accidents	Number of LFHS Accidents
Fall of Persons from Height	47
Stepping on, Striking Against or Struck by Object	20
Exposure to or Contact with Electric Current	11
Fall of Objects	8
Fall of Persons on the same level	5
Caught in or Between Objects	4
Exposure to or Contact with Extreme Temperature and Harmful Substances 1. Exposure to or Contact with Extreme Temperature (2) 2. Exposure to or Contact Harmful Substances (2)	4
Total	**99**

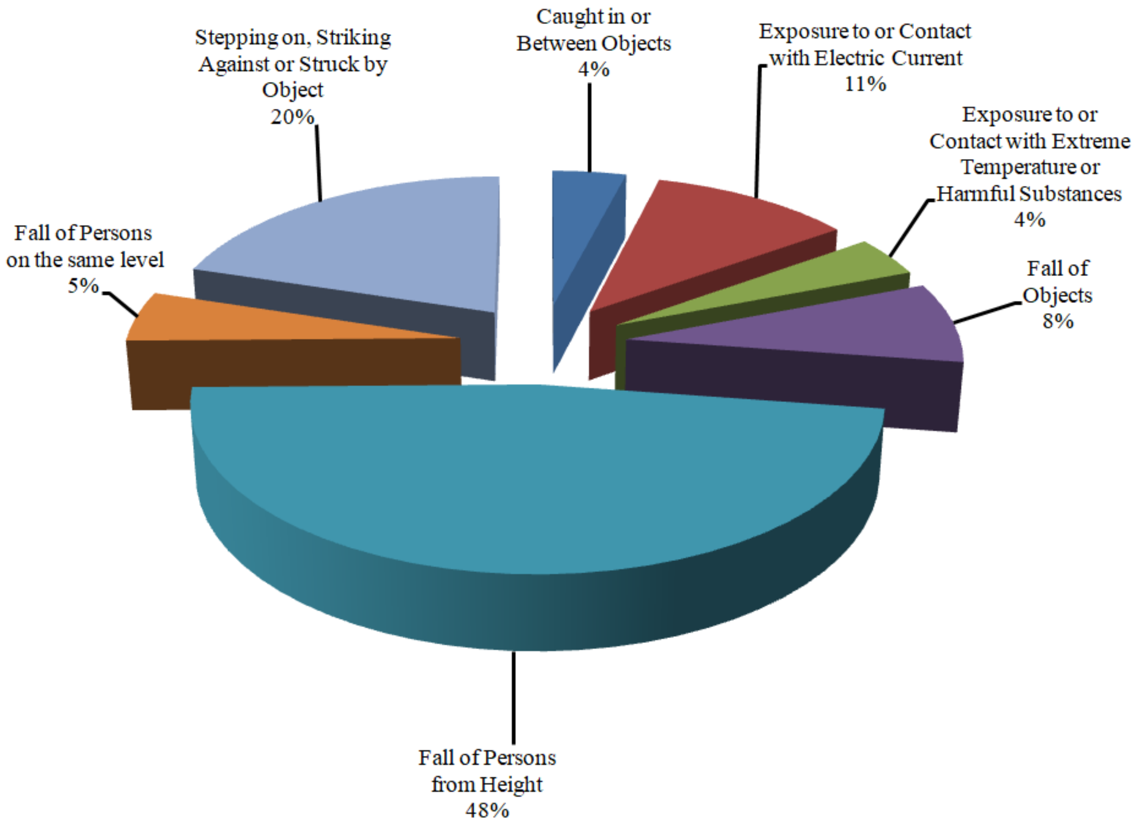

Figure 5.5: Significant 'Types' of LFHS Accidents

48 % of the LFHS Accidents were due to **'Fall of Persons from Height'** attributed to not anchoring safety harness while working at height, working over fragile surfaces at height without fall protection measures, lack of supervision, lack of following three point contact theory while using ladder, descending through the ladder by facing outwards, unsafe scaffoldings, platforms and ladders; shortfalls in certification of scaffoldings and platforms for safe use, lack of safe access for working at height, lack of hard barricading and caution signage at height, uncovered openings or openings covered with soft materials, dismantling of scaffolding while of workers were standing on it and poor area illumination. This can be addressed by ensuring that persons for working at height and valid height pass are only permitted to work at height, inspection and certification of scaffolding, platforms and ladders for safe use, training of workers on scaffolding and ladder safety, hard barricading of hazardous locations at height,

20% of the LFHS Accidents were due to **'Stepping on or Striking against or Struck by Objects'** attributed to deficiencies in material condition, design, layout and ageing of structures, systems and components; improper installation of equipment, not securing equipment or materials at work locations, not providing soft cushions on equipment with striking hazards, use of equipment with striking hazards, lack of machine guards, lack of hard barricading to restrict entry of unauthorized persons to work area with striking hazards, unsafe loading of vehicle during transportation, lack of caution signage or warning, lack of procedure, adopting wrong procedure, lack of attention to striking hazards, non-use of mechanical means for material handling, ineffective communication, non-use of correct tools, not using leather hand gloves during material handling or not wearing helmets in areas with bump hazards, lack of coordination, lack of supervision and not deploying signalmen while performing hazardous jobs with striking hazards. This can be corrected by periodic surveillance and correction of striking hazards, provision of machine guards, restricting entry of persons to areas with striking hazards with caution signage and barricading, use of mechanical means for material handling and use of required personal protective equipment

11 % of the LFHS Accidents were due to **'Exposure to or Contact with Electrical Current'** attributed to insufficient hazard identification and risk assessment; flash over caused by exposure to live circuit breaker components while working on electrical switchgear due to design deficiencies in the electrical equipment, non-compliance to guarantied isolation of power supply or work permit system before starting works on electrical systems, dust accumulation on switchgear, lack of periodic maintenance, non-adherence to procedures and work permit system, ineffective supervision and communication, lack of attention to live electrical circuits, exposed live contactors of equipment and cable terminals, non-use of arc protection suits and arc rated personal protective equipment; electric shock caused by degradation of electrical cables due to ageing, defective insulation of cables or cable terminals, use of non-standard power plug tops, wrong wiring of electrical extension boards, lack of Earth Leakage Circuit Breakers (ELCBs) in electrical circuits, inadequate earthing of electrical circuits, lack of awareness on color coding of cables in an extension board and deployment of unqualified persons for electrical works. This can be addressed by ensuring guarantied isolation of power supply and compliance to procedures and work permit system while working on electrical systems, use of proximity testers, isolation of live parts of electrical equipment, use of arc flash protection suits, provision of earthing and ELCBs and effective supervision.

8% of the LFHS Accidents were due to **'Fall of Objects'** from structures, systems and components attributed to failure of weld joints, placing materials at height in unsecured manner, holding materials in unsecured manner or inadequate slinging during material handling and lack of communication between the workers. This can be prevented by not keeping materials at height in unsecured manner, use of mechanical means for material handling instead of manual material handling, deployment of authorized persons for material handling, periodic inspection and housekeeping of work places at height.

5% of the LFHS Accidents were due to **'Fall of Persons on the Same Level'** attributed to slips, trips and falls on the floors caused by spillage of materials, use of unsafe personal protective equipment, laying of cables in haphazard manner, lack of communication among the workers during the jobs performed in group and damaged rubber mats. This can be addressed by safe storage of materials and regular plant safety inspection for identification and correction of slip, trip and fall hazards.

4% of the LFHS Accidents were due to **'Caught in or Between the Objects'** attributed to wrong procedure and lay out for storage of reinforcement rods, manual handling of heavy materials instead using mechanical means, overloading of tower cranes due to wrong assessment of load being lifted, deployment of unauthorized persons as riggers and signalmen during material handling, use of non-standard tools for material handling, non-use of personal protective equipment and use of unsafe personal protective equipment. This can be prevented by use of mechanical means for material handling instead of manual material handling, deployment of authorized persons and standard tools for material handling and use of required personal protective equipment while performing jobs.

4% of the LFHS Accidents were due to **'Exposure to or Contact with Extreme Temperature' (2%)** attributed to non-use of heat resistant protective cloths while testing steam relief valves, performing jobs on high temperature water system without depressurizing and draining; and **'Exposure to or Contact with Harmful Substances' (2%)** attributed to performing jobs on acid systems without depressurizing and draining, non-use of acid resistant protective cloths while working on acid systems and noncompliance to work procedures while working on acid systems. This can be corrected by use of heat resistant personal protective equipment while working on systems with high temperature; and compliance to work permit system and system isolation procedure and personal protective equipment while working on systems with harmful substances.

5.5.1.3 Analysis of LFHS Accidents Based on 'Locations of Injuries'

Table 5.10 lists the significant 'Locations of Injury', as given by our accident prediction models considering the LFHS Accidents that occurred during the period of 2006 to 2015, and all eight significant contributors given in **Table 5.7. Figure 5.6** gives the relative proportion of significant ''Locations of Injuries' due to the considered LFHS Accidents. In addition to 'Head' and 'Lower Limb'; 'Locations of Injuries' caused by accidents attributed to 'Lifting Machines and Applications', 'Pressure Vessels' and 'Electrical Installations'; and 'Locations of Injuries' caused by 'Exposure to or Contact with Electric Current', 'Fall of Persons from Height' and 'Stepping on Striking against or Struck by Object', are also considered for the analysis.

Table 5.10

Significant Locations of Injuries due to LFHS Accidents during the Period from 2006 to 2015 Based on Significant Contributors derived from Accident Prediction Models

Significant Locations of Injury due to LFHS Accidents	**Number of LFHS Accidents**
Head	26
Lower Limb	24
Upper limb	22
Multiple Locations	13
Trunk	9
General Injuries	4
Unspecified Locations	1
Total	**99**

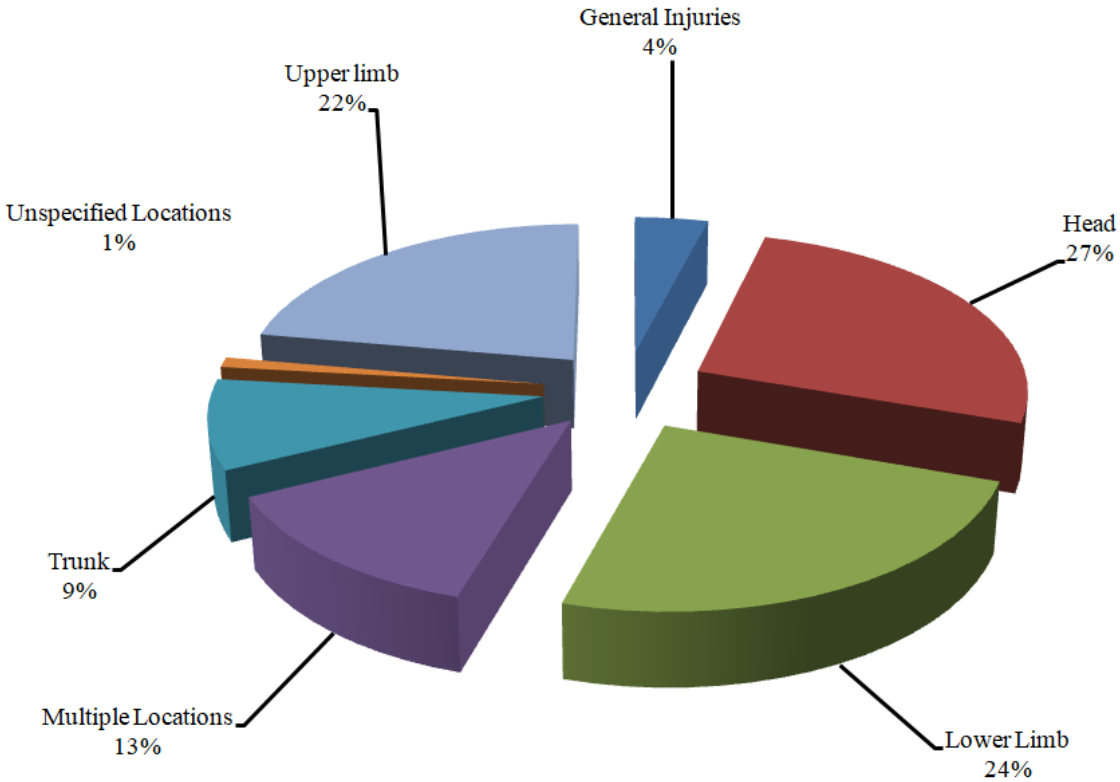

Figure 5.6: Significant 'Locations of Injuries' due to LFHS Accidents

27% of injuries due to LFHS accidents were on **'Head'** at different parts of head such as cranium region, mouth and other unspecified locations of the head attributed to fall of objects, fall of persons from height, stepping on or striking against or struck by objects, caught in or between the objects and exposure to or contact with harmful substances, associated with working environment, ladders, mobile ramps, tools, implements and appliances, scaffolding, wheeled means of transport, dusts, gases, liquids and chemicals and lifting machines and appliances and other miscellaneous agencies. Corrective actions already suggested for addressing fall of objects, fall of persons from height, stepping on or striking against or struck by objects, caught in or between the objects and exposure to or contact with harmful substances shall be complied.

