Occupational Health and Safety (OHS) Issues in Social Marketing

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BY

GOURI SHANKAR BERIHA

(ROLL NO. 508HS301)

NATIONAL INSTITUTE OF TECHNOLOGY
ROURKELA - 769008, INDIA
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CERTIFICATE

This is to certify that the thesis entitled, "**Occupational Health and Safety (OHS) Issues in Social Marketing**" being submitted by **Gouri Shankar Beriha** for the award of the degree of Doctor of Philosophy (Humanities and Social Sciences) of NIT Rourkela, is a record of bonafide research work carried out by him under our supervision and guidance. Mr. Gouri Shankar Beriha has worked for more than three years on the above problem at the Department of Humanities and Social Sciences, National Institute of Technology, Rourkela and this has reached the standard fulfilling the requirements and the regulation relating to the degree. The contents of this thesis, in full or part, have not been submitted to any other university or institution for the award of any degree or diploma.

Dr. Bhaswati Patnaik
Associate Professor
Department of Humanities and Social Sciences
NIT, Rourkela

Dr. Siba Sankar Mahapatra
Professor
Department of Mechanical Engineering
NIT, Rourkela

Place: Rourkela

Date:

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ABSTRACT

Social marketing has been contributing historically for a better application of public policy, health and safety, environment, education and human rights. Specifically, four major areas that social marketing efforts have focused over the years are health promotion, injury prevention, environmental protection, and community mobilization. Social marketing, at an industrial organization, emphasizes exchange of ideas between the target audience (i.e. the employees) and the marketer (i.e. the employer). This exchange requires that the employees be persuaded to give up the unsafe behaviors that they are accustomed to, to gain an enhanced level of safety with a greater likelihood of preventing injuries in the workplace. In an organizational context, the internal users are treated as customers and marketing inside the organization is an essential part of delivering value to the organization, and ultimately to the end customer. Therefore, effective management strategies are sought to develop the concept of internal marketing with a view to satisfy the employees and in turn, motivate them to do good work and produce a better product or service.

The success of any business enterprise largely depends on its manpower with regard to their professional skill level, positive attitude, job satisfaction, and involvement in quality improvement activities. The important aspect of corporate social responsibility (CSR) is the concern for safety and sound health of the workforce, so that employees feel secured and motivated. The concern becomes manifold when the workforce is exposed to menial tasks and occupational risk situations. To make a safe and conducive environment, an organization must build a solid foundation with a clear vision of the future and specific means by which it will achieve the safety mission of the organization. Safety, health and environment systems needs a continual and systematically managed efforts in order to achieve sustainable growth. Presently, many industries are focusing attention on occupational health and safety (OHS) that may help to achieve competitive advantage.

This research is concerned with the study of OHS issues in the context of injury prevention social marketing. A detailed study on workplace environment and safety climate makes the implementation of various social marketing principles easier. This may also be useful for the purpose of policy formulation on improving OHS in Indian industries. Three industrial sectors such as construction (Type 1), refractory (Type 2) and steel (Type 3) are considered in this study. These industries are generally viewed as hazardous due to usage of heavy equipment, unsafe and primitive tools, injurious materials and dust produced during operation. The study covers such organizations where size in manpower and investment varies, both organized and unorganized workforce exists, both public and private enterprises exist, and the level of sophistication of tools, methods, and work environment in terms of safety is poor.

A study on risk perceptions and understanding of OHS has been conducted in three industrial sectors. Thirty four items are included in the questionnaire through review of related literature and discussion with a focus group. The items are framed to suit the local work practices and culture covering various aspects of OHS. Two hundred eighty eight (or 288) useful responses were tested to examine the validity and reliability of the scale to ensure a quantitative and statistically proven identification of the responses. The test for quantitative variables was conducted by factor analysis on responses using the principal component method followed by varimax rotation to ensure that the variables are important and suitable for the model using SPSS 16.0. Finally, identified factors were again analyzed using discriminant analysis to highlight statistical difference among practices existing in three sectors. The pattern of influence of input parameters on outputs such as injury level and material damage is difficult to establish, possibly due to existence of some nonlinear relationship among them. Therefore, an artificial neural network (ANN) is adopted to carry out sensitivity analysis and important deficient items have been identified. A comparative evaluation on deficient items among three major types of Indian industries has been made. Quality function deployment (QFD) has been used to develop the system design requirements considering the deficient safety items as voice of customers. The interrelation among the system design

requirements is represented in a digraph using Interpretive Structural Modelling (ISM) approach. A predictive methodology for forecasting various types of injuries has been proposed using fuzzy inference system. As fuzzy inference system can be used with little mathematical knowledge and needs only expert knowledge, it can be easily implemented in the field to predict injury types. Further, fuzzy inference system can deal effectively in imprecise and uncertain situations. In order to transfer best practices among various organizations, a benchmarking study has been carried out using data envelopment analysis (DEA). The study finally provides some useful guidelines for the managers for improving safety performance in selected Indian industrial settings.

Keywords: Social marketing; Occupational health and safety (OHS); Corporate social responsibility (CSR); Health promotion; Injury prevention; Environmental protection; Principal component method; Discriminant analysis; Artificial neural network approach (ANN); Quality function deployment (QFD); Interpretive Structural Modelling (ISM); Fuzzy inference system; Data envelopment analysis (DEA).

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GLOSSARY OF TERMS

ACC-O	Accident output
AHP	Analytic hierarchy process
ANN	Artificial neural network
BCC	Banker, Charnes and Cooper
BOCR	Benefits, opportunities, costs and risks
BP	Back propagation algorithm
BPNN	Back propagation neural network
BSC	Balanced score card
CART	Classification and regression trees
CBA	Cost benefit analysis
CCR	Charnes, Cooper and Rhodes
CII	Confederation of Indian industries
CR	Customer requirements
CRS	Constant return to scale
CSI	Construction safety index
CSR	Corporate social responsibility
CTDs	Cumulative trauma disorders
DA	Design activities
DEA	Data envelopment analysis
DEAP	Data envelopment analysis programme
DMU	Decision making unit
DRS	Decreasing return to scale
FANP	Fuzzy analytic network process
FD	Functional descriptions
FIS	Fuzzy inference system
FPP	Fractional programming problem
GSCM	Green supply chain management
HANNP	Human artificial neural network process
HoQ	House of Quality
HSE	Health and safety environment
I	Input
IM	Internal marketing
IRS	Increasing return to scale
ISM	Interpretive structural modeling
KMO	Kaiser-Meyer-Olkin
LBD	Low back disorders
LDA	Linear discriminant analysis
LMS	Least mean square
LPP	Linear programming problem
MBNQA	Malcolm baldrige national quality award
MCDM	Multi criteria decision making
MCGDM	Multi-criteria group decision making
MIMO	Multi input and multi output
MLP	Multilayer perceptron
OHSAS	Occupation health and safety assessment series
OHSMS	Occupational health and safety management Systems
OHS	Occupational health and safety

QFD	Quality function deployment
RMSE	Root mean square error
RTS	Return to scale
SEM	Structural equation model
SE	Scale efficiency
SMEs	Small and medium sized enterprises
SM	Social marketing
SSCM	Sustainable supply chain management
SSIM	Structural self-interaction matrix
SSO	Social security organization
SWOT	Strength, weaknesses, opportunities and threats
TD	Technical descriptions
TE	Technical efficiency
TOPSIS	Technique of positive ideal solution
VOC	Voice of the customer
VOE	Voice of engineering
VRS	Variable return to scale

CHAPTER 1

BACKGROUND AND MOTIVATION

1.1 Introduction

The success of any business enterprise largely depends on its manpower with regard to their professional skill level, positive attitude, job satisfaction, and involvement in quality improvement activities [1]. The important aspect of corporate social responsibility (CSR) is the concern for safety and sound health of the workforce so that employees feel secured and motivated. The concern becomes manifold when the workforce is exposed to menial tasks and occupational risk situations. To maintain a safe and conducive environment, an organization must build a solid foundation with a clear vision of the future and the specific means by which it will achieve it. Safety, health and environment systems need a continual and systematically managed effort in order to achieve sustainable growth. Presently, many industries are focusing attention on occupational health and safety (OHS) that may help to achieve competitive advantage.

Occupational accident and work-related diseases are a worldwide problem. It causes a lot of suffering as well as loss to individual, organization, community and society. Safe, healthy and environmentally sound work environment should be of extreme priority for any socially responsible employer. Such an environment helps to build an organization's public image and contribute to positive public relations. Commitment to employees' safety and health extends beyond economic benefits to long term consequences for workforce and their families. Many companies have implemented occupation health and safety assessment series (OHSAS 18001 systems) as an effort to meet government guidelines and business (export) compulsions resulting in barely any visible impact. The reason being that consideration of organizational requirement, employees' needs and their participation are completely missing during implementation stage.

With the rise of knowledge economy and global competition, the quality of human resources becomes one of the important factors in business competition [2]. But a quality human resource does not guarantee a good job performance; rather willingness and initiation become driving factors for job performance. Employee's satisfaction is one of the factors to influence the willingness and initiation to do a good job. To the management, within a limited business resource, it is very important to understand the factors that influence employee's satisfaction. Employee's satisfaction is always the key point of researcher's interest. Research indicates that employee satisfaction has been shown to be one of the best predictors of turnover [3]. With regard to employee satisfaction, the 'job itself' and 'salary' are big factors in determination of turnover intention [4]. Employee's benefit also influences the level of employee's satisfaction [5]. To retain better human resource means maximization of profit for the organization. So OHS is a key factor for all organizations to satisfy employees. Employees sometimes exposed to disproportionate number of workplace accidents. It seems that a significant proportion of the accident propensity can be attributed to their relatively small level of experience as well as psychosocial variables relating to their stage of life. While these factors influence safety behavior, social marketing aims at improving safety knowledge and changing safety attitudes and perceptions leading to a significant impact on reducing accidents.

Enrichment of OHS can be made possible by treating an organization's internal users as customers. Marketing inside the organization is an essential part of delivering value to the organization and ultimately to the end customer. Hence, it is debated that employees are the first customer whereas external customers are the second customer [6]. Therefore, the effectiveness of management is tied to the concept of internal marketing (IM). Hence, an organization should consider internal customers and external customers with equal importance [7-15]. If an employee is unsatisfied, it is impossible to do good work and also to produce a good product or a good service. Employee's satisfaction also influences the external customer's acknowledgement towards service/product quality [16-19]. As unsatisfied internal customer shall hurt external customer's satisfaction, management must emphasize both internal customer's and external customer's satisfaction [11,20-22]. Therefore, employees are now being considered as important assets of the modern enterprises [23,24].

1.2 Internal and external customer

Customer is vital to an organization as business is to the world [25]. Customer is one who receives services or product from other person or other group. Customer can also be referred as the purchaser, the supplier or in terms of an organization. Customers are divided into two categories - internal and external [26,27]. Internal customer is the employees in an organization responsible to produce products/services. External customer is the consumer or other organization that uses product or service provided by the organization [28-31]. Treating employees as customer and promoting firm policies among employees is known as Internal Marketing (IM) [6,32,33]. The management plays a vital role in ensuring a safe working environment inside the organization. Therefore, top management must realize the importance of safety and commit towards promoting safety practices [34]. Effective internal marketing demands that regular training on safety must be imparted to the employees and develop a methodology to provide a hazard free environment. It is to be noted that promoting good health leads to good business for industrial organizations (Figure 1.1).

Figure 1.1 Marketing planning (Good health vs Good business)
(Source: http://pdf.usaid.gov/pdf_docs/PNABP892.pdf [35])

The key objective of IM is to make aware both the internal and external customer on safety issues and attempts to remove functional barriers to achieve organizational effectiveness [36]. The concept of internal customer suggests that every employee is both a supplier and a customer to other employees within the organization [37].

The quality of product/service delivered to external customer is often determined by the quality of product/service that internal customers (employees) provide each other [38]. The quality of product/service supplied to external customer largely depends on how well the internal customers are satisfied as shown in Figure 1.2. The key issue for satisfaction of internal customers rests on providing safe, healthy and congenial environment inside the organization.

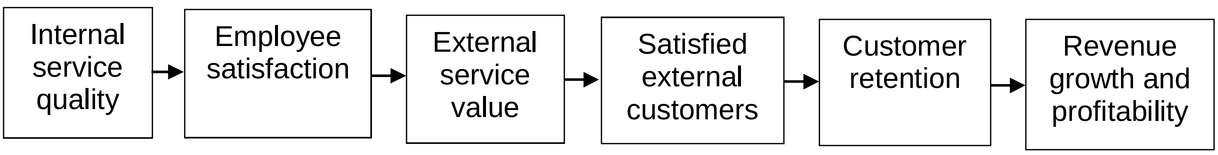


Figure 1.2 The bridge between internal and external customer

This holistic approach incorporating ethical, environmental, legal and social context of marketing is called social marketing (SM) [39]. The social marketing has been contributing, historically, for a better application of public politics, health and safety, environment, education and human rights [40]. SM addresses highly personal issues, invisible benefits, hazards that are difficult to reveal, and changes that take a long time. There are many serious challenges to implement social marketing principles such as cultural conflicts, public scrutiny, multiple audiences and limited budgets to overcome. In contrast to commercial marketing, social marketing is often delivered as limited-edition initiatives rather than an organizational approach and therefore, implementation may neglect cultural, behavioural, structural and procession barriers that SM can address [41]. The present study is concerned with current thinking within social marketing with respect to occupational health and safety (OHS).

1.3 Social marketing and workplace safety

The term “social marketing (SM)” was introduced by Kotler and Zaltman in 1970s [42-44]. In their article, they provided a clear definition for SM, discussed the requisite conditions for effective social marketing, elaborated on the social marketing approach, outlined the SM planning process, and deliberated on the social implications of social marketing. Kotler and Zaltman [44] defined SM as:

> “The design, implementation, and control of programs calculated to influence the acceptability of social ideas and involving considerations of product planning, pricing, communication, distribution, and marketing research”.

SM principles and techniques can be used to benefit society in general and the target audience in particular in several ways. There are four major arenas that social marketing efforts have focused on over the years: health promotion, injury prevention, environmental protection, and community mobilization [43,45-48].

Health promotion - related behavioral issues that could benefit from social marketing include tobacco use, heavy/binge drinking, obesity, teen pregnancy, HIV/AIDS, fruit and vegetable intake, high cholesterol, breast feeding, cancers, birth defects, immunizations, oral health, diabetes, blood pressure, and eating disorders [49].

Injury prevention - social marketing used for injury prevention, often targeting issues such as drinking and driving, responsible cell phone usage, drowning, domestic violence, sexual assault, fire prevention, emergency preparedness, safe gun storage, bike helmets, pedestrian safety, seat belt usage, suicide prevention, workplace injuries (occupational health and safety), hearing loss, and proper use of car seats and booster seats.