24% of injuries due to LFHS accidents were on **'Lower Limb'** at different parts of lower limb such as hip, thigh, knee, leg, ankle, foot and toes attributed to fall of objects, fall of persons from height, fall of persons on the same level, stepping on or striking against or struck by objects and caught in or between the objects, associated with working environment, scaffolding, pressure vessels, ladders, mobile ramps, lifting machines and appliances, wheeled means of transport and other miscellaneous agencies. Corrective actions already suggested to address fall of objects, fall of persons from height, fall of persons on the same level, stepping on or striking against or struck by objects and caught in or between the objects shall be complied.

22% of injuries due to LFHS accidents were on **'Upper Limb'** at different parts of upper limb such as elbow, forearm, wrist, hand and fingers attributed to fall of persons from height, fall of persons on the same level, stepping on, striking against or struck by objects, caught in or between the objects, exposure to or contact with electrical current, associated with working environment, tools, implements and appliances, electrical installations, metal working machines, lifting machines and appliances, ladders, mobile ramps and other miscellaneous agencies. Corrective measures already suggested against fall of persons from height, fall of persons on the same level, stepping on, striking against or struck by objects, caught in or between the objects and exposure to or contact with electrical current shall be complied.

13% of injuries due to LFHS Accidents were on **'Multiple Locations'** such as head, trunk or one or more limbs attributed to fall of persons from height, stepping on or striking against or struck by objects and exposure to or contact with extreme temperature, associated with working environment, scaffolding, ladders, mobile ramps and pressure vessels. Preventive measures already suggested to address fall of persons from height, stepping on or striking against or struck by objects and exposure to or contact with extreme temperature shall be complied.

9% of injuries due to LFHS accidents were on **'Trunk'** at different parts of trunk such as back, chest and abdomen attributed to fall of persons from height and fall of persons on the same level, associated with working environment, scaffolding, ladders, mobile ramps, wheeled means of transportation, pressure vessels and other miscellaneous agencies. Preventive measures already suggested for fall of persons from height and fall of persons on the same level shall be complied.

5% of injuries due to LFHS accidents were on **'General Injuries' (4%) or Unspecified Locations of Injury' (1%)** at various internal systems and other unspecified locations of human body attributed to fall of persons from height, caught in or between the objects and exposure to or contact with electrical current, associated with working environment, electrical installations and earth moving machines. Corrective measures already suggested for fall of persons from height, caught in or between the objects and exposure to or contact with electrical current shall be complied.

5.5.2 RECOMMENDATIONS TO PREVENT LFHS ACCIDENTS

Our analysis indicates that the LFHS accidents had occurred due to shortfalls in the:

i) Design of 'Agencies',

ii) Administrative Controls and

iii) Use of personal protective equipment to prevent accidents or reduce severity of accidents.

This can be resolved by implementing 'Safety through Design’, enforcing 'Administrative Controls’, and use of 'Personal Protective Equipment’. Our recommendations in this regard to prevent LFHS accidents are given in the following sections:

5.5.2.1 Safety through Design:

Machine Guarding

1. A comprehensive survey of systems and components should be carried out to identify machine guarding related deficiencies and guards should be provided to prevent approach of workers to hazardous components of systems or equipment. In case of new equipment, requirement of machine guarding shall be included in the purchase specifications as per Indian Standard IS 16809-2018 (IS 16809 Part 1-4, 2018 [15] [16] [17] [18]).

2. Fans should be provided with guards and wire mesh wrapped over the guards to prevent entry of body parts. Guards should be provided on the grinding wheels also.

3. Soft cushion with caution signage shall be provided over the lower end of the system components such as pipes, cable trays, supports etc., to prevent injury to body parts due to striking.

Barricading of Hazardous Locations with Caution Signage

4. Entry to hazardous locations such as edges of roof, fragile bodies or open sides of the structure with fall potential shall be prevented by hard barricading and caution signage.

5. Entry to area below the height works shall be restricted with barricading and caution signage to prevent injury due to fall of objects.

6. While carrying out hazardous operations, entry of unauthorized persons to the area shall be prohibited by barricading and caution signage.

Covering or Barricading of Pits, Floor Openings, Wall Openings and Manholes

7. Fencing, railing or hard barricading of at least 1 m height with caution signage and mid rail shall be provided around pits, floor openings, wall openings, manholes and other work locations with fall potential to prevent fall of persons; complying with the requirements of Indian Standard IS 4912 (IS 4912-2017 [19]).

8. To avoid fall of persons and objects; pits, floor openings, wall openings, and manholes must be covered with materials of sufficient strength, in accordance with Indian Standard IS 4912 (IS 4912-2017 [19]).

9. Plywood sheet shall not be used to cover openings. Instead, either metallic plate or close metallic grills of adequate strength shall be used to cover the openings.

10. Safety nets shall be provided below the floor openings and around wall openings to prevent fall of objects and fall of persons.

Scaffolding Safety

11. All scaffolding members, such as planks, braces, vertical supports, and horizontal supports, must be of sound material, well-built, and of sufficient strength.

12. Safe access shall be ensured at work places at height by suitable scaffoldings and platforms, with provisions for hooking of safety harness.

13. Safety nets shall be provided below the locations of works at height. Safety nets shall be wrapped on all sides of the scaffoldings and firmly secured to prevent fall of persons and materials.

14. Design of scaffolding and platforms shall meet the safety requirements; complying with Indian Standard IS-3696 on “Scaffolds and Ladders – Code of Safety” (IS-3696 (Part-1 and Part-2), 2017 [20] [21]).

15. Platforms of following minimum width shall be provided for various types of works as indicated below (GOI, 1996 [43]):

    i) Where platform is not more than 2 m above the ground or solid floor:

        a) For painters, decorators and similar workmen - 30 cm.

        b) For other types (Men and tools only) - 50 cm.

    ii) Where platform is more than 2 m above the ground or solid floor:

        a) For men, tools and materials - 120 cm.

        b) For men, tools, materials and vehicles such as wheel barrows - 150cm.

16. Open sides of the platforms shall be provided with toe-boards of 15 cm height, hand rails of 1 m height and mid rails.

17. Platform gratings shall be locked in secured manner. Alternatively press locking platform gratings shall be provided.

Ladder Safety (GOI, 1996 [43]; AERB, 2011 [4])

18. Every ladder must be well-built, made of sturdy materials, and of sufficient strength.

19. For work sites with a height of 4.5 meters or more, a prefabricated steel staircase must be used.

20. Step or rung spacing of ladders shall be uniform and shall not exceed 30 cm.

21. Man-guards must be installed on any vertical ladders over 3 m in height that are permanently installed.

22. The width between the styles (side bars) on ladders up to 3m in length must not be less than 30 cm. This width must be increased by at least 2 cm for each extra meter of ladder length.

23. Ladders must be anchored to the ground or rigid platforms, and top end ladders must be secured to a solid structure.

24. At all locations at height, where frequent entry is required, permanent ladders shall be provided, instead of temporary ladders.

25. Ladders must be kept in a safe position before use. The optimal angle for a ladder with the horizontal is 75 degrees, which means the length of the ladder to the base of the ladder from the wall must be in the ratio of 4:1.

<u>Fragile Roof</u>

26. Roof top ladders with anchoring facility for lanyards of safety harness shall be used for working over the fragile roof.

<u>Illumination</u>

27. General illumination in wok area shall be 20 lux and at locations where work is continuous in nature, illumination level shall be 100 to 150 lux.

<u>Anti-skid Floors</u>

28. Slippery floors at work locations should be replaced with anti-skid floors.

<u>Rain Water Protection</u>

29. Accumulation of rain water within the plant buildings shall be prevented by effective rainwater protection and drainage system.

<u>Anti-Slip Device or Pipe Shoes</u>

30. While handling pipes at height, anti-slip device or pipe shoes shall be provided to prevent fall of pipes due to slippage.

Material Handling

31. Mechanical means shall be used for lifting and shifting of heavy materials. Materials being handled at height shall be held in secured manner by mechanical means of clamps and chains. While handling heavy or over dimensional materials mechanical means shall only be used.

32. Lowering of materials shall be carried out with guiding knot on the rope with additional support, strong enough to take the load.

33. Standard crow bar shall be used for levering of materials during material handling.

34. Fabrication shops shall have facilities such as shed, leveled flooring, lifting arrangement etc., for safe material handling.

Storage of Pipe Materials

35. Semicircular wooden supports shall be used for storage of pipes, with adequate aisle space between the stored pipes.

36. Pipe materials shall be installed at work places in secured condition to prevent movement.

Safe Access to Work Location

37. Safe access and exit shall be provided at the work locations.

38. Safe walkways shall be provided with flat and clear surfaces for workers.

Electrical Safety

39. Insulated covers shall be provided on exposed electrical conductors in switchgears to avoid inadvertent contact while working on electrical systems.

40. A position switch should be provided on Motor Control Centre (MCC) compartment door such that whenever MCC compartment door is opened, power supply to MCC cell is cut off through a disconnect switch.

41. Passive online system for monitoring overheating of Terminals, Bus Bars and other points in electrical network subject to overheating because of faults shall be provided on switchgear components for early detection of electrical faults.

42. Mechanical interlock shall be provided on circuit breakers such that racking out of breaker is possible only if the shutters are in closed condition.

43. Switchgear shall be designed for Internal Arc Protection and qualified as per IEC 62271-200.

44. Standard three pin industrial plug top with provision for earthing and ELCBs shall only be used for the extension of power supply.

45. Phase to phase insulation barrier shall be provided in isolator switch and fuse base.

46. Visible double earthing shall be provided on tube light fixtures and electrical equipment

47. Electrical circuits shall be provided with provision for earthing and Earth Leakage Circuit Breakers (ELCBs).

48. Earthing shall be provided on scaffolding and platforms erected for working at height on electrical systems.

5.5.2.2 Administrative Controls:

<u>System Isolation and Work Permit System</u>

1. For effective control of floor openings, wall openings, and manholes, a work permit system should be implemented. The removal of grills or covers from these openings until they are normalized must be governed by a work permit system.

2. Works at height shall be carried out with approved Work Permits and Industrial Safety Permits for working at height.

3. Works on pressurized and high temperature systems or equipment or, acid or alkali systems shall be carried out with approved procedure, Work Permit and Industrial Safety Permit.

<u>Hazard Identification and Control Measures</u>

4. Job Hazard Analysis (JHA) shall be conducted for all routine and non-routine jobs in order to identify hazards and risks. Before starting the job, a JHA checklist comprising of hazard control measures shall be developed and incorporated in the work procedure. The job shall be performed with approved work procedure with JHA checklist. Hazard control measures recommended in JHA shall be implemented while performing the jobs. Engineer in charge responsible for the job shall monitor effective implementation of hazard control measures during the job.

5. JHAs and work procedures shall be periodically revised based on experience feedback by incorporating hazard control measures against latent hazards.

6. Work execution plan shall include contingency plan for rescue operations also. Effectiveness of rescue plan shall be verified by conducting periodic rescue exercises on different scenarios.

7. Before working on pressurized or high temperature system or equipment or; acid or alkali system, it should be depressurized and drained.

<u>Preventive Maintenance and Surveillance</u>

8. Ladders shall be inspected regularly and deficiencies if any, including burs in the hand railing, loose rungs etc., shall be corrected immediately.

9. Floor openings, wall openings and manholes with fall potential shall be identified and accounting of these openings shall be carried out with drawings. Floor opening covers, wall opening covers, and manhole covers must be inspected on regular basis, and any fault must be repaired or replaced as needed.

10. Periodic inspection of anti-skid rubber mats should be carried out and damaged mats should be replaced.

11. Weld joints should be inspected for its strength after welding to prevent fall of objects due to failure of weld joints.

12. Cables must be inspected and tested for ageing on a regular basis, and damaged or expired cables must be replaced.

13. Switchgear, MCCs, electrical equipment, and extension boards must be inspected and maintained on a regular basis and deficiencies if any must be rectified.

14. Before deploying for use, connections of extension boards shall be verified and certified as safe for use by persons designated for electrical works.

15. Periodic illumination surveys of work places must be conducted, and shortcomings must be corrected, in order to ensure adequate illumination at work places in accordance with legislative requirements.

Employee Training and Pre-job Briefing

16. Workers shall not be allowed to proceed to work locations without pre-job briefing. Before starting the job, job specific pre-job briefing covering specific hazards, control measures to be taken, procedures to be followed, safety precautions to be taken, potential injury due to lack of attention to the job while using tools or sharp edges on the materials being handled, personal protective equipment to be used and requirements of self-checking and peer checking while performing the job shall be given. Workers should be cautioned during pre-job briefing that before turning a fan, they should switch off the fan and ensure that fan has stalled.

17. Workers shall be trained on the use of equipment with hazardous components. While dismantling parts of tower crane, hazards due to sudden release of parts being dismantled and possibility of injury due to striking of released parts shall be explained to the workers during the pre-job briefing.

18. Blood pressure, epilepsy, flat feet, frequent headaches or spinning sensations, mental melancholy, limping stride, and acrophobia must be checked for those who work at a height of 2.5 meters or more. The persons medically fit for working at height shall undergo physical fitness on height work simulator by walking over a beam of 30 cm width at 2.5 m height by wearing safety harness without any ill effect. The persons successfully completed medical and physical test for working at height of 2.5 m and above shall be imparted with training on safety precautions to be taken and use of fall protection measures and personal protective equipment while working at height; and issued with height pass after examination. Validity of height pass shall be 1 year. Persons with valid height pass shall only be deployed for working at height (AERB, 2011 [4]).

19. Importance of using double lanyard safety harness, anchoring of one of the lanyards to life line or a firm structure while working or moving at height and tying of chinstraps of helmets should be discussed with employees during Industrial Safety training programs. Training program should cover hazards involved in fragile surfaces and safety measures to be taken while working on fragile surfaces also. The hazards of working at heights and on fragile surfaces, as well as the precautions to be taken, should be emphasized during pre-job briefings.

20. Safety precautions and procedure to be followed while using scaffolding and ladders should be demonstrated to the workers during the Industrial Safety training programs and pre-job briefings. This shall also include instructions that, they shall face towards the ladder and follow three-point contact theory of firmly holding at least three limbs out of two legs and two hands while using ladders.

21. Procedure for material handling shall be developed and specific safety requirements to be followed during material handling operations shall be covered during the industrial safety training programs and pre-job briefings.

22. Before engaging riggers, signalmen and crane operators for material handling operations, their competency shall be assessed based on hands-on skill test and trade test, irrespective of their past work experience. Material handling jobs shall be carried out by trained and authorized crane operators, riggers, signalmen only.

23. Employees with requisite qualifications as per the Central Electricity Authority (CEA) Regulations shall only be designated for working on electrical systems. Employees must be given site-specific training on electrical systems and the measures to be followed while working on electrical systems before being deployed for electrical system works.

24. During Industrial Safety training programs and Pre-Job Briefings, the hazards involved and the measures to be taken while working on pressurized or high temperature systems or equipment; or acid or alkali systems, shall be explained to the personnel.

25. Training on Cardio-Pulmonary-Resuscitation (CPR) shall be given to all persons working on electrical systems to rescue victims of electrical shock.

26. Trained and qualified staff only shall be deployed at the First-aid centers to take correct and prompt rescue operations during accidents.

Job Supervision

27. Job supervisors and safety supervisors of contractors shall be qualified and experienced to carry out the job safely. They shall be trained and made conversant with safe practices to be followed at work locations.

28. Works at height and hazardous locations with fall potential shall be carried out under supervision. Supervisors shall prevent workers from using fragile surfaces for performing job.

29. Supervisors shall ensure safe access for performing jobs; and they shall caution and prevent workers from climbing over the pipelines or adopting unsafe posture for performing jobs.

30. Supervisors shall ensure that workers are facing towards the ladder and following three-point contact theory of firmly holding at least three limbs out of two legs and two hands, while climbing up or descending down through the ladders.

31. Required number of Safety Officers and Safety Supervisors shall be deployed as per the statutory provisions. Since statutory provisions are minimum requirements, depending on the hazards involved in the job, quantum of jobs and number of workers deployed for the jobs; more number of Safety Officers and Safety Supervisors shall be deployed for effective safety oversight.

32. Every day, work supervisors shall visit work locations to identify hazards and appraise these hazards with control measures to workers before their deployment.

33. Work supervisors shall ensure effective communication and coordination between multiple agencies working in the same area using the same resources.

34. Work supervisors shall ensure the followings:

    a. Daily house-keeping of workplaces and safe disposal of debris materials.

    b. Workers under them do not cross barricading provided for restricting entry.

    c. Compliance to work procedures, JHA recommendations and stipulations of work permits before starting the job.

    d. Medically fit employees are only deployed for the job.

e. Appropriate personal protective equipment like helmets and double lanyard safety harness are used while working at height and one of the lanyards of double lanyard harness is always anchored to a life line or a firm structure.

f. Inspection of metallic joints after welding to prevent fall of objects due to failure of weld joints.

g. Periodical checks on clamping of pipes at height.

h. Checking of modular scaffolding structure for its structural stability and conformity with actual condition at the work spot with respect to effective width, stability of railings, storage of materials, material of construction of the platform, loading capacity of the platform and procedure for loading and unloading of platform.

i. Workers are using standard cable peeler for removing cable insulation.

j. Grinding wheels with guards are only used and the grinding wheel is operated in proper angle to prevent its failure.

k. Sharp edges of the materials being lifted are made smooth by covering with soft materials.

l. While dismantling parts of tower crane, the part being dismantled should be secured and prevented from striking the persons present nearby. Segment being released should be secured with riggers knot to prevent sudden release.

m. Drivers are sensitized for not keeping loose materials on the dash board, which may divert attention of driver.

n. Workers are following safe working practices during material handling.

Scaffolding Safety

35. Before use, scaffoldings, platforms, ladders, walkways and access paths shall be inspected, certified and tagged for safe use with expiry date by the authorized agency.

36. Inspection and certification of scaffoldings shall be carried out with approved checklist considering safety requirements which also include fixing of working platforms, width of working platforms, earthing, handrails, mid rails, toe boards, life line for hooking safety harness, safe access path, safety net, provision for lifting and lowering materials etc.

37. "Green" tags must be placed on scaffoldings that have been certified as safe to use, whereas "Red" tags must be placed on scaffoldings that are being erected or dismantled or are unsafe to use. Supervisors shall ensure that works are performed using scaffoldings with “Green” tags only and shall prohibit workers from using scaffoldings with “Red” tag.

38. Unsafe scaffoldings or scaffoldings with expired dates shall be “Red” tagged and shall not be used. Before use, scaffolding with expired dates shall be inspected and recertified by the authorized agency.

39. Scaffoldings shall be periodically inspected to ensure that no parts are disturbed or damaged. In case of any disturbance or damage to the scaffolding parts, deficiencies shall be corrected and scaffolding shall be recertified by the authorized agency for safe use.

40. Scaffolding shall not be dismantled with persons standing on it. Dismantling of scaffolding shall be carried out in sequential manner and load bearing members shall be removed only after all other members are removed.

Ladder Safety

41. Ladders shall be periodically inspected and tagged for safe use. Deficiencies in unsafe ladders shall be corrected and if deficiencies cannot be corrected, unsafe ladders shall be segregated and prohibited from use by tagging.

42. When using a portable ladder, be sure it is fastened and handled by someone else. Before using a ladder, it must be kept in a secured posture. The optimal angle for a ladder with the horizontal is 75 degree, which means the length of the ladder to the base of the ladder from the wall must be in the ratio of 4:1.

43. Rungs of the ladders shall be checked prior to use and oil traces if any shall be cleaned.

44. Workers shall follow three-point contact theory of firmly holding at least three limbs of two legs and two hands while climbing up or descending down though the ladders.

Electrical Safety

45. Job hazard analysis shall be carried out before taking maintenance on live electrical circuits and recommended hazard control measures shall be taken prior to and while performing job.

46. Arc Flash Hazard Analysis of the switchgears shall be conducted to determine arc flash incident energy and arc flash protection boundary for identifying required arc protection suit and arc rated PPEs for use while working on electrical switchgears, within arc flash protection boundaries. Arc Flash Protection Boundary within which arc resistant cloths should be used shall be displayed over the switchgear panel or should be marked in front of the panel (IEEE 1584, 2022 [59]; NFPA 70E, 2021 [83]).

47. Works on live electrical systems must be supervised by skilled and designated individuals for electrical works, and must be in accordance with approved procedures and work permits.

48. MCC compartment fuses shall be changed after racking out the breaker or taking positive isolation of Switch Fuse Units.

49. While performing jobs on electrical circuits, insulated tools shall be used. Fuses shall be removed with insulated fuse pullers only.

50. While working on live electrical systems, proximity testers shall be used to alert against approach to live electrical circuits and identify live electrical components in the vicinity.

51. MCC feeder isolator shall be normalized only after closing the door to prevent injury due to electrical arc flash.

52. If operating handle of MCC compartment becomes inoperable, MCC incoming breaker shall be de-energized before opening the compartment.

53. While wiring electrical circuits, insulation of the wires at its terminal points shall be checked for effective insulation. Open ends of electrical cables shall be covered or capped with insulation.

54. Before starting works on electrical systems, guaranteed isolation and compliance to work permit system shall be ensured.

55. While working near electrical circuits, workers shall not support their body to electrical equipment.

56. While working near high voltage lines, minimum safe working clearance shall be maintained as per Schedule-VII of CEA Regulations 2010.

57. Cable trays shall never be used as working platforms and tube light fixtures shall not be used as supports.

58. While working on live electrical circuits, one should be attentive about the electrical hazards. A caution signage in this regard should be displayed near the switchgears.

59. No worker shall be allowed to work on electrical systems, alone in restricted or confined area. Communication arrangement with display of emergency phone numbers shall be provided at confined spaces where electrical works are performed.

<u>Material Handling Safety</u>

60. Tower cranes must be installed, inspected, tested, operated, maintained, and altered according to manufacturer's instructions, with work permits and approved procedures.

61. All lifting machines, rope, chains and lifting tackles which have been modified, altered or repaired shall be retested and reexamined by competent person, before again taking in to use. Certificates of such tests and examinations shall be maintained.

62. Workers should be trained in manual material handling and ergonomics of manual material handling. Adequate number of persons should be deployed for holding materials in secured manner during manual material handling. While manually lifting materials collectively by a group of workers, coordination and communication among the workers should be ensured.

63. While transporting materials using mobile crane, clear vision of the driver shall be ensured with the support of signal man and pilot man at the front to caution the driver against presence of any unsafe condition.

64. Three-way communication must be ensured between mobile crane operator and rigger to ensure that boom is not retracted before removal of lifting clamp.

65. Material handling works should be carried out under supervision. Trained and authorized crane operators, riggers and signal men shall be deployed for material handling operations. Records on such authorizations shall be maintained.

66. While shifting the reinforcement bars, workers should not stand over reinforcement bar bundles.

67. Lower size reinforcement bars in bundles shall be handled by heavy-duty mobile cranes and specified number of reinforcement bars shall only be handled by the tower cranes.

68. Installation, testing and calibration of safety devices and automatic safe load indicator shall be carried out as per approved procedure based on manufacturer's instructions. Records in this regard shall be maintained.

69. Cranes must be examined and tested by competent persons, and records must be maintained.

Storage

70. Storage of reinforcement bars should be carried out alternatively in transverse and longitudinal manner. Not more than four reinforcement bar bundles should be stacked to prevent slippage of bundles, when the bundle is released.

Confine Space Safety

71. No person shall work alone in confined spaces. Works in confined locations shall be carried out along with an escort.

72. Works in confined space shall be carried out with approved work permit and entry to confined space shall be certified as safe by competent person.

Illumination

73. Periodic illumination survey shall be carried out and sufficient illumination shall be ensured at work places as per statutory requirements.