Environmental protection - The environmental protection related behavioral issues that could benefit from social marketing include waste reduction, wildlife habitat protection, forest destruction, toxic fertilizers and pesticides, water conservation, air pollution from automobiles and other sources, composting garbage and yard waste, unintentional fires, energy conservation, litter (such as cigarette butts), and watershed protection.

Community mobilization - The community mobilization related behavioral issues that could benefit from social marketing include organ donation, blood donation, voting, literacy, and animal adoption [43,50].

Social marketers are targeting the citizen to bring about individual change as well as policy makers and stakeholders to bring about institutional and social change. The approach provides genuinely new learning and practices in industrial settings. In an organizational setting, as far as injury prevention social marketing initiatives are concerned, the management must have clear vision and objectives for reduction of material damage and injury level so as to improve firm performance. Firm performance leads to net profit for the organization as well as positive image building in the competitive market environment. The management closely looks into the present safety climate and attempts to take decisions to formulate OHS policies or investments to reduce or prevent accidents. The relationships are shown in Figure 1.3.

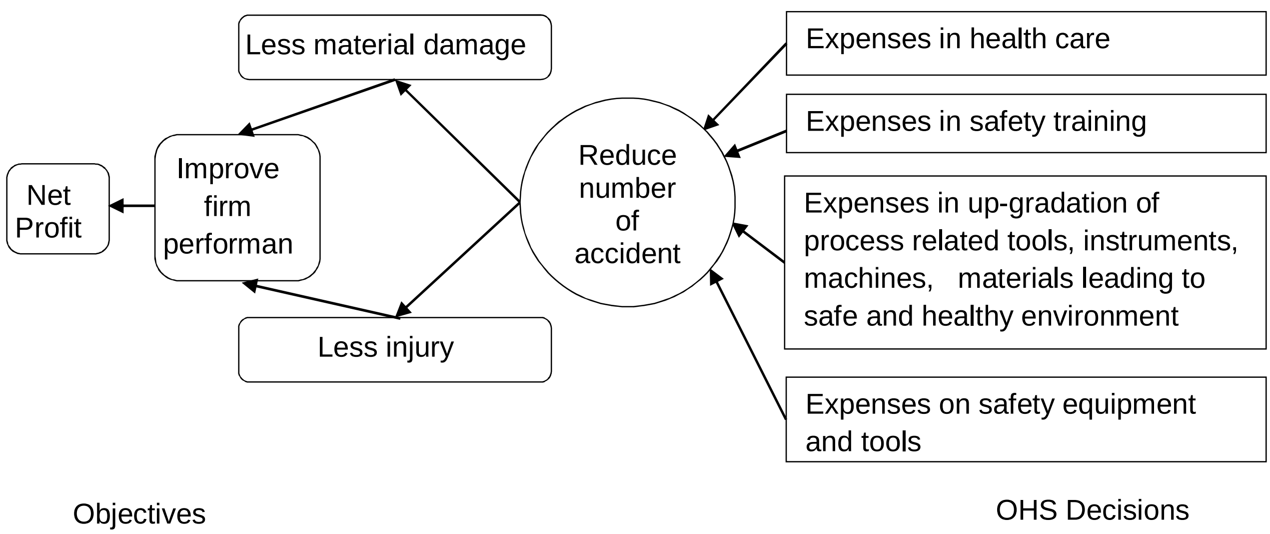


Figure 1.3 Relationship between OHS decisions and profit

1.4 Need for research

OHS is a sensitive issue for each and every organization and it is the responsibility of employees, managers and shareholders in an organization to improve OHS performance. OHS is the discipline concerned with preserving and protecting human and facility resources in the workplace. Now-a-days, industrial accidents often come to notice owing to their frequency all over the world. However, percentage of accidents occurring in manufacturing industries is higher compared to other sectors. The accidents occur because of poor planning for accident prevention, lack of awareness on safety norms, poor training and education of employees, use of old and outdated machines and tools, use of hazard prone materials and poorly designed handling and transport devices, and callousness of management. The sustained injury at the workplace due to industrial accidents directly affects the employees' health and mental agony, concern of their families and causes financial loss to the organization. Therefore, a safe working environment for employees is necessary by adopting organization-wide rules, regulation and policies. The risk of hazard to people and work environment seriously affects production throughout the world. To reduce the imbalance between production and safety climate, it is necessary to focus on policy formulation, prediction of various types of injuries in the workplace, and benchmarking of safety performance. While the primary objective of an organization is to maximize profit, risk management focuses on minimizing losses arising from unwanted and unforeseen loss making events. Such events can result in outcomes such as property damage, liability claims, bodily injury or other consequential losses. OHS standards are mandatory rules and standards set and enforced to eliminate or reduce hazards in the workplace. OHS standards aim to provide at least the minimum acceptable degree of protection that must be extended to every worker in relation to the working conditions and dangers of injury, sickness or death that may arise by reason of his or her occupation.

Thus, in accordance with good business practice and legal requirements, companies of all sizes should ensure that workplace hazards are identified, evaluated and controlled. As safety is regarded as primary concern in an organization, changes in cultural, environmental and investment plans (in safety tools, equipment and health care etc.) need to be enhanced to reflect the importance of safe behavior. Therefore, the present study attempts to develop a framework considering cultural and organizational factors for improving safety performance in industrial settings.

1.5 Choice of industries

The Indian construction, refractory and steel industries are more than a century old. With the passage of time, considerable improvements in these sectors have been observed both in terms of production volume and quality of products. The strength of these industries lies on abundant availability of raw materials as well as skilled and qualified manpower. The safety policy adopted in these industries in India is comparable to the policy followed internationally. However, implementation and monitoring of these policy guidelines is often poor resulting in significant number of accidents, casualties, disabilities, loss to plant and machinery, consequential loss of man-days and production. It calls for an introspection, research and review of the whole situation. It has been observed that adherence to safety measures and policy is lacking due to many factors viz., indifference on the part of management and employees, financial problems, lack of awareness, complicated and slack legal machinery and lack of adequate statutory provisions. Use of outdated technologies, still prevalent in India, intensifies the hazards and risks in the plant. The Indian refractory industry caters to a wide range of end-using sectors such as steel, cement, non-ferrous metals, glass etc. Indian steel and refractory companies pose the difficult challenges in the area of safety, health and environment as compared to many other industries due to complex nature of operation and wide range of hazards associated with them. Despite tremendous technological progress, the question of safety culture and safety at work still are serious issues. Construction sector is treated as a major employment generating sector in India. At the same time, it is associated with a disproportionately high number of job related accidents and diseases. Construction sector is an integral part of infrastructure development which gives tremendous boost to India's economy. Throughout the world, the construction industry is disproportionately more dangerous when compared to other industries [51]. The construction workers are one of the most vulnerable segments of the unorganized labor in India [52]. Workers are being exposed to wide variety of serious hazards. The construction sector is largely characterized by unorganized workforce and hardly follows standard regulations laid down by the government agencies whereas refractory and steel sectors have mixed organized and unorganized workforce. Both refractory and construction firms are usually small in size in terms of manpower and investment. However, few large firms also belong to construction sector having organized workforce.

1.6 Research objectives

Based on the discussions presented in previous sections, this section presents the issues and problems that the thesis attempts to address. The important theme of this research is to propose a framework providing guidelines for the managers in policy formulation to improve safety performance as an essential concept of injury prevention social marketing. The objective of the research is to develop models so that guidelines can be extracted to reduce injury level and material damage in an organization and these guidelines may be useful in formulating safety policy.

The overall objectives of the study are:

1. To design an instrument for judging overall occupational health and safety practices in Indian industries and differentiate among various occupational health related practices industry-wise using discriminant analysis.
2. To identify common deficient items through sensitivity analysis to gain insight into OHS practices in India.
3. To propose a framework for system design using Quality Function Deployment (QFD) with due consideration to deficient items and develop interrelationship among system design requirements.
4. To develop a robust control system for prediction of different types of occupational accidents using various safety related expenses as inputs.
5. To benchmark OHS performance in industrial settings so that best practices can be highlighted and transferred to non-performing units using Data Envelopment Analysis (DEA).

1.7 Organization of the thesis

To meet the above objectives, the thesis is organized into eight chapters including Chapter 1. A brief outline of each chapter is given as follows:

- Chapter 2: Literature review

The purpose of this chapter is to review related literature so as to provide background information on the issues to be considered in the thesis and to emphasize the relevance of the present study. Literature review provides a summary of the base knowledge already available in occupational health and safety issues. This chapter adopts an exploratory approach for identifying and examining a diverse range of issues in OHS. The chapter highlights the strategies and problems associated with various aspects of OHS with relevance to risk and hazard analysis, safety culture and climate, OHS policy, and productivity. Finally, the chapter is concluded by summarizing the OHS implication in industries and possible literature gap so that relevance of the present study can be emphasized.

- Chapter 3: Design of a construct for occupational health and safety

A critical analysis of OHS implementation in India reveals that the dimensions and the variables responsible for improving health and safety norms widely vary across industries and locations. A study on risk perceptions and understanding in OHS has been conducted in three Indian industrial sectors e.g. Construction, Refractory and Steel. Thirty six items (thirty four items referring to perceptions and two items on overall safety performance) form the questionnaire through review of related literature and discussion with a focus group. The questions are framed to suit the local work practices and culture covering various aspects of OHS. Two hundred twenty eight useful responses were tested to examine the validity and reliability of the scale to ensure a quantitative and statistically proven identification of the responses. The test for quantitative variables was conducted by factor analysis on responses using the principal component method followed by varimax rotation to ensure that the variables are important and suitable for the model using SPSS 16.0. Finally, identified factors were again analyzed using discriminant analysis to highlight statistical difference among practices existing in three sectors.

- Chapter 4: Assessing OHS practices in Indian industries: An artificial neural network approach

This chapter attempts to use an advanced intelligent technique, artificial neural network (ANN), for assessment of OHS practices. The instrument developed in Chapter 3 is used as inputs and two responses on safety performance obtained through questionnaire survey are used as outputs of the system. The pattern of influence of input parameters on outputs such as injury level and material damage is difficult to establish, possibly due to existence of some nonlinear relationship among them. Therefore, a neural network approach is adopted to carry out sensitivity analysis and identify important deficient items. A comparative evaluation on present practices among three major types of Indian industry has been made.

- Chapter 5: Framework for system design requirement

This chapter proposes a methodology for system design with due regard to deficient items obtained through neural networks using quality function deployment (QFD). Interrelation between the system design requirements is shown in a digraph using Interpretive Structural Modeling (ISM) approach.

- Chapter 6: Prediction of accidents using fuzzy logic approach

This chapter presents an artificial intelligence approach for prediction of different types of accidents (fatal to minor) in an uncertain environment. Likelihood of occurrence of accidents in the work place is a random phenomenon but judicious investment in various attribute such as expenses in health care, safety training, up-gradation of tools and machinery, and expenses on safety equipment and tools may lead to reduction in accident rate. The relationship between type of accidents and investments is difficult to establish because they do not follow any predictable rule rather associate in a non-linear manner. In such situations, fuzzy logic helps to map inputs and outputs in an efficient manner for building the inference engine so that various types of accidents can be predicted.

- Chapter 7: Safety performance evaluation

The chapter is to develop an appropriate methodology to benchmark safety performance in industrial setting so that deficiencies can be highlighted and possible strategies can be evolved to improve the performance. Data envelopment analysis (DEA), being a robust mathematical tool, has been employed to evaluate the safety performance of industries. DEA, basically, takes into account the input and output components of a decision making unit (DMU) to calculate technical efficiency (TE). TE is treated as an indicator for safety performance of DMUs and comparison has been made among them. A total of thirty Indian organizations belonging to three industrial categories such as construction, refractory and steel are chosen for comparison purpose.

- Chapter 8: Executive summary and conclusions

This chapter presents the summary of the conclusions, recommendations and scope for future work in the area of OHS. It also discusses the specific contributions made in this research work and the limitations.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

To minimize the health hazards, organizations usually implement an occupational health and safety (OHS) policy authorized by the organization's top management clearly stating overall OHS objectives and demonstrating commitment to improve safety performance. The organizations establish, implement and maintain documented procedures for hazard identification, hazard/risk assessment and control of hazards/risks of activities. The methodology adopted for such activities is based on operational experience. However, identification of risks and remedial measures in procedural format is difficult to establish and varies with contextual environment. The safety instruments that contribute to the improvement of safety performance in a specific situation need to be evolved depending on working environment. Identification of specific safety items in an organizational context is addressed in the literature to a limited extent. Therefore, it is vital to review the key factors that determine the efficacy of OHS codes of practices and guidance. OHS instruments need to be designed as OHS policy interventions on the basis of a clear understanding of the rationale for the instruments, how the employees are intended to work, and who or what supposed to change. This study adopts an exploratory approach for identifying and examining a diverse range of factors.

In this direction, the current chapter highlights the development of strategies and problems associated with various aspects of OHS with relevance to the risk and hazard analysis, safety culture and climate, productivity and OHS and OHS policy. With the concept of social marketing being introduced in the year 1970s, literature survey, with special reference to OHS begins with papers published after 1990 with maximum attention paid to last ten years. The research was restricted to those articles for which full text was available. Table 2.1 provides the source and number of citations from each source.

Table 2.1 Summary of publications referred

Name of Journals	Citation
Safety Science	26
Journal of Safety Research	6
Journal of Social Marketing	5
Journal of Business and Psychology	1
Journal of Management	1
International Journal of Nonprofit and Voluntary Sector Marketing	3
Training and Development Journal	1
Journal of Occupational Health Psychology	2
International Journal of Service Industry Management	2

Journal of Occupational Accidents	1
Journal of Business and Industrial Marketing	1
Journal of Applied Psychology	3
Accident Analysis and Prevention	6
International Journal of Risk Assessment and Management	1
International Journal of Indian Culture and Business Management	3
Academy of Journal Management	1
The Journal of Business Strategy	1
International Journal of Engineering and Technology	1
Journal of Marketing Management	1
Journal of Marketing	1
Journal of Services Marketing	2
Journal of Strategic Marketing	1
Journal of Loss Prevention in the Process Industries	2
Journal of Business Research	1
Expert Systems with Applications	9
Marketing Theory	3
The Journal of Business Strategy	1
International Journal of Business and Information	1
Environ Health Perspective	1
Journal of Marketing Practice and Applied Marketing Science	1
Industrial Marketing Management	2
Training and Development Journal	1
Research and Practice in Human Resource Management	1
International Journal of Industrial Ergonomics	3
Benchmarking: An International Journal	4
Journal of Advances in Management Research	1
Journal of Modelling in Management	1
European Journal of Scientific Research	1
European Journal of Marketing	1
Journal of Industrial Engineering and Management	1
Reliability Engineering and System Safety	2
Journal of Health Politics, Policy and Law	1
International Journal of Workplace Health Management	1
Work and Stress	3
Journal of Construction Engineering and Management	1
International Journal of Rural Management	1
Benchmarking for Quality Management and Technology	1
Disaster Prevention and Management	1
International Journal of Quality and Reliability Management	1
Safety Management	1
Industrial Marketing Management	5
Professional Safety	2
Journal of Loss Prevention in Process Industries	2
Health Promotion international	3
Books	12
Conference	9
Websites	5
Total	156

The literature review gives enough confidence to identify a pertinent gap or methodological weaknesses in the existing literature to solve the research problem. The literature is classified into four categories-each one dealing with specific issues associated with injury prevention social marketing as illustrated in Figure 2.1. Figure 2.2 provides the breakdown of the number of citations by research classification. The next sections provide a brief discussion on these issues. Finally, this chapter is concluded by summarizing the OHS implication in industries and possible literature gap so that relevance of the present study can be emphasized.