74. Before proceeding to locations with low illumination or areas with artificial illumination, workers shall carry battery operated portable lamps.

Safe Installation of Equipment

75. Equipment shall be installed at such locations that its cable can be laid in safe manner without posing any tripping hazard.

76. Procedure for pipe support erection must be developed such that once installed in position, pipes are clamped in secured manner.

77. Before performing job, inspection of work place shall be carried out to ensure that equipment and materials are installed at the workplace in secured manner.

Communication

78. Three-way communication shall be established between the persons holding the nozzle of high-pressure hose and the pump operator, to prevent fall of person holding the nozzle due to recoil force of sudden pressurization of hose. Pump Operator shall open delivery valves of hose, only after getting signal from the person holding the nozzle. The pump operator shall open the valve slowly with initial pressure not more than 1 kg/cm^2. This should be emphasized during the Industrial Safety training program and pre-job briefings.

79. While performing parallel jobs by multiple agencies, effective communication shall be established between the persons involved.

Housekeeping and Workplace Upkeep

80. While placing materials on platform at height, it should be ensured that work spot is not restricted and personal and material movements are not obstructed.

5.5.2.3 Personal Protective Equipment:

Fall Protection

81. While working or moving at height or on fragile surfaces, helmet and double lanyard safety harness shall be used. One of the lanyards shall always be anchored to a life line or a firm structure. Chinstraps of helmets shall be tied while using helmets. While working on fragile roof, roof top ladder shall be used.

82. Elastic type shoe covers which will fit tightly on feet shall be issued to the workers. Workers shall ensure that shoe covers are worn in tight fit manner.

Material Handling

83. Workers shall wear leather hand gloves, helmets and safety shoes during material handling and while handling materials with sharp edges.

Electrical Safety

84. Arc Flash Hazard Analysis of Switchgear shall be performed to evaluate arc flash incident energy and arc flash protection boundaries in order to define appropriate arc flash protection suit and arc rated PPE for usage when working on electrical switchgear within arc flash protection boundaries. Arc resistant suits and arc rated PPE shall be used while working on electrical switchgear within arc flash protection boundaries. Electrical rated hand gloves shall be used while working on live electrical equipment (IEEE 1584, 2022 [59]; NFPA 70E, 2021 [83]).

Chemical Safety

85. While working on acid and alkali systems, workers shall use acid and alkali resistant cloths and face shield.

Working High Temperature Area

86. While working on or near equipment with high temperature, workers shall wear heat resistant cloths and hand gloves.

Ear Protection

87. While performing jobs in area with noise level of 85 dBA and above, ear muffs or ear plugs shall be used.

88. At the entrance to a high-noise area, a warning sign with recommendations for wearing ear muffs or ear plugs must be shown.

5.6 CONCLUSION

Industrial Safety is a multi-disciplinary subject involving interaction between human, equipment and work environment. Though equipment and work environment can be under the control of organization, human factors are not always under total control, as every individual is unique. It is difficult to design equipment and work environment for each individual worker. Therefore, accident control measures cannot be implemented only through ‘Safety through Design’. In fact, ‘Administrative Controls’ and use of ‘Personal Protective Equipment’ should supplement ‘Safety through Design’.

In order to implement an effective accident control program, all accidents should be investigated and analyzed to identify significant contributors. This can be done effectively by developing accident prediction models. Regression analysis is one of the tools for development of accident prediction models and for identification of significant contributors to accidents there by.

This thesis chapter illustrates the development of accident prediction models on the principal factors/classes of IS-3786-2022, viz. ‘Agencies’, ‘Types of Accidents’ and ‘Locations of Injuries’. Accident prediction models were developed by multiple linear regression analysis and ANOVA for each of the three classes/factors mentioned above from the data of 113 LFHS accidents that occurred in the public sector power company under study, during the period of 10 years from 2006 to 2015. Accident prediction models developed for each class/factor had the number of LFHS accidents caused due to their respective sub classes as the Independent Variables, and the ‘man-days loss on account of LFHS accidents’ was the Dependent Variable for all of them. The models give satisfactory goodness of fit and statistical significance. Validation of the models, using independent data of accidents for the year 2018 demonstrated reasonable prediction capability.

According to our model, significant ‘Agencies’ that caused LFHS accidents were ‘Lifting Machines and Applications’, ‘Pressure Vessels’ and ‘Electrical Installations’. In addition to these, ‘Agencies’ which caused ‘Exposure to or Contact with Electric Current’, ‘Fall of Persons from Height’ and ‘Stepping on Striking against or Struck by Object’; and ‘Agencies’ which caused injury to ‘Head’ and ‘Lower Limb’ were also considered in the analysis.

Similarly, the significant ‘Types’ of LFHS accidents according to our corresponding model were ‘Exposure to or Contact with Electric Current’, ‘Fall of Persons from Height’ and ‘Stepping on, Striking Against or Struck by Object’. In addition to these, ‘Types of LFHS Accidents’ attributed to ‘Lifting Machines and Applications’, ‘Pressure Vessels’ and ‘Electrical Installations’; and ‘Types of LFHS Accidents’ which caused injury to ‘Head’ and ‘Lower Limb’ were also considered in the analysis.

According to our third model, the significant ‘Locations of Injuries’ due to LFHS accidents were ‘Head’ and ‘Lower Limb’. In addition to these, ‘Locations of Injuries’ attributed to ‘Lifting Machines and Applications’, ‘Pressure Vessels’ and ‘Electrical Installations’; and ‘Locations of Injuries’ caused by ‘Fall of Persons from Height’ and ‘Stepping on Striking against or Struck by Object’, were also considered for the analysis.

Our analysis of three principal factors and eight significant contributors indicates that 99 out of 113 LFHS accidents had significantly caused injuries and the consequent ‘man-days loss’. This chapter of the thesis discusses the reasons of the 99 LFHS accidents that were investigated, as well as our recommendations for preventing LFHS accidents through "Safety through Design," "Administrative Controls," and use of "Personal Protective Equipment”. We believe that effective execution of these strategies will prevent accidents and help the organization to achieve its goal of Zero Harm.

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CHAPTER-6

ANALYSIS OF SIGNIFICANT CONTRIBUTORS OF HIGH FREQUENCY AND LOW SEVERITY (HFLS) AND LOW FREQUENCY AND HIGH SEVERITY (LFHS) ACCIDENTS

6.1 PREAMBLE

The current study is based on the analysis of 2066 HFLS accidents and 113 LFHS accidents occurred in an Indian Public Sector Power Company with 11 twin-unit operating stations and 3 twin-unit construction project sites during the period of 10 years from 2006 and 2015. Analysis of HFLS accidents was carried out based on the Indian Standard IS 3786-2022 to arrive at significant contributors of these types of accidents as per 'Agencies', Types of Accidents' and 'Location of Injury'. Whereas accident prediction models were developed on 'Agencies', Types of Accidents' and 'Location of Injury' of Indian Standard IS 3786-2022 for finding significant contributors for LFHS accidents. HFLS accidents being precursors for LFHS accidents, an analysis of significant contributors of these accidents is carried out in this chapter to find out any correlation between the contributors of these accidents,

6.2 ANALYSIS OF SIGNIFICANT CONTRIBUTORS OF HFLS AND LFHS ACCIDENTS WITH RESPECT TO 'AGENCIES'

Table 6.1 gives comparison of significant contributors of HFLS and LFHS accidents with respect to 'Agencies'. Table indicates that 11 out of 14 'Agencies' are common significant contributors for both HFLS and LFHS accidents. This corresponds to about 98% and corroborates the fact that HFLS accidents are precursors or warning signals to LFHS accidents. It also demonstrates the strong correlation existing between contributors of HFLS and LFHS accidents. Since occurrence of HFLS accidents are more than LFHS accidents, identification of root causes and correction of causes of HFLS accidents will give more opportunity to prevent LFHS accidents. This will support the company in its accident prevention program.

Table 6.1

Comparison of Significant Contributors of HFLS and LFHS Accidents as per 'Agency' Classification of IS 3786-2022

Sl. No.	Significant Contributors of HFLS Accidents	Significant Contributors of LFHS Accidents
1.	Working Environment (52%)	Working Environment (38%)
2.	Electrical Installations (10%)	Electrical Installations (14%)
3.	Lifting Machines and Appliances (6%)	Scaffoldings (11%)
4.	Pressure Vessels (4%)	Ladders and Mobile Ramps (10%)
5.	Scaffoldings (3%)	Lifting Machines and Appliances (5%)
6.	Wheeled Means of Transportation (4.5%)	Pressure Vessels (4%)
7.	Tools, Implements and Appliances (3.3%)	Wheeled Means of Transportation (3%)
8.	Dusts, Gases, Liquids and Chemicals (2.5%)	Tools, Implements and Appliances (3%)
9.	Ladders and Mobile Ramps (1.7%)	Dusts, Gases, Liquids and Chemicals (2%)
10.	Metal Working Machines (1.3%)	Metal Working Machines (1%)
11.	Living Animals (1.0%)	Other Miscellaneous Equipment (9%)
12.	Transmission Machinery (0.6%)	
13.	Flying Objects (0.7%)	
14.	Other Miscellaneous Equipment (9.4%)	

6.3 ANALYSIS OF SIGNIFICANT CONTRIBUTORS OF HFLS AND LFHS ACCIDENTS WITH RESPECT TO 'TYPES OF ACCIDENTS'

Table 6.2 gives comparison of significant contributors of HFLS and LFHS accidents with respect to 'Types of Accidents'. Table indicates that 8 out of 11 'Types of Accidents' are common significant contributors for both HFLS and LFHS accidents. This corresponds to about 99% and again corroborates the fact that HFLS accidents are precursors or warning signals to LFHS accidents. It also demonstrates the strong correlation existing between contributors of HFLS and LFHS accidents. Since occurrence of HFLS accidents are more than LFHS accidents, identification of root causes and correction of causes of HFLS accidents will give more opportunity to prevent LFHS accidents. This will support the company in its accident prevention program.

Table 6.2

Comparison of Significant Contributors of HFLS and LFHS Accidents as per 'Types of Accidents' Classification of IS 3786-2022

Sl. No.	Significant Contributors of HFLS Accidents	Significant Contributors of LFHS Accidents
1.	Stepping on or Striking Against or Struck by Objects (28%)	Fall of Persons from Height (48%)
2.	Fall of Objects (27%)	Stepping on or Striking against or Struck by Objects (20%)
3.	Fall of Persons on the Same Level (14%)	Exposure to or Contact with Electrical Current (11%)
4.	Fall of Persons from Height (11%)	Fall of Objects (8%)
5.	Caught in or Between the Objects (8%)	Fall of Persons on the Same Level (5%)
6.	Exposure to or Contact with Electrical Current (5%)	Caught in or Between the Objects (4%)
7.	Exposure to or Contact with Extreme Temperature (3%)	Exposure to or Contact with Extreme Temperature (2%)
8.	Exposure to or Contact with Harmful Substances (3%)	Exposure to or Contact with Harmful Substances (2%)
9.	Over Exertions or Wrong Movements (0.4%)	
10.	Explosions (0.2%)	
11.	Others which are not classified elsewhere (0.4%)	

6.4 ANALYSIS OF SIGNIFICANT CONTRIBUTORS OF HFLS AND LFHS ACCIDENTS WITH RESPECT TO 'LOCATIONS OF INJURY'

Table 6.3 gives comparison of significant contributors of HFLS and LFHS accidents with respect to 'Locations of Injury'. Table indicates that 'Locations of Injury' for HFLS and LFHS accidents identical. This again corroborates the fact that HFLS accidents are precursors or warning signals to LFHS accidents. It also demonstrates the strong correlation existing between contributors of HFLS and LFHS accidents. Since occurrence of HFLS accidents are more than LFHS accidents, identification of root causes and correction of causes of HFLS accidents will give more opportunity to prevent LFHS accidents. This will support the company in its accident prevention program.

Table 6.3

Comparisons of Significant Contributors of HFLS and LFHS Accidents as per 'Locations of Injury' Classification of IS 3786-2022

Sl. No.	Significant Contributors of HFLS Accidents	Significant Contributors of LFHS Accidents
1.	Head (27%)	Head (27%)
2.	Upper Limb (19%)	Lower Limb (24%)
3.	General Injuries' or on 'Unspecified Locations of Injury (19%)	Upper Limb (22%)
4.	Lower Limb (17%)	Multiple Locations (13%)
5.	Multiple Locations (17%)	Trunk (9%)
6.	Trunk (1%)	General Injuries' or Unspecified Locations of Injury' (5%)

6.5 DISCUSSION AND RECOMMENDATIONS

Analysis of significant contributors of HFLS and LFHS accidents with respect to 'Agencies', 'Types of Injuries' and 'Locations of Injuries' indicate that most of the contributors are common for both types of accidents. Also, it infers that there exists a strong correlation between the contributors of HFLS and LFHS Accidents. This could be a study subject for future works. HFLS accidents being warning signals for an impending LFHS accident, it is essential to address the causes of HFLS accidents to prevent LFHS accidents.

6.6 CONCLUSION

There is a strong correlation between the contributors of HFLS and LFHS accidents. Hence, causes of all HFLS accidents should be addressed to prevent LFHS accidents or reduce the severity of LFHS accidents. **A correlation analysis on HFLS and LFHS causes and contributors could be a subject for future researches.**

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CHAPTER-7

SAFETY PERCEPTION SURVEY ON ACCIDENT PREVENTION AND CONTROL

7.1 PREAMBLE

An organization's safety is determined by its employees' perceptions of workplace safety. The perception of workplace safety by employees has a big impact on accident prevention and control. In reality, employees' perceptions of accident prevention and control, mirror those of the organization. A survey on perception of employees on accident prevention and control helps to understand the overall culture prevailing in the organization towards accident prevention and control. Corrective measures on weak attributes of organizational safety culture, support organization in accident prevention (Ryan D., 2009 [100]; Pisharody et al., 2021 [93]).

Safety climate, workgroup size, management support, colleague support, supervisory support, workplace safety procedures, and management commitment to workplace safety are among the organizational factors that are considered to play a substantial role in the likelihood of accidents. The underlying principles, standards, attitudes, and practices that exist within the organization and among individuals to ensure that safety-related issues are given the attention needed are referred to as organizational safety culture (Ryan D., 2009 [100]; Pisharody et al., 2021[93]).

If safety performance isn't measured, it is impossible to manage it. Organizations miss out on future improvements by failing to measure safety performance. A safety perception survey is a method for evaluating safety performance in relation to an organization's existing safety culture. Employees' collective expertise on accident prevention and control can be tapped through safety perception survey. A safety perception survey aids in the identification of elements that impact safety culture and behavior. Once these variables are identified, the activities necessary to attain safety excellence can be determined (Ryan D., 2009 [100]; Pisharody et al., 2021[93]).

According to Ryan D. (2009 [100]) and Pisharody et al. (2021 [93]), safety Perception surveys involve the following steps:

1. Development of Survey Questionnaire
2. Selection of Sample Size
3. Conduct of Test Survey
4. Communication of Intentions of Survey
5. Administration of Survey Questionnaire
6. Analysis of Safety Perception Survey Data
7. Validation of Safety Perception Survey Results

The following sections give details of safety perception survey carried out in our study on the Public Sector Power Company.

7.2 DEVELOPMENT OF SURVEY QUESTIONNAIRE

The first step for the survey was development of survey questionnaire. Survey questions were developed in a such way that those were understood by all the respondents and were clear to them. Each question consisted of multiple choices based on Likert scale with expected response from the most positive to the least positive as given below (Ryan D., 2009 [100]; Pisharody et al., 2021 [93]):

1. Strongly Agree
2. Agree
3. Do Not Know
4. Disagree
5. Strongly Disagree

The questions were designed to allow the respondent to choose from a multiple choice. With higher and lower levels of agreement, responses of 'Strongly Agree' and 'Agree' revealed the existence of a good safety culture. Similarly, responses of 'Strongly Disagree' and 'Disagree' transmitted stronger and lesser levels of disagreement, highlighting areas where improvement is needed. Corrective steps were required for any attribute with less than 90% agreement across all samples (Pisharody et al., 2021 [93]).

Table 7.1 gives the questionnaire used by us for the 'Safety Perception Survey on 'Accident Prevention & Control' (Pisharody et al., 2021 [93]).

Table 7.1:

Questionnaire for Safety Perception Survey on Industrial Accident Prevention & Control (Pisharody et al.; 2021 [93]).

Sl. No.	**Description of Question**	**Employee Perception (Put 'X' at the appropriate Column)**				
		Strongly Agree	**Agree**	**Neither Agree nor Disagree**	**Disagree**	**Strongly Disagree**
Employee Safety Involvement						
1.	Employees can raise safety issues and hazards without fear.					
Safe Work Environment						
2.	Equipment and tools available at the site are safe for use.					
Organizational Safety Leadership						
3.	Managers are committed to take prompt corrective actions on safety issues.					

Sl. No.	Description of Question	Employee Perception (Put 'X' at the appropriate Column)				
		Strongly Agree	Agree	Neither Agree nor Disagree	Disagree	Strongly Disagree
Safety Training and Coaching						
4.	JHAs and Safe Work Procedures are available for all hazardous jobs.					
5.	Employees are trained and coached on safe work procedures for the jobs.					
6.	Compliance to Safe Work Procedures and JHAs is ensured while performing jobs.					
Hazard Identification and Corrective Action Program						
7.	Safety Related Deficiencies are corrected promptly.					
8.	Whenever any job is planned, hazards are identified and corrective measures are taken.					
Accident Investigation and Corrective Action						
9.	All accidents are reported and investigated					
10.	Corrective actions are taken on all accidents to prevent recurrence.					

Sl. No.	Description of Question	Employee Perception (Put 'X' at the appropriate Column)				
		Strongly Agree	Agree	Neither Agree nor Disagree	Disagree	Strongly Disagree
Honesty						
11.	Employees work safely even when they know that they are not being watched.					
Importance to Safety						
12.	Employees consider that sometimes it is necessary to ignore safety issues to perform jobs.					
13.	Supervisors always insist and enforce safe work practices while working jobs.					
Strive for Excellence						
14.	Management always looks for engineering solutions to address safety issues.					
15.	Required type and quantity of Personal Protective Equipment are available to perform jobs.					

Designation of Questionnaire Filling Person

7.3 SELECTION OF SAMPLE SIZE

It is desirable to include all employees in the survey, so that everyone gets an opportunity to respond and express his or her perception. This also gives each employee a sense of participation. Most importantly, more the number of participants, higher the reliability of survey to represent organization's perception correctly. However, in a big organization, it is impractical to carry out survey of large number of employees, as it becomes time consuming. Analysis of collected information would also be difficult due to large quantity of data. In such cases, it is advantageous to go for sampling survey. We opted for it and the sample size was determined statistically based on the desired confidence level (Cochran W.G, 2008 [34]; Pisharody et al., 2021 [93]).

There were about 11,000 employees in the Public Sector Power Company, and we determined the sample size through the following two steps (Cochran W.G, 2008 [34]; Pisharody et al., 2021 [93]).

1. Calculation of sample size for the infinite population.
2. Adjustment of sample size to the required population.

7.3.1 Calculation of Sample Size for the Infinite Population

Sample size for infinite population was calculated by the following formula:

$$S = \frac{(\text{Z-Score})^2 * p * (1-p)}{(m)^2}$$

Where

S - Sample size for infinite population

Z - Z-Score

p - Population proportion, assumed to be 50% or 0.50

m - Margin of Error. Generally, the Margin of Error is considered as 5% or 0.05.

Z-Score is determined based on confidence level. Confidence level is the probability of a parameter falling within the specified range of values. **Table 7.2** gives Confidence Levels and Z-Scores. We considered a Confidence Level of 95% and corresponding Z-Score of 1.960.

Table 7.2:

Confidence Levels and Z Scores

Confidence Levels	Z Scores
90%	1.645
95%	1.960
99%	2.576

Margin Error is a small amount allowed for miscalculation or change of circumstances. Margin of Error considered by us was 5% or 0.05 as per standard assumption.

With the above values, we have calculated the sample size for infinite population as given below:

$$S = \frac{(Z\text{-Score})^2 * p * (1-p)}{(m)^2}$$

Z - 1.960

p - 0.50

m - 0.05

$$S = \frac{(1.960)^2 * 0.5 * (1-0.5)}{(0.05)^2} = 384.16$$

Therefore, **sample size estimated for infinite population was 384.16**

7.3.2 Adjustment of Sample Size to the Required Population

Adjustment of sample size for required population was determined by using the formula given below:

$$\text{Adjusted Sample Size} = \frac{(S)}{[1+((S-1)/\text{Population})]}$$

Sample size estimated for infinite population (S) = 384.16

Population = Number of employees in the Public Sector Power Company = 11, 000.

$$\text{Adjusted Sample Size} = \frac{(384.16)}{[1+((384.16-1)/11000)]}$$

$$= \frac{(384.16)}{(1+0.03483)}$$

$$= 371.23$$

$$= 371$$

Therefore, **the required sample size estimated for a population size of 11000 was 371.**

7.4 CONDUCT OF TEST SURVEY

Before the actual survey, a test survey of the sample was conducted in a group of **10 persons** to confirm that the questions were clearly understood and read correctly by the respondents. The feedback of test survey was included in the final questionnaire, and necessary changes were made before it was distributed (Pisharody et al.; 2021 [93]).

7.5 COMMUNICATION OF INTENTIONS OF SURVEY

Before submitting the questionnaire to the employees, the goal of the survey was explained to them. Information on accident prevention and control was sought in an anonymous manner in order to acquire an unbiased opinion without fear of retaliation (Pisharody et al.; 2021 [93]).

7.6 ADMINISTRATION OF SURVEY QUESTIONNAIRE

The survey was carried out by sending the questionnaire by emails to the employees comprising of managers, engineers, officers, supervisors and laborers of the Public Sector Power Company. **Though the statistically estimated sample size was 371, total 410 filled questionnaires were received from the participants and all 410 samples were considered for the analysis** (Pisharody et al.; 2021 [93]).

7.7 ANALYSIS OF SAFETY PERCEPTION SURVEY DATA

All the filled 410 questionnaires were analyzed with respect to the number of positive agreements, neutral agreements and negative agreements. Employee perceptions on attributes with 'Strongly Agree' and 'Agree' responses were considered as positive agreements, while the employee perceptions on attributes with 'Strongly Disagree' and 'Disagree' opinions were considered as negative agreements. Employee perceptions on attributes with 'Neither Agree nor Disagree' opinions were considered neutral agreements. Results of our survey are given in **Table 7.3** and **Table 7.4** (Pisharody et al.; 2021 [93]).

Table 7.3 gives the number of positive and negative agreements by the employees, as per the Likert Scale, in each attribute and **Table 7.4** shows percentage of positive and negative agreements in each attribute. Corrective actions are recommended by us on questions in which positive response was less than 90% (Pisharody et al.; 2021 [93]).