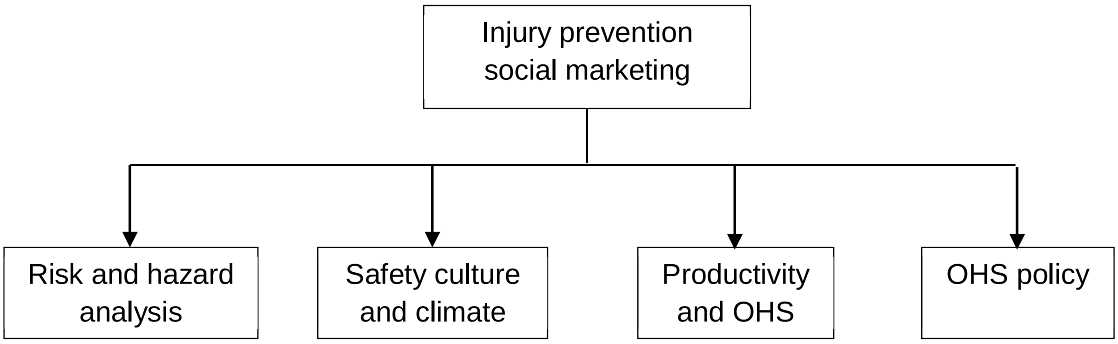


Figure 2.1 Research on injury prevention social marketing issues

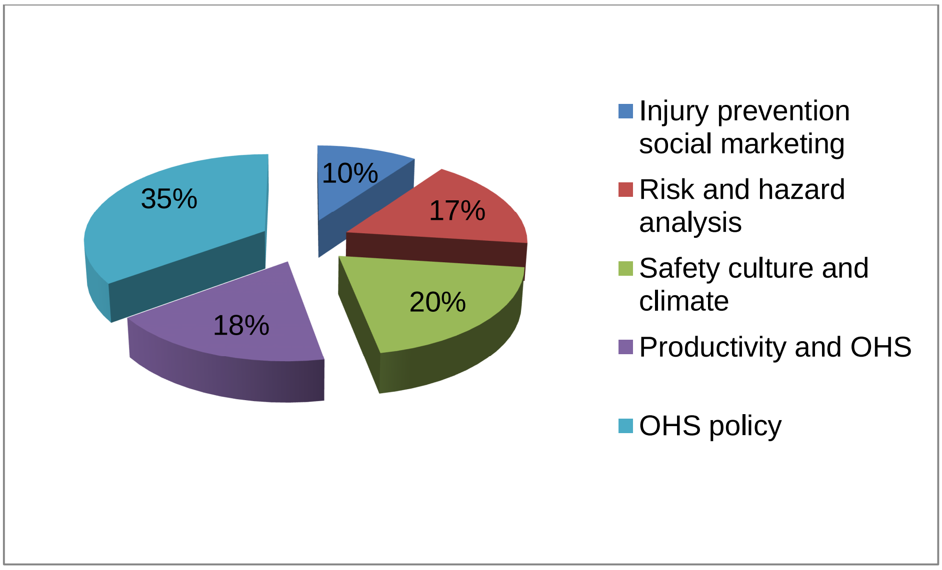


Figure 2.2 Percentage of paper surveyed

Companies engaged in sustainable business practices achieve benefits that include cost savings, higher revenues, a better image, lower staff turnover, increased productivity and access to finance and new markets. In addition, consumers, investors and policy makers around the world are becoming increasingly concerned about the impact of globalization on workers' rights, the environment, community welfare and corporate social responsibility and demand that producers around the world should act in a more responsible manner. So effective human resource management can also cut costs and boost productivity considerably. Fair wages, a clean and safe work environment, training opportunities and health and education benefits can all help make an organization more profitable by increasing productivity, reducing absences and lowering costs of recruiting and training new staff. The review of the literature together with key informants has revealed the evidence on effective marketing strategies to achieve workplace safety regulations and to minimize the injury level.

2.2 Injury prevention social marketing

Social marketing is based on the principles of commercial marketing technique to influence human behaviour in order to improve the society or to achieve non-commercial goals [53,24,44]. Social marketing has become increasingly popular among public and private sectors as an efficient and effective means of addressing serious health issues in developing counties [54]. Now, it is applied across many fields in public life and health including protection of the environment, campaigns against smoking and alcohol abuse and prevention and cure of malaria, leprosy, HIV, Hepatitis and Tuberculosis, family planning, recycling, waste management and water purity. Social marketing can also employ community-based approaches to promote desirable behaviors [55]. Industrial workers can benefit from community-based approaches that combine regulations, improved workplace design and safe and healthy environments in terms of injury prevention [56].

The review of the literature together with key informants has revealed a paucity of evidence on effective marketing strategies to achieve workplace safety regulations and to minimize the injury level and material damage. Lefebvre and Flora [57] have studied the principles and techniques of social marketing process using public health intervention. Tait and Walker [58] applied marketing techniques in health and safety consultancy firms for small enterprises and their managers. Flocks et al. [59] used agricultural safety project as a community-based social marketing. A social marketing program should be designed to fit the customer. To achieve this "custom fit", it is imperative to listen to the target audience and bring them into the decision-making process. Social marketing in the twenty-first century has grown in status as an innovative approach to social change [50,60].

Hastings and Saren [45] and Hastings [61] suggested that social marketing must continually learn from commercial marketing and in particular, its recent moves towards relational paradigms. McCloskey [8] identified factors associated with increased risk of injury while examining the use of social marketing approaches in the prevention of injury among young workers in Canada. Lavack et al. [40] concludes that social marketing can enhance the effectiveness of campaigns to reduce workplace injuries. Manuel et al. [14] have evaluated social marketing benchmark criteria by searching the PubMed database and the cumulative index to nursing and allied health behavioral interventions in healthcare settings.

Every organizational dimension of the workplace consists of activities and roles of management, labor, and their interface. Within each of these organizational domains, there are components which specifically address health and safety. Hence, workplace collaboration can occur among various levels of management and between senior managers and their workers. Since change in the business environment is vital today, the issue of industrial safety has been a matter of great concern for industries. In order to achieve this in a cost effective manner maintaining the reputation of the industries, new safety management theories have been evolved to balance between productivity and safety [48].

2.3 Risk and hazard analysis

Occupational health and safety (OHS) management system is a set of policies and practices aimed at positively implicating on the employee’s attitudes and behaviors in regard to risk with an aim to reduce their unsafe acts. One of the current challenges faced by Indian industries is increasing personal injury and material damage. So a system should create awareness on OHS to motivate the employees and improves the commitment level among all employees. To minimize accidents, Khan and Abbasi [62] had proposed a hazard management plan and assessments of risk process in chemical industries. Occupational accidents are not only limited to large scale industries but also small scale industries in agriculture, fisheries, tanneries, silk, and construction sectors. Kartam and Bouz [63] have identified that working at height representing a major cause of fatal accidents in construction industries. Prasanna Kumar and Dewangan [64] analyzed the agricultural accidents in north eastern region of India and reported that agriculture accident rate accounts 6.39 per 1000 workers/year in a tiny Indian province like Arunachal Pradesh.

Holmes et al. [65] emphasized the perceptions and understandings of risk and its control in OHS among employers of an Austrian small, blue-collar business industry. The findings of this study demonstrate that perceived quality of risk and its control are mediated by the social context of work. Ren et al. [66] applied linear discriminant analysis in classification of skin sensitizers when employees are exposed to different environmental conditions in the industries. Taha and Nazaruddin [67] have proposed a model based on artificial neural networks to predict carpal tunnel syndrome (CTS) and cumulative trauma disorders (CTDs) when workers are exposed to dusty environment particularly in construction works. The model suggests that grip strength is a critical consideration while designing handling tools to reduce such ailments. Zurada et al. [68] have proposed an artificial neural network-based diagnostic system which is capable of classifying industrial jobs according to the potential risk for low back disorders (LBD) due to workplace design. Such a system could be useful in hazard analysis and injury prevention due to manual handling of loads in industrial environments. Further, the developed diagnostic system can successfully classify jobs into the low and high risk categories of LBDs based on lifting task characteristics.

Asensio-Cuesta et al. [69] have proposed an artificial neural network approach for classifying the risk of low back disorders (LBDs) presented by certain lifting jobs. McCauley-Bell et al. [70] have developed a predictive model using fuzzy set theory to identify the risk of sustaining occupational injuries and illnesses in today's workplace. The prediction model aids significantly in preventing and controlling the development of occupational injuries and illnesses and thereby minimizes the frequency and severity of these problems. Sii et al. [71] have developed a safety model to carry out risk analysis for marine systems using fuzzy logic approach. Saurin et al. [72] have analyzed construction safety management practices from three cognitive systems engineering perspective (flexibility, learning and awareness). The safety management processes considered in the study are transparent, safety planning, proactive performance measurement, accident investigations, and identification and monitoring of pressures. Huang [73] has proposed adoption of artificial neural network model for remote health monitoring. These studies mainly focus on either classification of injury types or prediction of injury level in certain type of activities or industries but the effect of various OHS measures on safety performance is not investigated extensively. Qualitatively the problems of OHS and the needs of workers' health are in principle similar worldwide but often wide quantitative differences are present [74]. So, mutual collaboration with industry and Government on OHS resulted in long-term commitment to research and development work aiming at improvements in workers' health. Rundmo and Iversen [75] have pointed out that risk perception affects job security, job satisfaction and risk carrying attitude among employees. Chen et al. [76] used feed forward neural network (FNN) for classification of the low - back disorder (LBD) risk associated with jobs in small scale industries.

Manjunatha et al. [77] have studied the health status of industrial workers and identified iron and steel industries are particularly hazardous places of work. The survey results (sample size=2525) reveals that proportion of sickness absenteeism is 66.9%. Overall 16.4 days were lost per worker per year (male = 16.5 and females = 16.2) due to sickness absence. A blue collar worker lost 21.5 days compared to 11.9 days by a white collar worker ($p < 0.01$). Among workers, health ailments related to the musculoskeletal system (31.4%), gastrointestinal system (25.8%), hypertension (24.4%), respiratory system (18.1%) and other minor ailments (19.3%) were found. Azadeh et al. [78] have designed a fuzzy expert system for performance assessment of health, safety, environment (HSE) and ergonomics system factors in a gas refinery. It is claimed that the use of fuzzy expert systems can reduce human error, create expert knowledge and interpret large amounts of vague data in an efficient manner.

Fabiano et al. [79] have examined 2,983,753 total no. of non-fatal and fatal injuries of Italian industrial firms between 1995 and 2000 and statistical analysis of data revealed that smaller organizations are more likely to have a higher incidence of injuries. Vredenburgh [80] have observed similar results using a more flexible approach to injury data collected from secondary sources i.e. 62 hospitals in USA. Bevilacqua, et al. [81] have identified important relationships between accidents and system variables known as decision-making rules using the CART (Classification and Regression Trees) method in a medium-sized refinery. Haen [82] analyzed the risk of accidents in the pharmaceutical industry using knowledge culture conditioned bounded rationality and human artificial neural network process (HANNP). In the broad spectrum of occupational health and safety (OHS), several attempts have been made to assess risk as a safety practice. Gurcanli and Mungen [83] have proposed a method for assessment of the risks that workers are exposed in construction sites using a fuzzy rule-based safety analysis to deal with uncertain and insufficient data. Using this approach, historical accident data, subjective judgments of experts, and the current safety level of a construction site can be combined. Hadipriono et al. [84] have introduced the fuzzy event tree analysis

(FETA) to identify the events that cause failures of temporary structures so that their failures during construction can be prevented. Fujino [85] has demonstrated the applicability of the fuzzy fault tree analysis (FFTA) to few case studies of construction site accidents in Japan.

Blockley [86] has studied the likelihood of structural accidents in structural engineering by introducing fuzzy concepts. Choi et al. [87] and Cho et al. [88] have analyzed the risk assessment methodology for underground construction projects using a model based on fuzzy concept. Blockley [89] continued his work on this subject and introduced fuzzy set concepts for the analysis of the causes of structural accidents. Teo and Linga [90] has developed a model called construction safety index (CSI) to measure the effectiveness of safety management systems of construction sites using analytic hierarchy process (AHP). Brown et al. [91] have proposed that workplace accidents can be minimized through accurate prediction of safe employee behavior in regard to social, technical, and personal related factors in the steel industry. Komaki et al. [92,93] have found that the tendency to engage in risky behaviors in work setting can be reduced through training and behavioral reinforcement. The study also identifies the significant difference in some safety climate scales among accidental involvements and organizations. However, a large numbers of studies have been devoted to the assessment of safety practices in various kinds of industries but prediction in different types of accidents vis-à-vis investment in different type's preventive measures has not been adequately addressed in the literature. Prediction of different types of accidents is vital to develop a strategic framework to improve safety performance.

2.4 Safety culture and climate

The concept of safety culture has its origin in the social and behavioral psychology of the 1950's and 1960's that came to the fore in the organizational psychology, organizational behavior, and management literature of the 1980's. This literature offers a number of definitions of organizational cultures and climates that clearly resonate with those presented on safety cultures and climates. Measuring safety culture and climate has been undertaken in many industries in the past as a proactive method of collecting safety information about the current level of safety in the organization [22]. A safety culture exists within an organization where each individual employee regardless of the position accepts and assumes an active role in error prevention and this role is supported by the organization. In fact, safety culture is a set of guidelines by which group of individuals guided to change their behavior with a joint belief in the importance of safety and share the understanding that every member willingly upholds the group's safety norms. Fuller and Vassie [94] revealed that safety culture as an important phrase and concept came into distinction in the late 1980s. Wiegmann et al. [95] and Wiegmann et al. [96] defined safety culture as a set of beliefs, norms, attitudes, roles, and social and technical practices that are concerned with minimizing the exposure of employees, managers, and members of the public to conditions considered dangerous or injurious.

Safety climate is the temporal state measure of safety culture subjected to commonalities among individual perceptions of the organization. It is therefore situational based referred to the perceived state of safety at a particular place at a particular time; it is relatively unstable and subject to change depending on the features of the current environment or prevailing conditions [96]. In brief, safety culture, as defined in the literature, is commonly viewed as an enduring characteristic of an organization that is reflected in its consistent posture with critical safety issues. On the other hand, safety climate is viewed as a temporary state of an organization that is subject to change depending on the features of the specific operational or economic circumstances. Safety in the construction industry is a major concern, especially in developing countries, because of the lack of safety acts [97-99]. It is to be noted that it is difficult to establish a direct relationship between work practices and safety culture being adopted in a specific organization. However, it is true that good work practices may lead to less damage to materials and manpower. Work practices can be improved through adequate training and motivation whereas safety can be enhanced through proper design of job, way of handling tools, ergonomic aspects, and investment in safety equipment, training, and above all safety policies of the organization. Usually, good safety culture leads to improved trust between management and workers (Figure 2.3).

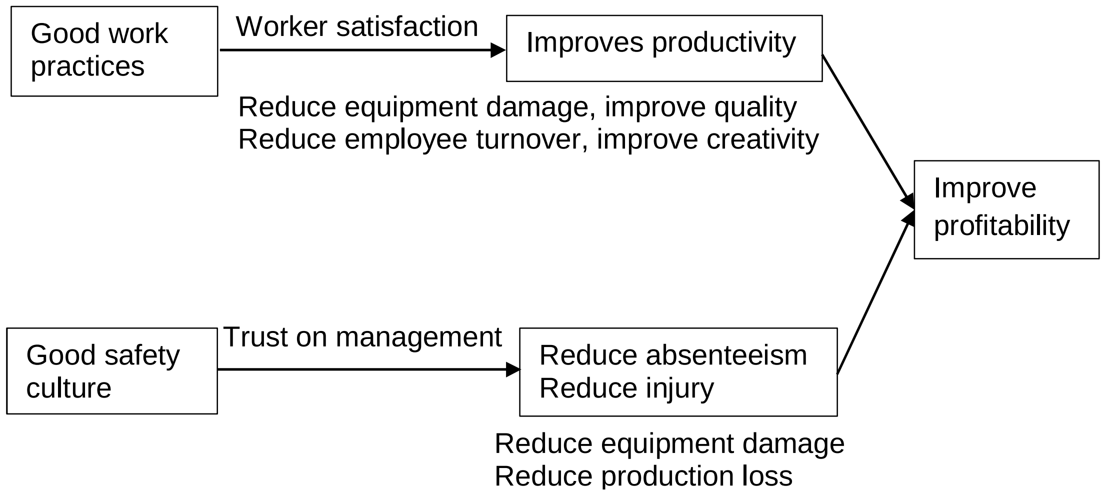


Figure 2.3 Relationship between firm profitability with work practices and safety culture

While assessing determinants and role of safety climate, Brown and Holmes [100] have opined that cultural differences among populations may have a large influence on safety climate. Hofmann and Stetzer [101] found that the perceived safety climate was significantly associated with unsafe work behavior using a sample of two hundred twenty two workers in a Midwestern chemical processing plant. Cox and Flin [102] have stated that safety climate is regarded as a safety culture manifestation in behavior expressed in the attitude of employees. Griffin and Neal [103] found that safety climate influences safety performance and employees' attitudes towards safety persuaded by their perceptions of risk, management, safety rule and procedures in construction industry. Cox and Cox [104] and Clarke [105] studied the relationship between safety climate and specific measures of safety performance and found that a positive correlation exists between safety climate scores with the ranking of safety practice and accident prevention programs. Wills et al. [106] have proposed a methodology for benchmarking of organizations based on safety culture using principal components factor analysis. Lin et al. [107] have proposed that factors like safety awareness and competency, safety communication, organizational environment, management support, risk judgment, safety precautions and safety training represent safety climate as these factors explains 70.5% variance in a questionnaire survey analysis using factor analysis. The study also identifies the significant difference in some safety climate scales among accidental involvements and organizations.

Vinodkumar and Bhasi [108] have studied the safety climate factors in a chemical industry in India using principal component factor analysis with varimax rotation. Qinqquo and Jinqpenq [109] have proposed that safety performance constitutes factors such as safety climate, management support, risk management, safety communication, employee's safety competency and safety training through a broad based questionnaire survey in manufacturing firms. Flin et al. [110] have pointed out that direct comparison between safety climate factor levels and safety items across industries and countries are not justifiable because of inconsistencies existing in methodologies used for the purpose and cultural and language difference across countries and industries. Gupta and Tyagi [111] have studied the influence of stressors on employees' attitudes towards work and organization in private sector. Dash et al. [112] have attempted to assess the culture of the organizations with environmental responsibility in Indian textile industry. Gupta et al. [113] have proposed the impact of self-esteem, perceived job security, availability of time, reward and organizational cultural values on intention to share knowledge in Indian private organizations. Molenaar et al. [114] described and quantifies the relationships between corporate cultures on construction safety performance from three companies using structural equation model (SEM).

2.5 Productivity and OHS

It is argued that sustainable designed work environments may contribute to a reduction of sickness absenteeism leading to less productivity losses in an organization [115]. Dejoy et al. [116] have stated that employees' attitudes plays a vital role in safety issues. They have also pointed out that industrial accidents not only affect human capital but also generate financial losses due to disruptions in industrial processes, damages to production machinery and harm the firm's reputation. If safety performance measurement system is implemented, the organizations can apply it to understand the cost of ill-health and injury using a cost-benefit ratio as a basic tool of economic assessment [117-122]. However, organizations also need to examine non-economic factors when assessing workplace safety, for example the cultural aspects or any management system already in place. One such system could be a safety management policy focusing on process quality, efficiency, organizational culture, knowledge capital and aspects of personnel policy such as the formal induction of a new member of staff to organizational processes, security culture, and potential risks and hazards. One tool that can be used to highlight all these specific factors when assessing the financial impact of OHS is the balanced score card (BSC). This is an organizational performance measurement system that has been successfully used to gauge the impact of safety and health policies. The score card identifies four categories or indicators: management, operational, customer satisfaction, and the learning and growth of individual personnel and the organization as a whole [123].

The research in this direction try to synthesize the evidence on the economic evaluation of workplace-based interventions focused on prevention of injuries and material damage in industrial settings. Arocena et al. [124] have analyzed the impact of risk perception practices and occupational factors on occupational injuries for flexible production technologies in Spanish industrial workers. Occupational accidents are not only limited to large scale industries but also small scale industries in agriculture, fisheries, tanneries, silk, and construction sectors. In order to encourage organizations to link OHS with efficient economic performance, it is necessary for them to understand the links between the two so that they can clearly see what can be gained from moving in this direction.

2.6 OHS policy

Compliance with government guidelines, regulations and laws is generally the primary focus of OHS policies. However, the strong economic advantages of good occupational health practice need to be highlighted continuously to organizations because the failure to acknowledge the importance of this link will limit the effectiveness of interventions aimed at preventing disease and injury [125,126]. Additionally, while the cost of ensuring safety is important, “unsafety” is also costly [127,128]. Therefore, any safety policy must encourage safe acts.

Occupational Health Safety Administration (OSHA), implemented by many organizations, encourages employers and employees to put efforts for reduction of number of accidents at places of employment and to stimulate employers and employees to perfect existing programs for providing safe and healthy working conditions [129,130]. Hence, workplace organizational policies and practices (OPPs) play a fundamental role in managing injury and infirmity [131]. The workplace organizational structure has been linked with occupational injuries. Factors such as the presence of an effective joint health and safety committee, an active return-to-work program, early communication between stakeholders, positive relationships between management and union, and the existence of a people-oriented work culture are important not only in preventing injuries but also in controlling the costs related to excessive time lost from work due to injury [132,133]. Habeck et al. [134] demonstrated a relationship between OPPs and disability outcomes. Workplaces maintaining high performance in safety diligence and safety training (disability prevention) exhibit fewer lost workdays, workplaces that adopted early return-to-work programs (disability management) are better performers in both disability incidence and duration rates, and workplaces endorsing a greater involvement in safety leadership from management (corporate culture) are better performers on all outcome measures. Mohaghegh and Mosleh [135] have proposed a measurement technique for organizational safety causal models in capturing the relation between organizational factors and safety performance using a Bayesian approach. Occupational health and safety in Indian industry has been considered as an important issue with construction industry being the most dangerous industries. This is especially applicable to most of the developing countries because of lack of Safety Acts. Ciarapica and Giacchetta [136] have demonstrated the flexibility and advantages of using neuro-fuzzy network for occupational injury study. Using these techniques, they have analyzed injury data in the Italian region for developing classification schemes according to the trend in injury and subsequently carry out a sensitivity analysis concerning the frequency of the injury.

Tepe and Tim [137] have reported that an organization needs to define its OHS strategy, clarify its commitment to OHS, and examine its OHS systems in order to provide an effective OHS management and corporate governance system. Beriha et al. [138] developed an appropriate construct to benchmark OHS performance in Indian industrial setting so that deficiencies can be highlighted and possible strategies can be evolved to improve the performance. Kongtip et al. [139] have presented an overall picture of OHS management in small and medium sized industries to gain information related to employment, welfare and health facilities, health education, accident statistics, occupational health and safety management and safety activities in Thailand.

In addition to above categories of injury prevention social marketing, bench marking is used as an important tool for the managers to transfer best practices and developing OHS policies. Tyteca [140] applied data envelopment analysis (DEA) to analyze the measurement of the environmental performance of various firms in an industry with respect to certain environmental characteristics. Fuller [141] has attempted to benchmark health and safety management in intra- and inter-company of a large food manufacturer. Feroz et al. [142] have used data envelopment analysis to test the economic consequences of the occupational health and safety administration caused due to cotton dust in fabric industries. Sarkar et al. [143] have conducted a safety performance evaluation of underground coal mines in terms of productivity, efficiency, and profitability using DEA and fuzzy set theory. El-Mashaleh et al. [144] have used DEA to study the impact of information technology on contractors' performance. Odeck [145] have identified best practices for traffic safety with an application of DEA. Vinter et al. [146] have used DEA to compare project efficiency in a multi-project environment. Zhou et al. [147] have proposed energy and environmental modeling to minimize environmental pollution using DEA. Hermans et al. [148] have studied the road safety performance in the construction process using factor analysis, analytic hierarchy process (AHP), and data envelopment analysis (DEA). Lei and Ri-Jia [149] have analyzed efficiency assessment of coal mines safety using DEA and recommended the use of funds and management resources to improve efficiency. Shen et al. [150] have analyzed road safety performance of various counties using DEA and proposed a composite safety index. In another study, Hermans et al. [151] have proposed benchmarking of road safety using DEA considering different risk aspects of road safety system. Abbaspour et al. [152] have applied DEA to assess the efficiency of environmental performance concerning health and safety of twelve oil and gas contractors.

Besides OHS, several studies of literature find application of DEA in other fields. Athanassopoulos et al. [153] have developed a policy making scenario to identify the response of production units of electricity generating power plants regarding the demand of services, costs, and polluting emissions using DEA. Ramanathan [154] has used DEA to compare the risk assessment of eight different energy supply technologies. Khan et al. [155] applied DEA model to evaluate quality assessment of Technical Education System (TES) in India using two types of models known a constant return to scale (CRS) and variable return to scale (VRS). Sahoo and Tone [156] have proposed a DEA model for comparison of various technologies used in Indian banks. Wang et al. [157] have proposed a fuzzy DEA model for ranking performances of eight manufacturing enterprises in China.

2.7 Conclusions

The growing industrialization and complex restructuring of service as well as manufacturing industries find it difficult to survive in the market place due to huge social pressure and increased awareness level of people with regard to environmental pollution, exploitation of labour, and occupational related ailments and injuries,. Now, safety and green environment are treated as two vital elements to develop or retain the goodwill in the marketplace. The industries normally use continuous improvement approaches to progress in both aspects as an image building strategy so that competition may become easier. However, both the aspects are not only important for existence but also help to improve the motivation level of employees resulting in higher productivity and profitability for the organization. The fact has been realized quite early in India and safety of working personnel in industries has become a major concern for management ever since the enactment of Factories Act, 1948. The industrial setting in India addresses the occupational health and safety (OHS) to reduce work related injuries and material damage through an “injury prevention social marketing” approach and formulate policies recognizing the need to adapt based on attitudes and learning styles of employees.

CHAPTER 3

DESIGN OF A CONSTRUCT FOR OCCUPATIONAL HEALTH AND SAFETY

3.1 Introduction

Literature survey presented in the previous chapter reveals that few studies have been directed to assess safety performance in different types of industries and its discrimination to each other. In this chapter, an attempt has been made to analyze safety performance through a questionnaire survey by collecting data from managers, safety officers and workers. Risk perceptions and understanding of OHS by respondents have been considered in three Indian industrial sectors, i.e. Construction, Refractory and Steel industries. It is to be noted that perception and understanding of risk in workplace among employers and employees influence the control of risk at work. The work environment in three sectors (construction, refractory and steel) considered in this study is generally viewed as hazardous due to usage of heavy equipment, unsafe and primitive tools, injurious materials and dust produced during operation. There are many other sectors such as fishing, agriculture, nuclear installations, electricity generating plants etc. where safety is of prime importance. However, the study area covers such industries where the size of manpower and investment varies, both organized and unorganized workforce exist, both public and private enterprises exist, and level of sophistication of tools, methods, and work environment is poor. A cross sectional survey is conducted covering various aspects of current OHS practices in industries. The responses are analyzed using factor analysis and nine factors are extracted and interpreted. Finally, identified factors again are analyzed using discriminant analysis to highlight statistical difference among practices existing in three sectors.

As factors and the variables responsible for improving health and safety norms widely vary across industries and locations, it is vital to develop a generic construct that can be uniform over a variety of industry types so that policies can be formulated to improve the morale of employees. The construction sector is largely characterized by unorganized workforce and hardly follows standard regulations laid down by the government agencies whereas refractory and steel sectors have a mix of organized and unorganized workforce. Construction firms are usually small in size in terms of manpower and investment while other sectors vary from large to medium.

3.2 Critical analysis of OHS

Critical analysis of OHS standards implementation reveals that the factors and the variables responsible for improving health and safety norms vary widely across industries and locations [158]. Therefore, it is essential to study various aspects of health and safety practices in Indian conditions. Moreover, significant factors in various industries need to be identified so that policies can be formulated in a judicious manner for larger managerial implications. There are two reasons for the examination of underlying meanings of risk and its control that emerge from employee or employer's judgment. Firstly, it can explore approaches that contribute to different perspectives on the control of risk and help to understand the interaction among different approaches that might construct the meanings of risk and its control in OHS. Secondly, it can look at the implications of conflicting risk perceptions and understanding for the promotion of OHS in Indian industries.