Table 7.3:

Number of Positive and Negative Agreements by the Employees during the perception survey on Industrial Accident Prevention & Control

Sl. No.	Description of Question	Employee Perception					Total
		Strongly Agree	Agree	Neither Agree nor Disagree	Disagree	Strongly Disagree	
Employee Safety Involvement							
1.	Employees can raise safety issues and hazards without fear	326	78	1	5	0	410
Safe Work Environment							
2.	Equipment and tools available at the site are safe for use.	230	174	4	1	1	410
Organizational Safety Leadership							
3.	Managers are committed to take prompt corrective actions on safety issues.	218	157	29	6	0	410
Safety Training and Coaching							
4.	JHAs and Safe Work Procedures are available for all hazardous jobs.	204	165	32	7	2	410
5.	Employees are trained and coached on safe work procedures for the jobs.	233	151	15	10	1	410
6.	Compliance to Safe Work Procedures and JHAs is ensured while performing jobs.	195	181	20	12	2	410

Sl. No.	Description of Question	Employee Perception					Total
		Strongly Agree	Agree	Neither Agree nor Disagree	Disagree	Strongly Disagree	
Hazard Identification & Corrective Action Program							
7.	Safety Related Deficiencies are corrected promptly.	208	157	19	24	2	410
8.	Whenever any job is planned, hazards are identified and corrective measures are taken.	185	188	20	15	2	410
Accident Investigation and Corrective Action							
9.	All accidents are reported and investigated	241	154	10	5	0	410
10.	Corrective actions are taken on all accidents to prevent recurrence.	241	150	16	3	0	410
Honesty							
11.	Employees work safely even when they know that they are not being watched.	163	186	38	22	1	410
Importance to Safety							
12.	Employees consider that sometimes it is necessary to ignore safety issues to perform jobs.	40	78	39	133	120	410
13.	Supervisors always insist and enforce safe work practices while working jobs.	140	199	41	22	8	410

Sl. No.	Description of Question	Employee Perception					Total
		Strongly Agree	Agree	Neither Agree nor Disagree	Disagree	Strongly Disagree	
Strive for Excellence							
14.	Management always looks for engineering solutions to address safety issues.	170	194	32	13	1	410
15.	Required type and quantity of Personal Protective Equipment are available to perform jobs.	195	184	17	12	2	410

Table 7.4:

Percentage of Positive and Negative Agreements by the Employees during the perception survey on Industrial Accident Prevention& Control

Sl. No.	Description of Question	Employee Perception in Percentage (%)			Total
		Positive Agreement	Neutral Perception	Negative Agreement	
		Strongly Agree and Agree	Neither Agree Nor Disagree	Disagree and Strongly Disagree	
Employee Safety Involvement					
1.	Employees can raise safety issues and hazards without fear	98.54%	0.24%	1.22%	100%
Safe Work Environment					
2.	Equipment and tools available at the site are safe for use.	98.54%	0.98%	0.49%	100%

Sl. No.	Description of Question	Employee Perception in Percentage (%)			Total
		Positive Agreement	Neutral Perception	Negative Agreement	
		Strongly Agree and Agree	Neither Agree Nor Disagree	Disagree and Strongly Disagree	
Organizational Safety Leadership					
3.	Managers are committed to take prompt corrective actions on safety issues.	91.46%	7.07%	1.46%	100%
Safety Training and Coaching					
4.	JHAs and Safe Work Procedures are available for all hazardous jobs.	90.00%	7.80%	2.20%	100%
5.	Employees are trained and coached on safe work procedures for the jobs.	93.66%	3.66%	2.68%	100%
6.	Compliance to Safe Work Procedures and JHAs is ensured while performing jobs.	91.71%	4.88%	3.41%	100%
Hazard Identification & Corrective Action Program					
7.	Safety Related Deficiencies are corrected promptly.	**89.02%**	**4.63%**	**6.34%**	100%
8.	Whenever any job is planned, hazards are identified and corrective measures are taken.	90.98%	4.88%	4.15%	100%
Accident Investigation and Corrective Action					
9.	All accidents are reported and investigated	96.34%	2.44%	1.22%	100%
10.	Corrective actions are taken on all accidents to prevent recurrence.	95.37%	3.90%	0.73%	100%

Sl. No.	Description of Question	Employee Perception in Percentage (%)			Total
		Positive Agreement	Neutral Perception	Negative Agreement	
		Strongly Agree and Agree	Neither Agree Nor Disagree	Disagree and Strongly Disagree	
Honesty					
11.	Employees work safely even when they know that they are not being watched.	**85.12%**	**9.27%**	**5.61%**	100%
Importance to Safety					
12.	Employees consider that sometimes it is necessary to ignore safety issues to perform jobs.	**28.78%**	**9.51%**	**61.71%**	100%
13.	Supervisors always insist and enforce safe work practices while working jobs.	**82.68%**	**10.00%**	**7.32%**	100%
Strive for Excellence					
14.	Management always looks for engineering solutions to address safety issues.	**88.78%**	**7.80%**	**3.41%**	100%
15.	Required type and quantity of Personal Protective Equipment are available to perform jobs.	92.44%	4.15%	3.41%	100%

It can be seen from Table 7.4 that in our survey, **following attributes received less than 90% positive agreements in the employee perception** (Pisharody et al.; 2021 [93]):

1. **Hazard Identification & Corrective Action Program - Safety Related Deficiencies are Corrected Promptly**

   Safety Related Deficiencies (SRDs) are detected during plant safety inspections, when employees perform their jobs, or during job observations by independent agencies other than the performing employees. When these deficiencies interact with humans, there can be accidents. Safety Related Deficiency Management System (SRDMS) is used to report and track the SRDs. However, if SRDs are not corrected as soon as possible, the deficiencies will remain in the workplace, thus will increase the risk of accidents. **Figure 7.1 gives pictorial depiction of our survey result, which indicates that 89.02% of the employees believed that SRDs were corrected promptly, which is slightly below the acceptance level of 90%**. This implies that SRDMS needs to be reinforced more in order to correct the SRDs promptly.

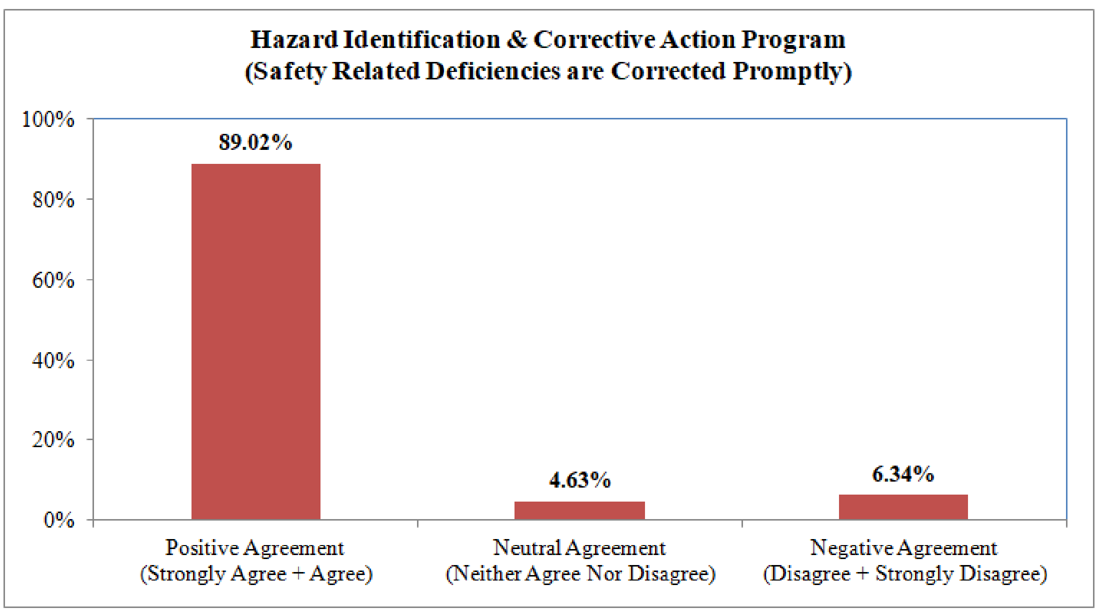

Figure 7.1: Hazard Identification & Corrective Action Program - Safety Related Deficiencies are corrected promptly

2. **Honesty - Employees work safely even when they know that they are not being watched**

When people perform their duties in a safe manner by following safe work procedures, in accordance with the recommendations of Job Hazard Analysis, even in the absence of supervision, an organisation is said to have a good Safety Culture. **Figure 7.2 gives pictorial depiction of our survey result, which indicate that 85.12% of the employees believed that employees work safely even when they know that they are not being watched, a percentage which is below the acceptance level of 90%.** Therefore, management should implement additional safety culture initiatives to raise employee awareness and ensure that Safe Work Procedures and Job Hazard Analysis recommendations are followed. This is a continuous process, and both line managers and employees must work together to achieve it. During safety training programs, pre-job briefings, pre-employment personal talks, and toolbox talks, as well as during job execution, line managers and supervisors should emphasize the importance of adhering to safety requirements.

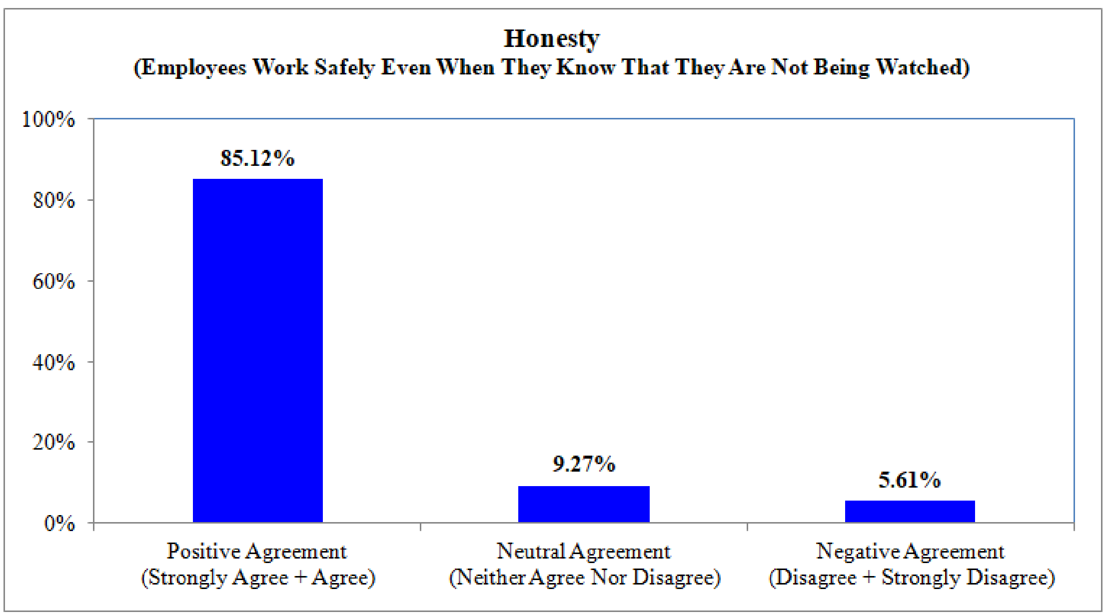

Figure 7.2: Honesty - Employees work safely even when they know that they are not being watched

3. Importance to Safety - Employees consider that sometimes it is necessary to ignore safety issues to perform jobs

A safety culture needs a top-down approach to safety concerns. In general, organizations adhere to the 'Safety First, Production Next' approach. However, due to job pressure, this guideline is not always followed. Production-related considerations take precedence over safety-related issues in such circumstances. This may result in non-compliance with safe work procedures, non-compliance with Job Hazard Analysis recommendations, delays in addressing safety-related deficiencies, non-use of required personal protective equipment, insufficient employee safety training and awareness programs, and non-compliance with conduct of safety committee meetings and other statutory requirements, among other things. In such circumstances, accident investigations may not be thorough enough to determine the root causes, resulting in the occurrence and recurrence of accidents. **Figure 7.3 gives pictorial depiction of our survey result, which indicates that only 61.71% of the employees consider that it is necessary to comply with safety issues to perform jobs, which is below the acceptance level of 90%.** This indicates that the organization should put more effort into improving safety culture and emphasizing it during training sessions, safety committee meetings, and management meetings to ensure that no one disregards safety requirements. To encourage employees to complete jobs in a safe manner, the organization may implement an incentive plan for adherence to safety requirements during job execution.