3.3 Development of OHS instrument in Indian context

Occupational Health and Safety Management Systems (OHSMS) now figure heavily in the thinking and strategies of the OHS jurisdictions and the management of many Indian organizations. The requirement under duty of care legislation is that OHS should be managed in a systematic fashion to achieve an effective internal control of OHS. OHSMS is undoubtedly a useful tool to organize and execute the activities supporting a systematic approach to manage OHS whether an organization has an OHSMS in place or not. However, OHSMS can potentially be treated as a part of the problem rather than the solution. Despite the persistent promotion of OHSMS and the dedicated view of most OHS stakeholders that OHSMS are needed, there remains a range of issues and concerns regarding the use of OHSMS and their effectiveness [159].

A survey using a questionnaire is widely accepted as a method for measuring perception of managers, safety officers and workers on OHS (Appendix - 3.1). To address this issue, thirty six items (thirty four items referring to perception of OHS practices and two items on overall safety performance of the organization) that constitute the questionnaire are selected through a review of related literature and theory as well as discussion with a group of experts in the field comprising of managers, safety officers and workers. The items in the questionnaire covering various areas of OHS are shown Table 3.1. All the items are relevant to Indian industries, basically of construction, refractory and steel. The questions are framed to suit the local work practices and culture. Before conducting the survey, the questionnaire was discussed with focus groups in three industrial sectors to ensure face validity.

Table 3.1 Perception of OHS practices in social marketing

Sl. No.	OHS Items	Source
1	Firm is committed to well-being of the workers through its health and safety policies along with other HR policies.	Means, et al. [160] McAfee and Winn [161]
2	A written declaration, reflecting management's concern for safety, principles of action, and objectives to achieve, is available to all workers.	Fernandez-Muniz et al. [162] Fernandez-Muniz et al. [163]
3	A format on functions of commitment, participation and responsibilities is established on all safety aspects and available to all organization members.	Bottani et al. [164] Fernandez-Muniz et al. [163]
4	Safety policy promotes commitment to continuous improvement and attempts to improve objectives already achieved.	Fernandez-Muniz et al. [162] Fernandez-Muniz et al. [163]
5	Incentives are frequently offered to workers to put in practice the principles and procedures of action (e.g., correct use of protective equipment).	Fernandez-Muniz et al. [162] Fernandez-Muniz et al. [163]
6	Periodical meetings between managers and workers are held to take decisions affecting organization of work.	Proposed by experts
7	Teams made up of workers from different parts of organization are frequently used to resolve specific problems relating to working conditions.	Fernandez-Muniz et al. [165]
8	Workers are sufficiently trained while entering firm, changing jobs or using new technique.	Self-developed
9	Follow-up of training needs and repercussion of training previously given is regularly done.	Fernandez-Muniz et al. [162] Fernandez-Muniz et al. [165]
10	Training actions are continuous and periodic and are integrated in formally established training plan.	Glennon [166] Fernandez-Muniz et al. [163]
11	Specific training are planed taking into account firm's particular characteristics and job positions.	Proposed by experts
12	Training plan is decided jointly with workers or their representatives	Fernandez-Muniz et al. [162] Fernandez-Muniz et al. [165] Fernandez-Muniz et al. [163]
13	OHS training actions are carried out during working days.	Fernandez-Muniz et al. [163] Donald and Canter [167] Fleming [168]
14	Firm helps workers for OHS training in-house.	Fernandez-Muniz et al. [163] Donald and Canter [167] Cox et al. [169]
15	Instruction manuals or work procedures are elaborated to aid in preventive action.	Fernandez-Muniz et al. [163] Silva et al. [170]
16	Rules and principles are effectively communicated in meetings, campaigns and oral presentations.	Proposed by experts
17	When starting in new job position, workers are provided written information about procedures and correct way of doing tasks.	Fernandez-Muniz et al. [162] Fernandez-Muniz et al. [163] Fernandez-Muniz et al. [165]
18	Workers are informed about risks associated with their work and how to prevent accidents through written circulars and meetings.	Self-developed
19	Firm has systems to identify risks in all job positions.	Fernandez-Muniz et al. [163]

		O'Toole [171] Guldenmund [172]
20	System is in place to evaluate risks detected in all job positions.	Fernandez-Muniz et al. [163] O'Toole [171] Guldenmund [172] HSE [17 3]
21	Prevention plans are formulated on the basis of information provided by evaluation of risks in all job positions.	O'Toole [171] Guldenmund [172]
22	Prevention plans clearly specify person responsible for carrying out action.	O'Toole [171] Guldenmund [172] HSE [173]
23	Standards of action or work procedures are elaborated on the basis of risk evaluation.	O'Toole [171] Guldenmund [172] Fernandez-Muniz et al. [163]
24	Prevention plans are circulated among all workers.	Fernandez-Muniz et al. [163]
25	Prevention plans are periodically reviewed and updated when job are conditions modified or worker's health is affected.	Fernandez-Muniz et al. [163] Guldenmund [172]
26	Firm has elaborated emergency plan for serious risks.	Fernandez-Muniz et al. [163] Guldenmund [172]
27	All workers are informed about emergency plan.	Fernandez-Muniz et al. [163] Guldenmund [172]
28	Periodic checks are conducted on execution of prevention plans and compliance level of regulations.	Zohar [174] Donald and Canter [167] Cabrera et al. [175]
29	Pre-determined plans and actual steps are frequently compared to identify gaps.	Vredenburgh [80] Shannon et al. [176]
30	Procedures to check achievement of objectives are allocated to managers.	Lee [177] Vredenburgh [80] Shannon et al. [176] Fernandez-Muniz et al. [163]
31	Systematic inspections are conducted periodically to ensure effective functioning of whole system.	Fernandez-Muniz et al. [163] Vredenburgh [80]
32	Accidents and incidents are reported, investigated, analysed and recorded.	Fernandez-Muniz et al. [163] Vredenburgh [80] Shannon et al. [176]
33	Firm's accident rates are regularly compared with those of other organizations from same sectors using similar production processes.	Fuller [141] Lingard and Rowlinson [178]
34	Firm's techniques and management practices are regularly compared with those of other organizations from all sectors to obtain new ideas about management of similar problems.	Kotler [179] Ali et al. [180]
Overall safety performance of the organization		
1	Personal injuries in the organization are very low.	Fabiano et al. [79] Hofmann and Stetzer [101] Ali et al. [180]
2	Material damage is low in the organization.	Fabiano et al. [79] Kotler [179]

3.3.1 Data collection

The questionnaire used in this study contained thirty six items and the respondent needed to answer all the items using 1 to 5 Likert-type scale (1-strongly disagree and 5-strongly agree). The responses were collected from managers, safety officers and workers of different industries (both private and public) across India through e-mail/postal/personal contacts. The perceptions on thirty six items from respondents related to occupational health and safety in three industry types were compiled. The perception of the managers, safety officers and workers in each item was captured in similar fashion as service quality is measured using Performance-only (SERVPERF) proposed by Cronin and Taylor [181] due to its superiority as demonstrated by Brady et al. [182].

The list of industries was selected through accessing different websites, suggestions made by Confederation of Indian Industries (CII) and personal contacts. The study used probability as well as non-probability sampling for selecting the industries and respondents. In probability sampling, stratified random sampling was used whereas convenience and judgmental sampling was used for non-probability sampling. Stratified sampling uses random selection of study units from various groups based on similarity in certain characteristics. In non-probability convenience sampling, the study units (the safety officers, HR manager and workers) that happen to be available at the time of data collection are selected for the purpose of convenience. Non-probability judgmental sampling considers different elements of survey design while deciding upon the study units.

The survey was conducted through different modes of collecting responses over a period of four months (from April 2009 to July 2009). It was carried out in the eastern zone of the country. A total of 345 questionnaires were sent and 307 responses (88%) were received. Responses were screened based on completeness, rational scoring, and adherence to scale and finally 288 responses (83%) were considered for further analysis. For construction industries, 115 questionnaires were sent and 88 responded (76%) and 27 (24%) did not respond. For Refractory industries, 115 questionnaires were sent and 102 responded (88%) and 13 (12%) did not participate in the survey. Similarly, for Steel industries, 115 questionnaires were sent and 98 responded (85%) and rest 17 (15%) were not used for analysis due to reasons mentioned above.

3.4 Methodology

First, factor analysis has been carried out to develop a construct for OHS in Indian industries as discussed in section 3.4.1 and then industry-wise difference has been analyzed using discriminant analysis as mentioned in sub section 3.4.2.

3.4.1 Factor analysis

Two hundred eighty eight useful responses were tested to examine the validity and reliability of the scale so as to obtain a quantitative and statistically proven identification of the responses. The test for quantitative variable was conducted by factor analysis on 288 responses using the principal component method followed by varimax rotation to ensure that the variables are important and suitable for the model using SPSS 16.0. The algorithms for Principal Component Method Factor Analysis and varimax rotation are given in Appendix 3.2 and Appendix 3.3 respectively. Twenty three items were loaded more than 0.6. These twenty three items were categorized under nine social factors constituting various variables for proposed instrument to measure the relation between occupational safety management and firm performance as perceived by safety officers and workers. These nine social factors are defined as Preventive procedure, OHS training, Risk management, Work practices, Periodic plans, Continuous improvement, Injury avoidance, Emergency plans and Health care. The items that failed to get loaded more than 0.6 were not considered for further analysis. This was true for refer to items 4, 7, 9, 11, 14, 16, 17, 20, 25, 30 and 32.

Percentage of total variance explained was found to be 75% which is an acceptable value for the principal component varimax rotated factor loading procedure [183]. The internal consistency of the actual survey data were tested by computing the Cronbach's Alpha (α). The value of alpha for each factor is shown in Table 3.2, and the value of alpha for all factors is 0.817, which is well above the acceptable value of 0.70 for demonstrating internal consistency of the established scale [184]. The value of Kaiser-Meyer-Olkin (KMO), which is a measure of sampling adequacy was found to be 0.782 indicating that the factor analysis test has proceeded correctly and the sample used is adequate as the minimum acceptable value of KMO is 0.5 [185]. Therefore, it can be concluded that the matrix did not suffer from multicollinearity or singularity. The result of Bartlett test of Sphericity shows that it is highly significant (sig=0.000) which indicates that the factor analysis processes is correct and suitable for testing multifactorality [185]. Therefore, the statistical tests indicated that the proposed items and all factors of the instrument are sound enough for analysis.

Table 3.2 Factors loading score

Factor	Item No.	F1	F2	F3	F4	F5	F6	F7	F8	F9	Cronbach's Alpha
Preventive Procedures	21	0.628									0.800
	24	0.735									
	29	0.713									
	34	0.824									
OHS Training	5		0.845								0.783
	12		0.816								
	22		0.785								
Risk Management	31			0.735							0.661
	33			0.805							
Work practices	2				0.775						0.727
	8				0.741						
	13				0.751						
Periodic plans	6					0.660					0.635
	28					0.723					
Continuous Improvement	10						0.806				0.710
	15						0.757				
Injury Avoidance	3							0.789			0.797
	23							0.683			
	26							0.789			
Emergency Plan	19								0.854		0.831
	27								0.782		
Health Care	1									0.867	0.644
	18									0.604	

The percentage of variation explained by factor analysis with varimax rotation is explained in Table 3.3. Injury Avoidance happened to be the most important factor whereas Risk Management (factor nine) is least important factor. OHS Training is considered to be next important factor followed by Preventive Procedures, Work Practices and Continuous Improvement. Periodic Plans is the sixth ranked factor followed by Emergency Plans and Health Care. The average perception of twenty three items loaded on various factors are plotted industry-wise in Figure 3.1 to check if any difference exist in OHS practices in three sectors. It is found that average perception vary widely over industry types. However, it is important to study statistically proven significant differences on average perception of items in three types. To analyze in an efficient manner, Linear Discriminant analysis is adopted as discussed below.

Table 3.3 Percentage of variation explained by factor analysis

Factors	Percentage of Communalities Variance Explained	Ranking of Factors
Injury Avoidance	12.136	1
OHS Training	9.169	2
Preventive Procedures	8.425	3
Work Practices	7.302	4
Continuous Improvement	7.101	5
Periodic Plans	6.059	6
Emergency Plans	5.820	7
Health Care	5.628	8
Risk Management	5.561	9

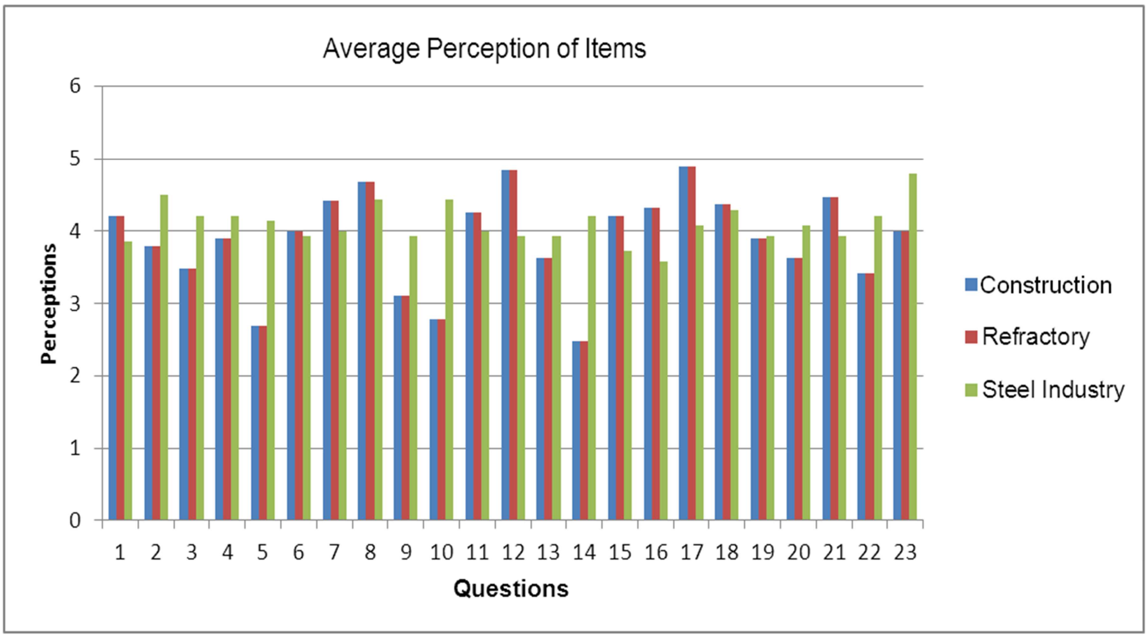


Figure 3.1 Industry-wise average perception of items

3.4.2 Linear discriminant analysis (LDA)

Discriminant analysis is the appropriate statistical technique when the dependent variable is a categorical (nominal or nonmetric) variable and the independent variables are metric variables. The dependent variable may consist of two groups or multiple (three or more) classifications. Example of a two-group classification may be, male and female or high versus low. In more than two groups, the classifications may be defined as low, medium and high or, say in educational settings, it may be student, alumni, parents and recruiters. When two-group classifications are involved, the technique is referred to as two-group discriminant analysis. In other instance, three or more classification technique is referred as multiple discriminant analysis (MDA). The detail is available in Appendix 3.4.

Discriminant analysis involves deriving a **variate**. The discriminant variate is the linear combination of the two (or more) independent variables that will discriminate best between the objects (persons, firms, etc.) in the groups defined a priori. Discrimination is achieved by calculating the variate's weights for each independent variable to maximize the difference between the groups (i.e., the between-group variance relative to the within-group variance). The variate for a discriminant analysis, also known as the **discriminant function**, is derived from an equation 3.1 [186-188].

$$Z_{jk} = a + W_1X_{1k} + W_2X_{2k} + ... + W_nX_{nk} \quad (3.1)$$

where

Z_{jk} = discriminant Z score of discriminant function j for object k

a = intercept

W_i = discriminant weight for independent variable i

X_{ik} = independent variable i for object k

This technique is the appropriate statistical technique for testing the hypothesis that the group means of a set of dependent variables for two or more groups are equal. By averaging the discriminant scores for all the individuals within a particular group, one can arrive at the group mean. This group mean is referred to as a **centroid**. When the analysis involves two groups, there are two centroids; with three groups, there are three centroids; and so on. The centroids indicate the most typical location of any member from a particular group, and a comparison of the group centroids shows how far apart the groups are in terms of that discriminant function.

3.5 Results and discussions

LDA is a pattern recognition method providing a classification model based on the combination of variables that best predicts the category or group to which a given object belongs. In this study, the independent variables are firm performance about occupational health and safety as perceived by safety officers and workers, and group variables are three sectors of industries (Industry Type 1 - Construction, Industry Type 2 - Refractory and Industry Type 3 - Steel). Statistical analyses were performed using the SPSS 16.0 statistical software. The procedures focused on finding out significant difference of variables (items) under each factor in three industry types. The responses are divided into three groups industry wise. In linear discriminant analysis, the minimum F entry value (F_{min}) is set to 3.84 and the maximum F removal value (F_{max}) is set to 2.71 since these are default setting values in software SPSS. Stepwise discriminant analysis was carried out for all nine factors obtained in factor analysis. The decision is made based on Wilks' Lambda because a lambda of 1.00 occurs when observed group means are equal (all the variance is explained by factors other than difference between those means) while a small lambda occurs when within-groups variability is small compared to the total variability. A small lambda indicates that group means appear to differ. It can be seen from Table 3.4 that Items 3, 23 and 26 differ significantly in Refractory (Industry Type 2) and Steel Industry (Industry Type 3) under factor 1 (Injury avoidance). For example, Lambda of 0.721 has a significant value (Sig. = 0.000) for item 23; thus, the group means appear to differ for industry types 2 and 3. In Table 3.5, the items under factor 3 (Preventive procedure) are presented and it can be observed that Wilks' Lambda is smallest for item 29 with a significance value of 0.000. Therefore, significant difference in mean values for item 29 exists in Construction (Industry Type 1) and Steel (Industry Type 3) industry. Analysis of Table 3.6 shows that significant difference in mean values exist in Construction (Industry Type 1) and Steel (Industry Type 3) industry for Item 8 contained in factor 4 (Work practices). As far as factor 8 (Health care) is concerned, significant difference in mean values exist in Refractory (Industry Type 2) and Steel Industry (Industry Type 3) for item 18 (Table 3.7). Similarly, from Table 3.8, it can be seen that item 33 differ significantly in its mean value in Refractory (Industry Type 2) and Steel Industry (Industry Type 3) contained in factor 9 (Risk management). However, it is to be noted that not a single item in factor 2 (OHS training), factor 5 (Continuous improvement), factor 6 (Periodic plans) and factor 7 (Emergency plan) shows statistically significant difference industry wise.

Table 3.4 Sector-wise difference for Injury avoidance

Independent Items	Mean Values			Wilks' Lambda	F value	Sig.	Min. D Squared	Between Group
	Construction	Refractory	Steel					
Item 3	3.8947	4.2143	4.1765	0.977	0.560	0.575	0.002	2 and 3
Item 23	2.6842	4.1429	3.8235	0.721	9.074	0.000	0.092	2 and 3
Item 26	3.1053	3.7143	3.8235	0.914	2.206	0.121	0.010	2 and 3

At each step, the question that minimizes the overall Wilks' Lambda is entered.
a. Minimum partial F to enter is 3.84.
b. Maximum partial F to remove is 2.71.

Table 3.5 Sector-wise difference for Preventive procedure

Independent Items	Mean Values			Wilks' Lambda	F value	Sig.	Min. D Squared	Between Group
	Construction	Refractory	Steel					
Item 21	3.4737	4.2143	4.0000	0.918	2.101	0.134	0.039	2 and 3
Item 24	4.2105	3.7143	3.9412	0.951	1.221	0.304	0.062	2 and 3
Item 29	4.8947	4.0714	4.7059	0.760	7.408	0.000	0.092	1 and 3
Item 34	4.1053	4.2857	4.7059	0.845	4.323	0.019	0.084	1 and 2

At each step, the question that minimizes the overall Wilks' Lambda is entered.
a. Minimum partial F to enter is 3.84.
b. Maximum partial F to remove is 2.71.

Table 3.6 Sector-wise difference for Work practices

Independent Items	Mean Values			Wilks' Lambda	F value	Sig	Min. D Squared	Between Group
	Construction	Refractory	Steel					
Item 2	3.7895	4.5000	4.4118	0.869	3.530	0.037	0.011	2 and 3
Item 8	2.7895	4.4286	3.5882	0.723	9.025	0.000	0.529	1 and 3
Item 13	3.4211	4.2143	4.1765	0.849	4.193	0.021	0.002	2 and 3

At each step, the question that minimizes the overall Wilks' Lambda is entered.
a. Minimum partial F to enter is 3.84.
b. Maximum partial F to remove is 2.71.

Table 3.7 Sector-wise difference for Health care

Independent Items	Mean Values			Wilks' Lambda	F value	Sig.	Min. D Squared	Between Group
	Construction	Refractory	Steel					
Item 1	4.2105	3.8571	4.3529	0.926	1.866	0.166	0.039	1 and 3
Item 18	4.8421	3.9286	4.3529	0.773	6.890	0.000	0.363	2 and 3

At each step, the question that minimizes the overall Wilks' Lambda is entered.
a. Minimum partial F to enter is 3.84.
b. Maximum partial F to remove is 2.71.

Table 3.8 Sector-wise difference for Risk management

Independent Items	Mean Values			Wilks' Lambda	F value	Sig.	Min. D Squared	Between Group
	Construction	Refractory	Steel					
Item 31	3.8947	3.2986	3.2941	0.900	2.613	0.084	0.001	1 and 2
Item 33	4.0000	4.7857	4.8235	0.764	7.262	0.000	0.003	2 and 3

At each step, the question that minimizes the overall Wilks' Lambda is entered.
a. Minimum partial F to enter is 3.84.
b. Maximum partial F to remove is 2.71.

3.6 Conclusions

The work environment in three sectors considered in this study was generally viewed as hazardous compared to other sectors due to usage of heavy equipment, unsafe and primitive tools, injurious materials and dust produced during processing. All of them increase the potential for serious occupational health and hazards. Therefore, it is evident that a focused dedication towards occupational health is needed in these sectors. It can be inferred from the survey that the management, safety officers and workers have the opportunities to influence the sense of safety and the quality of work environment. In this study, factor analysis followed by linear discriminant analysis (LDA) were used to develop constructs suitable for improving OHS in these sectors and identify sector-wise perception of safety norms so that policy formulation and its implementation becomes easier. The proposed LDA discriminant function could provide some insight into what structural features are related to OHS. The work also aimed at analyzing the effect of implementing an occupational safety management system on firms' performance. The nine factors identified suits most of the companies and twenty three items describes most of the aspects of OHS. Occupational health using managers, safety officers and worker's perspective is hardly found in Indian industrial settings. Since safety officers and workers are competent enough to deal OHS aspects in industries in an effective manner, their perception leads to vital information. However, safety budget and participation of safety officers and workers in programme implementation and decision making stage do not seem to be encouraging enough in industries. The study presents evidence that occupational health and hazard perception in Indian industrial settings can be reliably measured with twenty three items loading on nine factors such as Preventive procedures, OHS training, Risk management, Work practices, Periodic plans, Continuous improvement, Injury avoidance, Emergency plans, and Health care. Some of the factors are slightly different from a previous study in literature [107,109]. The new factors pertinent to Indian organizations are Injury avoidance, Continuous improvement and Health care. These three factors are developed through a prolonged deliberation with managers, safety officers and workers. The study indicates that OHS is governed by the policy specifically formulated to avoid injuries rather than prevent them through process improvement and investment on technology. Training and written preventive procedures are followed but work practices prevalent at present hardly meet international standards. Continuous improvement that can improve skill level and prevent accidents are missing in Indian industries. Health care practices are still worse in these industries although government regulation require that employee insurance, health schemes, and medical facilities are extended to the employees. Health care facility, although not good enough, exists for regular employees. However, such facility is hardly extended to casual and temporary employees who constitute a significant percentage of the workforce due to outsourcing practices being adopted after liberalization to become competitive through cost reduction. The LDA suggests that item-wise difference exist in industry types. This serves as vital information at the stage of policy formulation on OHS. Therefore, it can be corroborated that OHS policy must be developed to meet the specific needs of an organization.

CHAPTER 4

ASSESSING OHS PRACTICES IN INDIAN INDUSTRIES: AN ARTIFICIAL NEURAL NETWORK APPROACH

4.1 Introduction

This chapter aims to assess the perception of managers, safety officers and workers about OHS norms extended to workforce in Indian industries in order to, understand its implementation levels as well as to identify any deficiency existing thereon. In the previous chapter, exploratory factor analysis has been carried out on the responses to the designed questionnaire. Nine factors with twenty three items have been extracted and interpreted. Utilizing the construct that resulted through the factor analysis, assessment of the existing safety practices and deficiency of OHS norms in three major industrial sectors (construction, refractory and steel) is discussed in detail. Neural network is used for modeling purpose. As neural networks are capable of mimicking human cognitive process, the perception mechanism of managers, safety officers and workers can be easily modeled via neural networks. Sector-wise deficient items have been identified and strategies for improvement upon them have been proposed. The pattern of influence of input parameters on outputs such as injury level and material damage is difficult to establish, possibly due to existence of some nonlinear relationships among them. Therefore, a neural network approach is adopted to carry out sensitivity analysis and identify important deficient items. Although perception of managers, safety officers and workers regarding immediate work environment help to formulate constructive safety policy and procedures, involvement of few representatives from workforce during implementation level may help in substantially reducing the injury level and material damage because it is the workers who not only are more conversant with work practices and directly exposed to risk environments but also sustain injuries in case of fatal accidents.

This work attempts to use advanced statistical and intelligent techniques for assessment of OHS practices. A comparative evaluation of present practices in three major types of Indian industry has been made. This offers a new direction for OHS construct in Indian industry to devise a comprehensive methodology that aims at improving satisfaction level of internal customers through embedding social marketing concepts in managerial activities. Rest of this chapter is organized as follows. Section 4.2 accounts a brief description on Artificial Neural Networks (ANN) which includes the transfer functions of ANN, Network Layers, Architecture of Neural Networks, The Learning process and The Back Propagation (BP) Algorithm. Section 4.3 describes Network Parameters and section 4.4 describes the Design of Models or Performance of model. Sensitivity Analysis, which articulates the experimental results of ANN, is summarized in section 4.5. Conclusions from the present study are summarized in section 4.6.

4.2 Artificial Neural Networks (ANN)

Due to advent of modern computer technology and information science, sophisticated information systems can be built to make decisions or predictions based on information contained in the available data. Such systems are called learning systems and are currently used for the purpose of classification and prediction [189]. Most of the early applications of neural networks have been in systems such as signal stabilizer, word recognizer, process monitor, sonar classifier and risk analyzer [190,191]. Since neural networks are best at identifying patterns or trends in data, they are well suited for prediction or forecasting needs in the following areas:

- Sales forecasting
- Consumer research
- Target marketing
- Risk management
- Industrial process control

Other applications of neural networks found in the literature include the field of advertising, sales forecasting, manufacturing, medical tourism, banking, securities market, portfolio management and market research [192-198]. An ANN is an information-processing paradigm that is inspired by the way biological nervous systems, such as the human brain, process information. The key element of this paradigm is the novel structure of the information processing system. It is composed of a large number of highly interconnected processing elements (neurons) working in conjunction to solve specific problems. ANNs, like people, learn by example. An ANN is configured for a specific application such as pattern recognition or data classification through a learning process. Learning in biological systems involves adjustments to the connections that exist between the neurons which are true for ANNs as well. A neural network consists of a network of neurons. Each neuron is associated with an input vector, a weight vector corresponding to the input vector, a scalar bias, a transfer function and an output vector as shown in Figure 4.1. In Figure 4.1, X_j's and W_j's are known as inputs and weights. A neural network may consist of one or more neurons in each layer. In a network, the final layer is called the output layer and the first layer is known as input layer whereas all other layers between them are called hidden layers. In the hidden layers, the output of a layer becomes the input for the following layer. The transfer function of a neuron converts the input to the output of the neuron. Multilayer neural networks are quite powerful tools used in solving many different problems. Various types of neural networks are available for different purposes. In this research, we have attempted to use the neural networks technique in the field of OHS with multilayer back propagation neural network architecture.

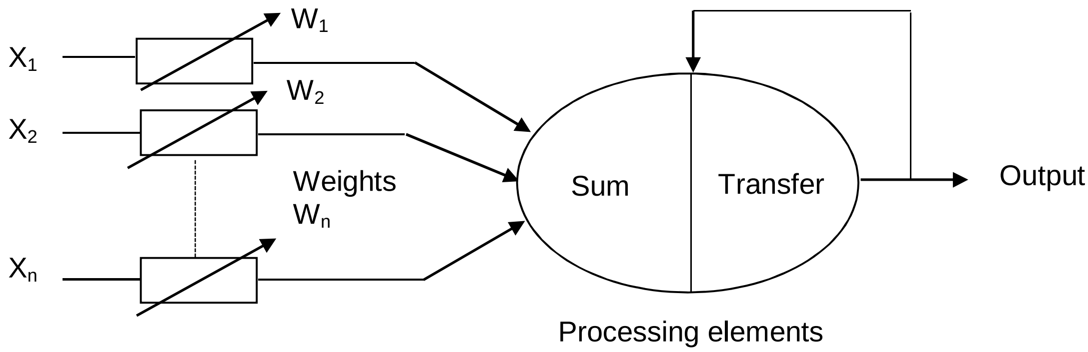


Figure 4.1 A Typical neuron

4.2.1 The transfer functions

The behavior of an ANN depends on both the weights and the input-output function (transfer function) that is specified for the units. There are three main types of transfer functions: (1) Linear (or ramp) (2) Threshold and (3) Sigmoid as shown in the Figures 4.2, 4.3 and 4.4 respectively. In **linear transfer functions** (Figure 4.2), the output activity is proportional to the total weighted output. For **threshold transfer functions** (Figure 4.3), the output is set at one of two levels depending on whether the total input is greater than or less than some threshold value. In **sigmoid transfer functions** (Figure 4.4), the output varies continuously but not linearly as the input changes. Sigmoid units bear a greater resemblance to real neurons than the linear or threshold transfer functions but all three are considered to be rough approximations.