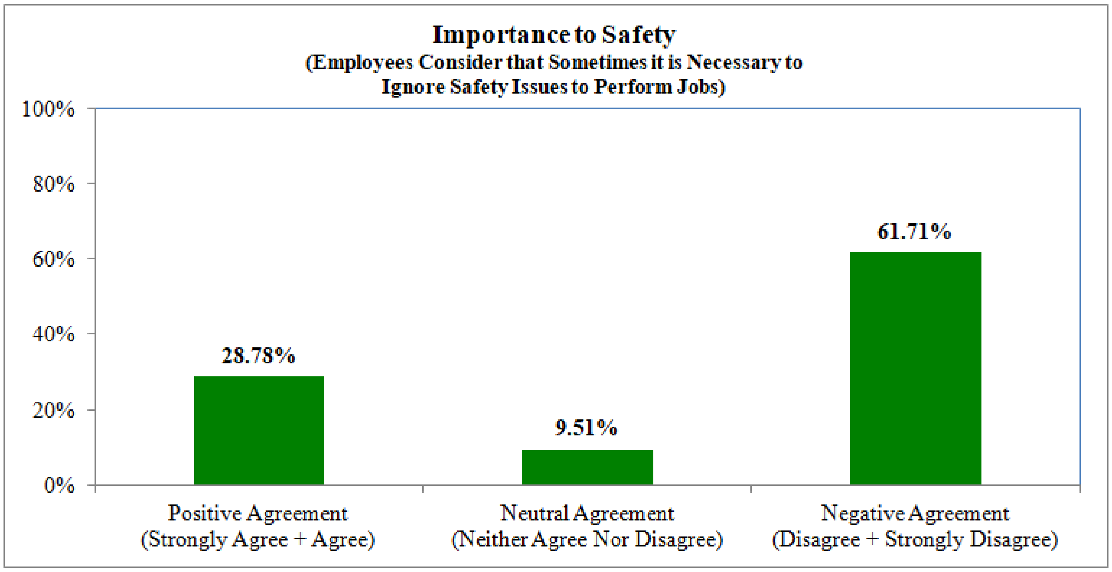

Figure 7.3: Importance to Safety - Employees consider that sometimes it is necessary to ignore safety issues to perform jobs

4. **Importance to Safety - Supervisors always insist and enforce safe work practices while working jobs**

Work supervisors play a critical role in enforcing safety regulations during the execution of a job. During safety training programmes, pre-job briefings, pre-employment personal talks or toolbox talks, and training programmes, supervisors must insist on adherence to safety requirements. In addition, if any employee is in a position to violate safety standards, supervisors must intervene to prevent such breaches and enforce safety requirements so that the job is done safely. **Figure 7.4 gives pictorial depiction of our survey result, which indicates that only 82.68% of the employees believe that supervisors always insist and enforce safe work practices while working jobs, which is below the acceptance level of 90%**. This means that supervisors should place a higher priority on safety throughout job execution and enforce safety requirements. For supervisors and line managers, management may conduct a training and awareness program on the role of supervisors in enforcing safety requirements.

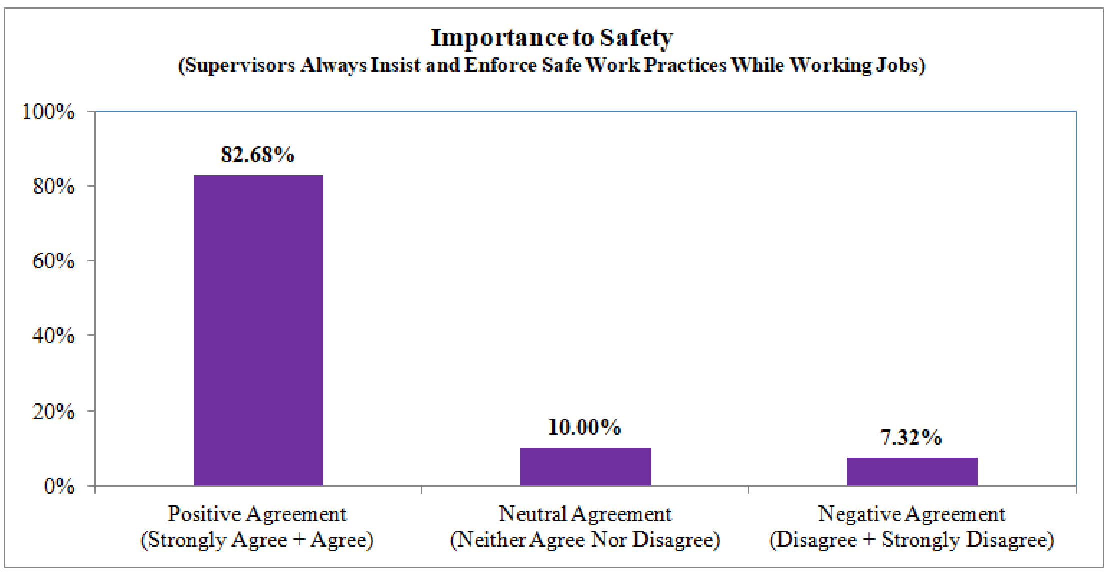

Figure 7.4: Importance to Safety - Supervisors always insist and enforce safe work practices while working jobs

5. **Strive for Excellence - Management always looks for engineering solutions to address safety issues**

Safety is a function that is managed by management and implemented by employees. As a result, management commitment is critical in developing a strong safety culture within the organization. The hierarchy of hazard control should be followed to find solutions to safety challenges. Management efforts should focus on engineering solutions to execute safety measures. 'Safety through Design,' which encompasses elimination, substitution, and engineering control, can help to achieve this. **Figure 7.5 gives pictorial depiction of our survey result, which indicates that only 88.78% of the employees believe that management always looks for engineering solutions to address safety issues, which is below the acceptance level of 90%.** 'Safety through Design' has the potential to improve management's approach to address safety issues.

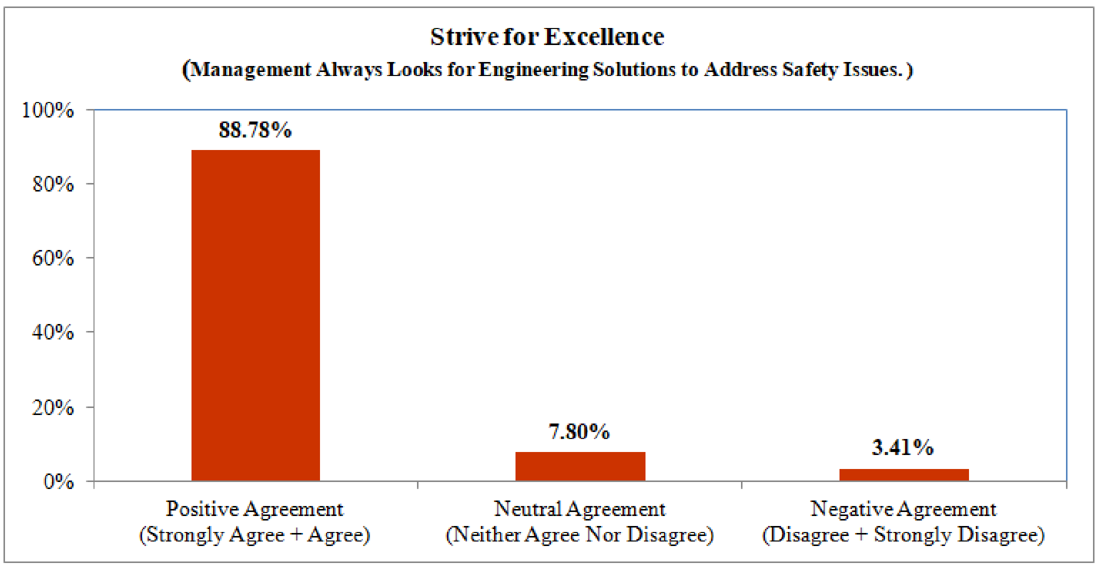

Figure 7.5: Importance to Safety - Supervisors always insist and enforce safe work practices while working jobs

7.8 VALIDATION OF SAFETY PERCEPTION SURVEY RESULTS

The results of our safety perception survey were discussed with a focused group of employees. Their observations on practices being followed at work locations were also corroborating with our survey results (Pisharody et al.; 2021 [93]).

7.9 DISCUSSION AND RECOMMENDATIONS

Our safety perception survey revealed the following weaknesses, for which corrective actions are required to improve safety culture and, hence to establish a robust system for accident prevention and control in the Public Sector Power Company under the study (Pisharody et al.; 2021 [93]):

1. Hazard Identification & Corrective Action Program - Safety related deficiencies are corrected promptly.
2. Honesty - Employees work safely even when they know that they are not being watched.
3. Importance to Safety - Employees consider that sometimes it is necessary to ignore safety issues to perform jobs.
4. Importance to Safety - Supervisors always insist and enforce safe work practices while working jobs.
5. Strive for Excellence - Management always looks for engineering solutions to address safety issues.

The above should be addressed through implementation of the recommendations made, by means of ‘Safety through Design’, ‘Administrative Controls’ and use of ‘Personal Protective Equipment”, which are as detailed below:

Safety through Design

Safety-Related Deficiencies should be rectified as soon as possible, taking into account the hierarchy of hazard control as outlined by 'Safety through Design.' Elimination, substitution, and engineering controls should be used to address safety concerns at the design stage. If the Safety Related Deficiencies were not anticipated during the design phase, such deficiencies should be corrected subsequently through design changes.

Administrative Controls

1. Safety Related Deficiency Management System (SRDMS) should be strengthened even more by ensuring that SRDs are promptly corrected based on their safety significance. Critical and significant SRDs with potential for loss of life, injury or property loss should be addressed on priority when compared SRDs for safety improvement.

2. During pre-job briefings, pre-employment personal talks, and toolbox talks, as well as during job execution, line managers and supervisors should emphasize the importance of adhering to safety requirements stipulated in the procedures and Job Hazard Analysis.

3. Employees' safety culture should be strengthened by highlighting it at training sessions, safety committee meetings, and management meetings, so that no one disregards safety requirements.

4. To encourage employees to complete jobs in a safe manner without ignoring safety requirements, the company may implement an incentive plan for adherence to safety requirements during job execution.

5. Supervisors and line managers should be given training and be made aware of their role and responsibilities in enforcing safety requirements.

Personal Protective Equipment

Employees should be motivated and encouraged through training and awareness programs to develop a culture that promotes adherence to the safety requirements and use of personal protective equipment even in the absence of supervision.

7.10 CONCLUSION

Safety perception survey on accident prevention and control is a method to understand organizational culture on accident prevention and control. It makes it easier to identify weak safety culture attributes within an organization that contribute to accidents. Identifying the weak attributes enables the organization to address the causes and enhance the organization's accident prevention and control culture. This chapter presented details of our safety perception survey. The responses received on our survey, their analysis and our observations on them are presented in this thesis chapter. This chapter also gives our recommendations, especially the accident control measures to be taken by 'Safety through Design', 'Administrative Controls' and 'Personal Protective Equipment'. We believe that effective execution of these strategies will prevent accidents and help the organization to achieve its goal of **Zero Harm.**

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CHAPTER-8

CONCLUSIONS AND SUGGESTIONS FOR FURTHER WORKS

Industrial safety enforcement checks and prevents not only loss of life or permanent disability of personnel, but also their minor injuries, stoppage of work and loss of production. Although all types of industries are getting increasingly more aware and sophisticated about safety, accidents continue to occur and even recur. This clearly implies that the present methods for accident prevention and control through identification and rectification of hazards in work environment are not effective enough to prevent accidents. Therefore, the need for alternative methods to further reinforce and upgrade accident prevention programs is increasingly being recognized by the industries. Accident prediction models are presently being considered to be at the forefront of such alternative methods.

With this perspective, a study was carried out on all, near misses and industrial accidents that happened in a period of 10 years from 2006 to 2015, in a prominent Public Sector Power Company in India, at its 11-twin unit Operating Stations and 3-twin unit Construction Project sites. The company is involved in the design, construction, commissioning, and operation of power plants in India, and it has a well-established organizational set-up to comply with applicable legislation and regulations regarding industrial safety. The company has a system for reporting and correction of Safety Related Deficiencies (SRDs) through Safety Related Deficiency Management System (SRDMS). The company also has an Accident Reporting System for accident investigation and rectification of causes of accidents. Yet accidents continue to occur and recur there. The near misses and industrial accidents that happened in the above said period of 10 years were studied in detail in the present work, with a view to establish the scope of alternative methods in the existing scheme of safety mechanisms of the industry.

The HFLS accidents were studied and analyzed in the present work according to the criteria of Agencies, Types of Accidents and Locations of Injuries, as prescribed by the Indian Standard IS-3786-2022. This though being quite detailed, **the prime achievements of the present doctoral work were the development of accident prediction models on LFHS accidents and the analysis of LFHS accidents to identify significant contributors to accidents.** It may be noted that while extensive literature is available for accident prediction models on road accidents, crash models and chemical accidents, literature on accident prediction models on conventional industrial accidents is very sparse. Besides these, **a Safety Perception Survey on Accident Prevention & Control was also conducted under the present work among the employees of the Public Sector Power Company to identify significant organizational contributors of accidents.**

All the above-mentioned segments of the present doctoral study have helped to identify accident prevention and control measures that would upgrade the Public Sector Power Company's accident prevention and control program. The upgradation can be achieved by the three-pronged implementation, namely, through 1) ‘Safety through Design’, 2) reinforcement of ‘Administrative Controls’ and 3) strengthening the use of ‘Personal Protective Equipment’. While the implementation of 1) and 3) are through engineering solutions, 2) provides for the administrative ones. The details of which are provided below.