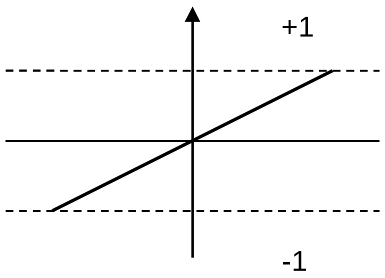


Figure 4.2 Linear transfer function

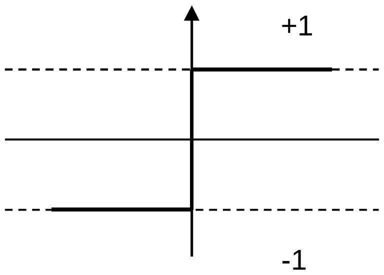


Figure 4.3 Threshold transfer function

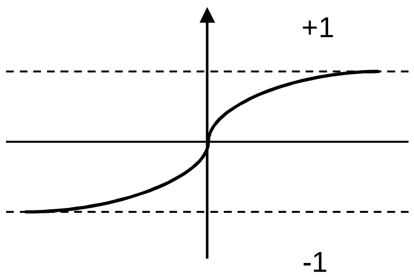


Figure 4.4 Sigmoid transfer function

Each neuron in the network is a processing element that performs summation and the transfer functions in converting input to output. The summation function evaluates the signed weighted sum of all inputs at a given node. The resulting total input is passed through the transfer or activation function to create the output. Network behavior depends substantially on the transfer functions of a node. For a typical semi-linear sigmoid function, the input X is converted to desired output through the equation (4.1) that is used in majority of neural network designs.

$$f(X) = \frac{1}{1 + e^{-X}} \tag{4. 1}$$

4.2.2 Network layers

The most common type of artificial neural network consists of three groups or layers of units (neurons) - a layer of "**input**" units is connected to a layer of "**hidden**" units, which is connected to a layer of **"output"** units (Figure 4.5). The activity of the input units represents the raw information that is fed into the network while the activity of each hidden unit is determined by the activities of the input units and the weights on the connections between the input and the hidden units. The behavior of the output units depends on the activity of the hidden units and the weights between the hidden and output units. The architectures of ANN may be single-layer or multi-layer. In the single-layer organization, all units are connected to one another. It constitutes the most general case and is of more potential computational power than hierarchically structured multi-layer organizations.

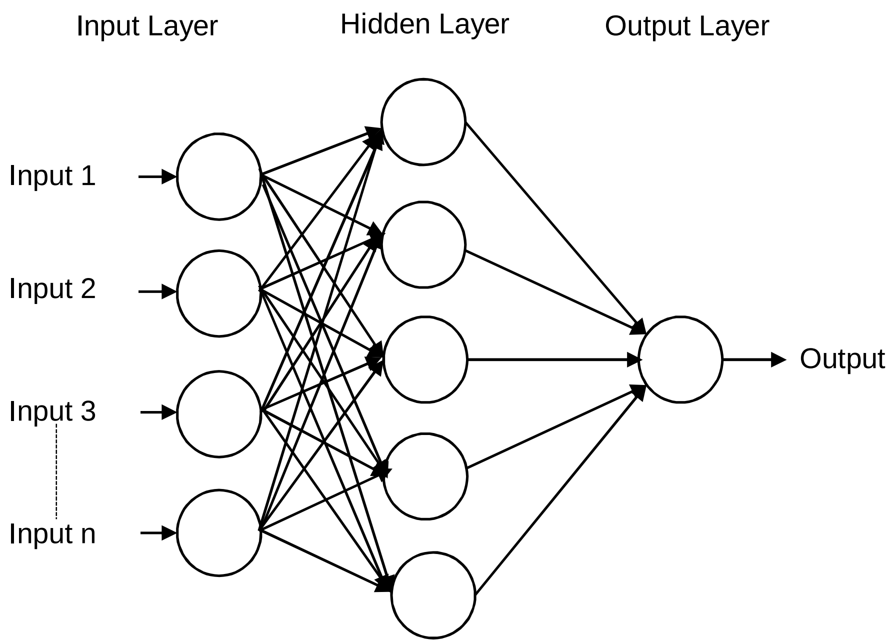


Figure 4.5 A simple feed forward neural network with three layers

4.2.3 Architecture of neural networks

There are basically two architectures of neural networks. They are

a) Feed-forward networks
b) Feedback networks

Feed-forward networks allow signals to travel one way only from input to output. There is no feedback (loops) i.e. the output of any layer does not affect that same layer. Feed-forward networks tend to be straight forward networks that associate inputs with outputs. They are extensively used in pattern recognition. This type of organization is also referred to as bottom-up or top-down.

Feedback networks can have signals traveling in both directions by introducing loops in the network. Feedback networks are very powerful and are complicated. These types of networks are dynamic and their 'state' is changing continuously until they reach equilibrium point. They remain at the equilibrium point until the input changes and a new equilibrium needs to be found out. Feedback architectures are also referred to as interactive or recurrent although the latter term is often used to denote feedback connections in single-layer organizations.

4.2.4 The learning process

The memorization of patterns and the subsequent response of the network are known as learning or training process of neural networks. Every neural network possesses knowledge that is contained in the values of the connection weights. Modifying the knowledge stored in the network as a function of experience implies a learning rule for changing the values of the weights. All information is stored in the weight matrix 'W' of a neural network. Learning is the determination of the weights. There are two major categories of neural networks learning:

1. **Fixed network** learning in which the weights cannot be changed i.e. $dW/dt = 0$. In such networks, the weights are fixed according to the problem to solve.
2. **Adaptive network learning** which are able to change their weights i.e. $dW/dt \neq 0$.

All learning methods used for adaptive neural networks can be classified into two major categories:

I. Supervised learning
II. Unsupervised learning

Supervised learning incorporates an external teacher so that each output unit is told what its desired response to input signals ought to be. During the learning process, global information may be required. Paradigms of supervised learning include error-correction learning, reinforcement learning and stochastic learning. An important issue concerning supervised learning is the problem of error convergence i.e. the minimization of error between the desired and computed unit values. The aim is to determine a set of weights that minimizes the error. One well-known method, which is common to many learning paradigms, is the least mean square (LMS) convergence.

Unsupervised learning uses no external teacher and is based upon only local information. It is also referred to as self-organization in the sense that it self-organizes data presented to the network and detects their emergent collective properties. Paradigms of unsupervised learning are Hebbian and competitive learning. Usually, supervised learning is performed off-line whereas unsupervised learning is performed on-line.

4.2.5 The back propagation (BP) algorithm

The l-m-n (l input neurons, m hidden neurons, and n output neurons) architecture of a back propagation neural network model as shown in Figure 4.5. Input layer receives information from the external sources and passes this information to the network for processing. Hidden layer receives information from the input layer, and does all the information processing, and output layer receives processed information from the network, and sends the results out to an external receptor. The input signals are modified by interconnection weight, known as weight factor w_{ij}, which represents the interconnection of i^{th} node of the first layer to j^{th} node of the second layer. The sum of modified signals (total activation) is then modified by a sigmoidal transfer function (f). Similarly, output signals of hidden layer are modified by interconnection weight (w_{ij}) of k^{th} node of output layer to j^{th} node of hidden layer. The sum of the modified signal is then modified by a pure linear transfer (f) function and output is collected at output layer [199,200].

Let $I_p = (I_1, I_2, \ldots, I_{pl})$ $P = 1, 2, \ldots., N$ be the p^{th} pattern among N input patterns. W_{ji} and W_{kj} are connection weights between i^{th} input neuron to j^{th} hidden neuron, and j^{th} hidden neuron to k^{th} output neuron, respectively.

Output from a neuron in the input layer is,

$$O_{pi} = I_{pi}, i = 1,2,....l \quad (4.2)$$

Output from a neuron in the hidden layer is,

$$O_{pj} = f(NET_{pj}) = f\left(\sum_{i=0}^{l} W_{ji} O_{pi}\right), j = 1,2,......m \quad (4.3)$$

Output from a neuron in the output layer is,

$$O_{pk} = f(NET_{pk}) = f\left(\sum_{i=0}^{l} W_{kj} O_{pj}\right), k = 1,2,......n \quad (4.4)$$

Sigmoid transfer function

A bounded, monotonic, non-decreasing, S-shaped function provides a graded nonlinear response. It includes the logistic sigmoid function

$$f(x) = \frac{1}{1 + e^{-x}} \quad (4.5)$$

where x = input parameters taken as described above.

Batch mode type of supervised learning has been used in the present case in which interconnection weights are adjusted using delta rule algorithm after sending the entire training sample to the network. During training, the predicted output is compared with the desired output, and the mean square error is calculated. If the mean square error is more than a prescribed limiting value, it is back propagated from output to input, and weights are further modified till the error or number of iterations is within a prescribed limit [201,202].

Mean square error, E_p for pattern p is defined as

$$E_p = \sum_{i=1}^{n} \frac{1}{2} (D_{pi} - O_{pi})^2 \quad (4.6)$$

where, D_{pi} is the target output, and O_{pi} is the computed output for the i^{th} pattern.

Weight change at any time t, is given by

$$\Delta W(t) = -\eta E_p(t) + \alpha \times \Delta W(t-1) \qquad (4.7)$$

η = learning rate i.e. $0 < \eta < 1$

α = momentum coefficient i.e. $0 < \alpha < 1$

4.3 Network parameters

The responses obtained from three industries for the twenty three items with regard to perceptions of safety officers and workers are used to measure the OHS in Indian industries. The network consists of three layers having a desired number of nodes in the input (I) as well as a hidden layer and single node in the output layer. Two outputs regarding the overall responses evaluation of OHS as injury level and material damage in the organization are considered as the outputs. Two separate models have been developed with injury level and material damage as output for the same set of inputs. The back-propagation module of the neural network MATLAB R2009b was used for training and testing of 288 numbers survey data owing to its fast generalization capability. For better prediction, 75% (216) of survey data are taken as training set and 25% (72) are taken as testing set.

All data are normalized in the 0.1-0.9 range to avoid the scaling effect of parameter values. Therefore, all the data (X_i) are converted to normalized values (X_{norm}) as follows [203].

$$X_{norm} = 0.8 \times \frac{(X_i - X_{min})}{(X_{max} - X_{min})} + 0.1 \qquad (4.8)$$

where X_i is i^{th} input or output variable. X_{min} and X_{max} are minimum and maximum value of variable X. Initially, the connection weights are generated randomly in the range of -1 to +1. Xu and Chen [204] have shown that for a small or medium-sized dataset (with less than 5000 training pairs), when N/d is less than or close to 30, the optimal number of neurons in the hidden layer (n) most frequently occurs on its maximum (N/d) where d is the input dimension and N is the number of training pairs. However, when N/d is greater than 30, the optimal n is close to the value of $(N/(d \log N))^{1/2}$. To determine the number of neurons in the hidden layer, different ANN structures with varying number of neurons in the hidden layer is tested at constant cycles of 50000, learning rate of 1%, error tolerance of 0.01, momentum parameter of 5%. The network performance is evaluated using Root Mean Square Error (RMSE). The network having seven neurons in the hidden layer shows minimum RMSE.

Batch mode type of supervised learning has been adopted in the present case where interconnection weights are adjusted using delta rule algorithm after sending the entire training sample to the network. During training, the predicted output is compared with the desired output, and the mean square error is calculated. If the mean square error is more than a prescribed limiting value, it is back propagated from output to input, and weights are further modified till the error or number of iterations is within a prescribed limit.

4.4 Performance of the model

A neural network model was designed to capture the perception of safety managers and workers on OHS management. Twenty three items loaded above 0.6 in factor analysis are used as inputs and performance of OHS practices like material damage and injury level are taken as outputs. Two separate models were constructed for two outputs. Each model is run varying the learning parameter, momentum parameter and number of cycles till RMSE is minimized. The model are run for 40799 and 46466 epochs (cycles) to obtain RMSE of 0.0125 for two outputs respectively (Figure 4.6 and Figure 4.7). Training of the network is stopped at this point.

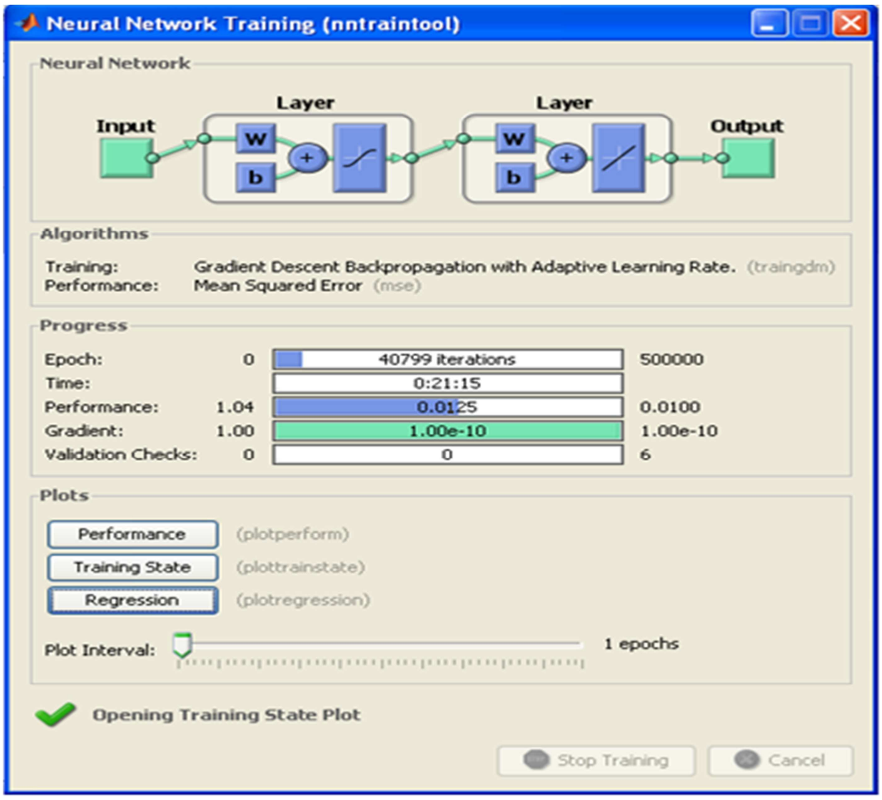


Figure 4.6 Neural network training for output 1 (Injury level)