The HFLS accidents were analyzed to identify significant ‘Agencies’, ‘Types of Accidents’ and ‘Locations of Injuries’ contributing to HFLS accidents. The ‘**Significant Agencies’** that contributed HFLS accidents were **‘**Working Environments’, ‘Electrical Installations’, ‘Lifting Machines and Appliances’, ‘Pressure Vessels’ and ‘Scaffoldings’. **Significant ‘Types of Accidents’** that contributed HFLS accidents were ‘Stepping on, Striking against or Struck by Objects’, ‘Fall of Objects’, ‘Fall of Persons on the Same Level’, ‘Fall of Persons from Height’, ‘Caught in or Between the Objects’ and ‘Exposure to or Contact with Electrical Current’. The **Significant ‘Locations of Injuries’** for HFLS Accidents were ‘Head’, ‘Upper Limb’, ‘General Injuries or Unspecified Locations of Injury’, ‘Lower Limb’, ‘Multiple Locations’ and ‘Trunk’. HFLS accidents being precursors of LFHS accidents, corrective actions on significant contributors of HFLS accidents will prevent accidents and upgrade accident prevention program in the company.

All the LFHS accidents were analyzed and accident prediction models on ‘Agencies’, ‘Types of Accidents’ and ‘Locations of Injuries’ were developed to identify significant contributors of LFHS accidents. Multiple linear regression analysis and Analysis of Variance (ANOVA) in Microsoft Excel platform was used for the development of accident prediction models. Independent Variables considered in the models were number of LFHS accidents based on ‘Agencies’, ‘Types of Accidents’ and ‘Locations of Injuries’ and Dependent Variable was mandays loss on account of LFHS accidents. The 'Coefficients of Multiple Determination,' i.e. R Square and Adjusted R Square, were used to determine goodness fit of the models, and the statistical significance of the models was determined using F-Test, T-Test, and p-values. **Goodness**

of fit and statistical significance of the models was found to be satisfactory and at least one Independent Variable was found to contribute information for the prediction of Dependent Variable.

Validation of the models was carried out with the independent data for the year 2018. Comparison of observed and estimated man-days loss on account of LFHS accidents during the period from the year 2006 to 2015 and for the year 2018 indicated that estimated man-days loss during the period from 2006 to 2015 is in agreement with the observed man-days loss. **Prediction capabilities of the models on 'Agencies', 'Types of Accidents' and 'Locations of Injuries' were about 33%, 75% and 66% respectively, which are fairly a good result.**

Significant 'Agencies', 'Types' and 'Locations of Injuries' attributed to LFHS accidents were derived from the models. Significant 'Agencies' determined were Lifting Machines and Applications, Pressure Vessels and Electrical Installations; significant 'Types of LFHS Accidents' determined were Exposure to or Contact with Electric Current, Fall of Persons from Height and Stepping on, Striking against or Struck by Object and significant 'Locations of Injuries' due to LFHS accidents were Head and Lower Limb. Analysis of these principal factors and significant contributors indicated that 99 out of 113 LFHS accidents had significantly caused injuries and consequent man-days loss**. All 99 LFHS accidents were further analyzed to identify significant 'Agencies' caused LFHS Accidents, 'Types of LFHS Accidents' and 'Locations of Injuries' due to LFHS Accidents.**

Significant 'Agencies' that caused LFHS Accidents were **'**Working Environments', 'Electrical Installations', 'Scaffoldings', 'Ladders, Mobile Ramps', 'Lifting Machines and Appliances', 'Pressure Vessels', 'Wheeled Means of Transportation' and 'Tools, Implements and Appliances'. **Significant 'Types of LFHS Accidents'** were 'Fall of Persons from Height', 'Stepping on, Striking against or Struck by Objects', 'Exposure to or Contact with Electrical Current', 'Fall of Objects', 'Fall of Persons on the Same Level', Caught in or Between the Objects', 'Exposure to or Contact with Extreme Temperature' and 'Exposure to or Contact with Harmful Substances'. **Significant 'Locations of Injuries'** due to LFHS Accidents were 'Head', 'Lower Limb', 'Upper Limb', 'Multiple Locations' and 'Trunk'.

Since organizational safety depends on its employees' perception on workplace safety, a **safety perception survey on accident prevention and control was conducted among the employees** to understand the overall safety culture prevailing in the company. The **safety perception survey indicated that in order to upgrade accident prevention and control culture in the company, a focused attention needs to be given on Hazard Identification & Corrective Action Program** - Safety related deficiencies are corrected promptly; **Honesty** - Employees work safely even when they know that they are not being watched; **Importance to Safety** - Employees shall always not ignore safety issues while performing jobs and Supervisors shall always insist and enforce safe work practices while working jobs; and **Strive for Excellence** - Management shall always look for engineering solutions to address safety issues.

Effective implementation of corrective measures on significant contributors of HFLS and LFHS accidents will prevent accidents and upgrade accident prevention program in the company. In addition, a focused attention to address weak attributes of safety culture will support its accident prevention program. **Accident preventive and control measures are implemented as per the hierarchy of hazard control** i.e. Elimination, Substitution, Engineering Controls, Administrative Controls and Personal Protective Equipment. The upper tier measures of Elimination, Substitution and Engineering Controls are applied in the design by 'Safety through Design'. However, implementation of workers' safety during the design phase has certain limitations as the individuals involved in the accidents have unique personal characteristics and culture; and everything cannot be anticipated as accidents may happen on conditions unforeseen during the design phase. Therefore, in an effective accident prevention and control program, 'Safety through Design' should be supplemented by 'Administrative Controls' and 'Personal Protective Equipment'. **Measures for prevention and control of accidents by 'Safety through Design', 'Administrative Controls' and 'Personal Protective Equipment' will upgrade accident prevention and control program in the Public Sector Power Company.**

Since the research was carried out at Operating Plants and Construction Projects of the company spread across India, identification of specific engineering solutions by 'Safety through Design' was a challenging task. Therefore, conscious efforts were made for application of engineering methods such as development of accident prediction models, analysis of accidents and safety perception survey; for identification of significant contributors of accidents. **Engineering solutions are recommended by the way of 'Safety through Design', by design modifications in hardware components, and by the use of appropriate 'Personal Protective Equipment'.**

The Engineering solutions have to be customized for local ground conditions. The Engineering solutions recommended by 'Safety through Design' were reinforcement of machine guarding and fencing or barricading of hazardous work locations with caution signage; construction of standard scaffolding and platforms with safe access and measures to protect persons and objects from falling; provision and installation of standard safe ladders; provision of roof top ladders with anchoring facility for lanyards of safety harness while working over the fragile roofs; reinforcement of illumination levels at work locations to meet standard safety requirements, replacement of slippery floors at work locations with anti-skid floors; prevention of rain water accumulation within the plant buildings by provision of rainwater spillage protection; provision of anti-slip device such as pipe shoes while handling pipes at height to prevent fall of pipes due to slippage; use of mechanical means for material handling; securing pipe materials during transportation and storage; insulation of exposed components of electrical circuits and switchgear; provision for earthing and Earth Leakage Circuit Breakers (ELCBs) in electrical circuits; use of standard electrical connecters at the joints in electrical circuits; earthing of scaffoldings and platforms; provision of switchgear designed for arc-protection; erecting barriers on access paths beneath overhead electrical lines to prevent mobile cranes with extended booms from entering; designing cable trays with extra capacity to accommodate more cables for plant modifications; and addressing Safety Related Deficiencies promptly by giving due consideration to the hierarchy of hazard control by 'Safety through Design'.

'Administrative Controls' recommended for application of engineering solutions were reinforcing system isolation and work permit system by ensuring compliance to safety requirements and guaranteed isolation of power source; hazard identification and control measures through Job Hazard Analysis (JHA) and implementation of hazard control measures while performing job through work procedures; reinforcing preventive maintenance and surveillance program on structures, systems and components, ensuring that employees receive safety induction training and a pre-job briefing on safety precautions before being deployed on the job; deploying trained and authorized persons for scaffolding erection and dismantling, working at height, material handing operations and working on electrical equipment, deploying qualified and experienced persons for job supervision and ensuring safety requirements by effective supervision while performing job; inspection and certification of scaffoldings, platforms and ladders for safe use by authorized agencies; installation of ladders in safe and secured position; getting approval from all relevant agencies prior to beginning any excavation work; inspection and testing of cables for ageing and damage on a regular basis, as well as the replacement of aged and damaged cables; conducting Arc Flash Hazard Analysis of the switchgears and provision of arc protection suit and arc rated Personal Protective Equipment while working on electrical switchgears; maintaining safe working clearance from high voltage lines; providing protective covers over the flanges and valves of systems carrying hazardous chemicals; safe segregation of chemicals with qualities that are incompatible during storage and transportation; chaining of gas cylinders in secured manner and ensuring cylinder valve caps or guards during transportation and storage; controlling transient storage of flammable and hazardous materials at work places through permit system; testing and examination of lifting machines and lifting tackles after alteration or repair by competent person; periodic illumination surveys and maintaining adequate lighting at work places in accordance with statutory requirements and emphasizing the importance of adhering to safety requirements of procedure and job hazard analysis during pre-job briefings, pre-employment personal talks and toolbox talks; and during job execution.

‘Personal Protective Equipment’ recommended for application of engineering solutions were use of double lanyard safety harness and helmet while working or moving at height or on fragile surfaces to prevent injuries due to fall of persons; helmets to prevent injuries due to fall of objects and striking hazards; goggles and face shields during hot works; ear muffs or ear plugs while performing jobs in high noise area; leather hand gloves, helmets and safety shoes during material handling; arc resistant suits and arc rated Personal Protective Equipment while working on electrical switchgear; electrical rated hand gloves while working on live electrical equipment; acid or alkali resistant cloth and face shield while working on acid or alkali systems and heat resistant cloths and hand gloves while working on or near equipment with high temperature.

Thus, near misses and accidents were studied in detail, and predictive models were developed successfully in the present work from the LFHS accidents. The prediction capabilities of the models were found to be satisfactory. Validation of the models was achieved satisfactorily with independent data of the same industry for the year 2018.

A lot of scope remains for future research on accident prediction models in conventional industries. It is proposed that in future an exhaustive study may be carried out with more data and validation of predictive models be carried out with independent data from some other similar industry. It is recommended that accident data may be compared with accident data of peer industry. Also, periodic bench marking of accident data may be carried out with domestic and international data of comparable industries. HFLS accidents being precursors and warning signs for LFHS accidents, a correlation analysis of HFLS and LFHS accident data is also proposed for future works to derive a credible relationship between these accidents. Accident prediction models can be developed using Artificial Neural Networks (ANN), and Bayesian Regression approach as well. It is suggested that future research can include development of accident prediction models using Artificial Neural Networks (ANN) and Bayesian Regression analysis.

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LIST OF PUBLICATIONS

As part of research work, following papers were developed as detailed below:

Sl. No.	Description of Paper	Journal Publishing
1.	Accident Prevention and Control - An Overview of Literature. 1. Mr. N. N. Pisharody 2. Dr. Kanchan Bahukhandi, 3. Dr. Prashant S Rawat 4. Dr. R. K. Elangovan	International Journal of Engineering, Science and Mathematics, Vol. 7, Issue 4, April 2018, p 84-97. Indexing: Scopus
2.	Analysis of Industrial Accidents in a Public Sector Power Company – Causes and Preventive Measures 1. Mr. N. N. Pisharody 2. Dr. Kanchan Bahukhandi, 3. Dr. Prashant S Rawat 4. Dr. R. K. Elangovan	Advances in Industrial Safety Springer Transactions in Civil and Environmental Engineering, 2018, P 173-190 Indexing: Web of Science
3.	Organizational Safety Perception Survey - A Tool to Identify and Correct Organizational Contributors for Industrial Accidents 1. Mr. N. N. Pisharody 2. Dr. Kanchan Bahukhandi 3. Dr. Prashant S Rawat 4. Dr. R. K. Elangovan	Advances in Environment Engineering and Management, Springer Proceedings in Earth and Environmental Sciences, 2021, P 477-494. Indexing: Scopus
4.	Development of Accident Prediction Model for Low Frequency and High Severity (LFHS) Industrial Accidents. 1. Mr. N. N. Pisharody 2. Dr. Kanchan Bahukhandi, 3. Dr. Prashant S Rawat 4. Dr. R. K. Elangovan	Envrionmental Pollution and Natural Resource Management', Springer Proceedings in Earth and Environmental Sciences, 2022, P 409-427 Indexing: Scopus

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