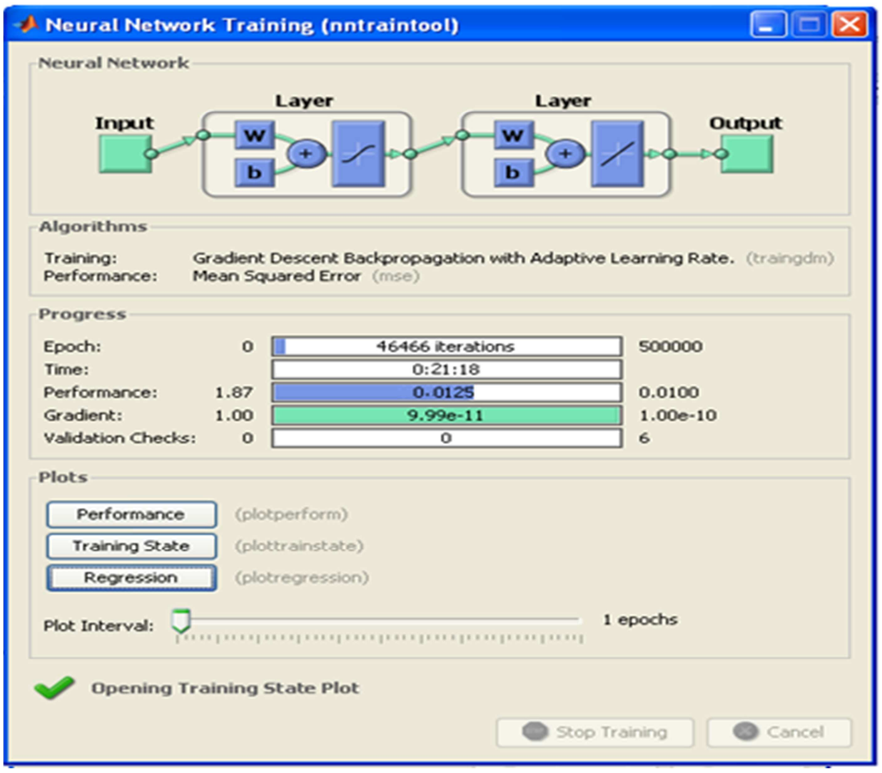


Figure 4.7 Neural network training for output 2 (Material damage)

Figures 4.8 shows the convergence of mean square error for output 1 (injury level) during training. Figure 4.9 shows the fit between actual and predicted values. Similarly, convergence of mean square error and fit between actual and values during training are shown in Figures 4.10 and 4.11 respectively for the output material damage. It should be noted that coefficient of determination is obtained as 0.85394 and 0.83734 respectively for outputs injury level and material damage respectively when a sample of data set is run on MATLAB. As both the models have been trained adequately, they can be used for testing of data or prediction purpose.

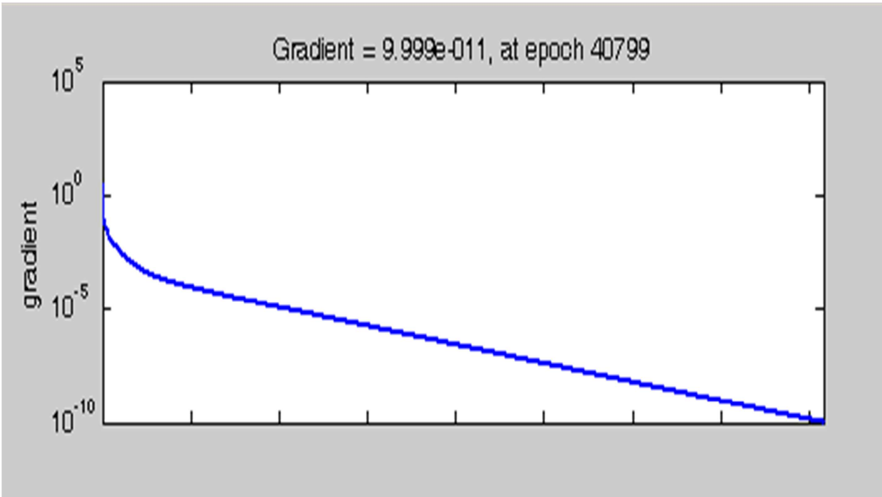


Figure 4.8 Mean square error of output 1 (Injury level)

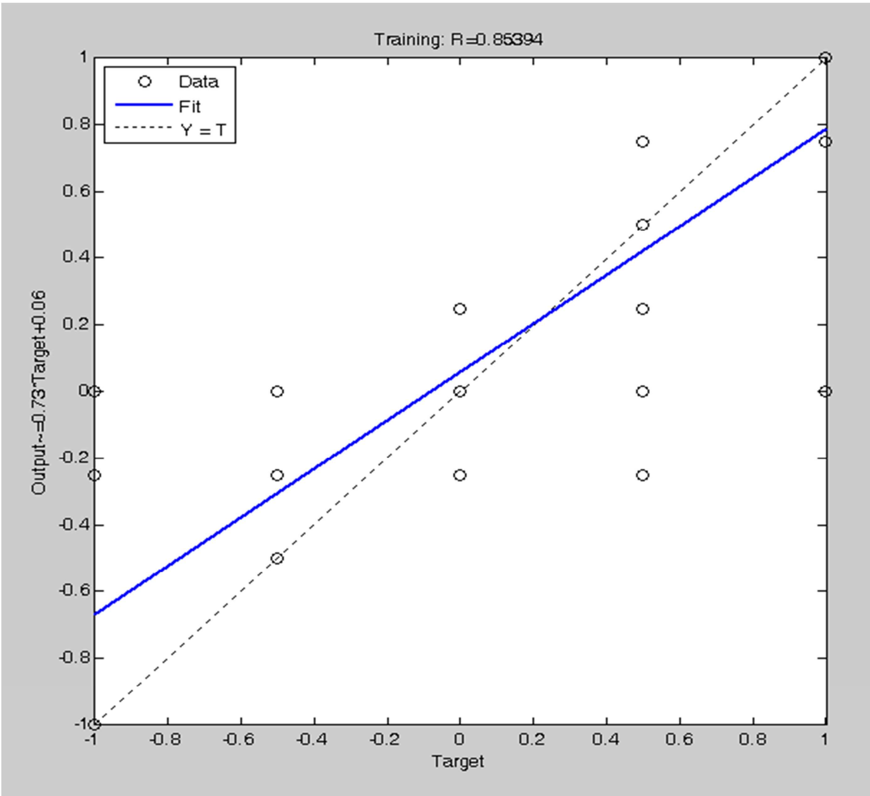


Figure 4.9 Actual Vs predicted of output 1 (Injury level)

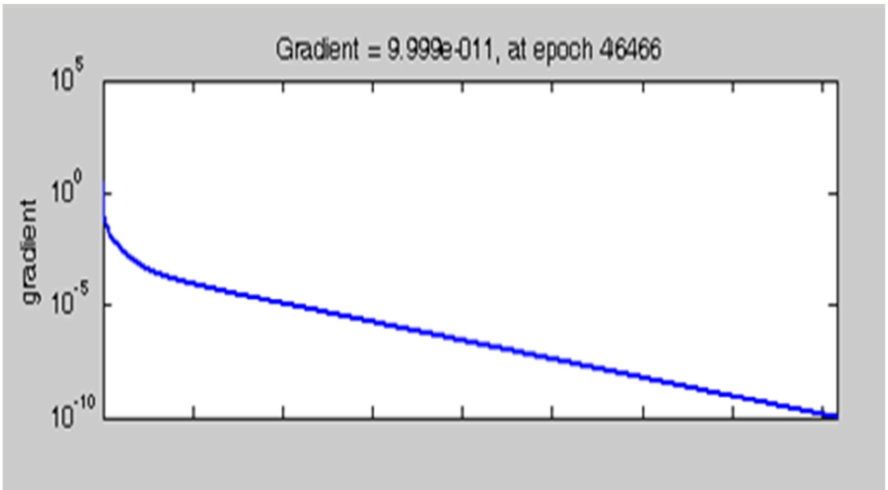


Figure 4.10 Mean square error of output 2 (Material damage)

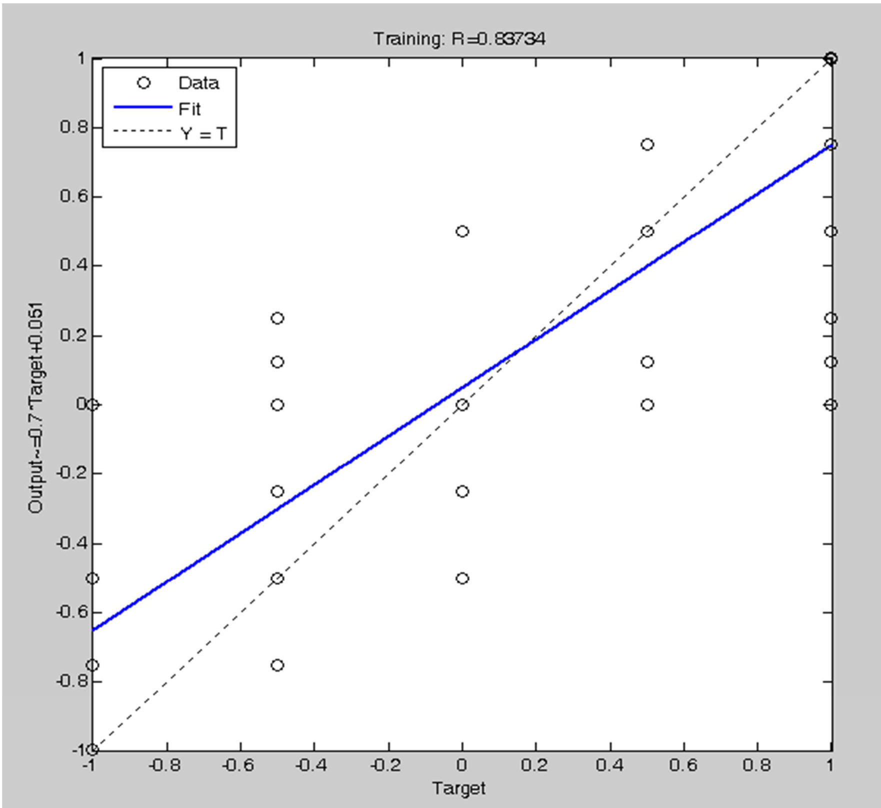


Figure 4.11 Actual Vs predicted of output 2 (Material damage)

4.5 Results and discussions

In order to find the robustness of the proposed model, sensitivity analysis was carried out. Sensitivity analysis is used to study the impact of changes in OHS performance along the various items (inputs) in OHS construct. The inputs in the test samples are varied one at a time systematically, up and down 10% (±10%) from its base value holding other items at their original values. By doing so, the average effect of input under consideration on the output can be estimated. Once the network is well trained, the relationship among inputs and outputs are established and network provides the scope for assessment of impact of each input on output. The scaled change in output is calculated with the current input increased by 10% and the current input decreased by 10%. The scaled change in output is given in equation 4.9.

$$\text{Scaled change in output} = \frac{\text{Scaled output for 10\% increase in input} - \text{Scaled output for 10\% decrease in input}}{2} \qquad (4.\ 2)$$

Thus, the results obtained are the scaled output change per 10% change in input. The calculation is repeated for every input and every fact and then averaged across all the facts, yielding a single-mean scaled change in output for each input criterion. Increase/decrease of an input from its base value results in increase/decrease in performance level. Logically, the net effect of change in input results in a positive score for average scaled change in output. About 98% of input items produced positive OHS performance changes, as expected. However, negative or reduction in performance level is also observed in all cases. This irregularity may be attributed to the noisiness of the survey data. Noisy data exist when safety officers and workers responding to a survey have a similar evaluation on individual questions but different evaluation of the overall OHS performance level.

This results in similar input data for the neural network with very different corresponding outputs (material damage and injury level). The averaged scaled change in output for two safety performances such injury level and material damage for three industry categories is shown in Table 4.1 and 4.2 respectively. A closer look at the results shows that changes in input level hardly influence the change in output in a linear sense. The non-linear relationship between the set of inputs and performance measures is difficult to establish but neural network provides a basic framework for the purpose capturing perception mechanism of the managers, safety officers and workers in an efficient manner. In order to find out the impact of input items on safety performance measures, a threshold value of 0.10 is considered. An item resulting in scaled change in output above 0.10 is treated as important item for improving OHS performance and management must find ways and means to implement them on priority basis. Items resulting less than 0.10 may be deferred without causing massive impact on OHS performance. It is to be noted from Table 4.1 and 4.2 that important items widely vary across three types of industries.

Table 4.1 Result of neural network model in output1 (Injury level)

Dimension	Items	Number of cycles	RMS error	Construction	Refractory	Steel
Preventive procedure	Item 21	40799	0.0125	0.081320	0.098210	0.102940*
	Item 24	40799	0.0125	0.145530*	0.274640*	0.257650*
	Item 29	40799	0.0125	0.183158*	0.244286*	0.227941*
	Item 34	40799	0.0125	0.040789	0.089643	0.094706
OHS training	Item 5	40799	0.0125	0.014474	-0.066430	0.126470*
	Item 12	40799	0.0125	0.034211	0.412500*	0.615000*
	Item 22	40799	0.0125	0.046842	0.008214	0.013529
Risk management	Item 31	40799	0.0125	0.116840*	0.168930*	0.134410*
	Item 33	40799	0.0125	-0.011580	0.036786	0.029118
Work practices	Item 2	40799	0.0125	0.029210	0.016070	0.044410
	Item 8	40799	0.0125	0.045260	0.236790	0.090290
	Item 13	40799	0.0125	0.077630	0.093210	-0.096180
Periodic plan	Item 6	40799	0.0125	0.025163	0.014286	0.020588
	Item 28	40799	0.0125	0.101316*	0.287857*	0.238824*
Continuous improvement	Item 10	40799	0.0125	0.051579	0.295000*	0.102059*
	Item 15	40799	0.0125	0.077895	0.057143	0.257941*
Injury avoidance	Item 3	40799	0.0125	0.066840	0.078570	0.094120
	Item 23	40799	0.0125	0.239210*	0.311070*	0.248240*
	Item 26	40799	0.0125	0.019526	0.313929*	0.295882*
Emergency plan	Item 19	40799	0.0125	0.431050*	0.574640*	0.543530*
	Item 27	40799	0.0125	0.147632*	0.166071*	0.166471*
Health care	Item 1	40799	0.0125	0.099737	0.092140	0.092941
	Item 18	40799	0.0125	0.148684*	0.184643*	0.173824*

*indicates average change in output above 0.10 for ±10% change in input

Table 4.2 Result of neural network model in output2 (Material damage)

Dimension	Items	Number of cycles	RMS error	Construction	Refractory	Steel
Preventive procedure	Item 21	46466	0.0125	0.014470	0.051070	-0.018820
	Item 24	46466	0.0125	0.012368	0.184036*	0.129412*
	Item 29	46466	0.0125	0.484210*	0.096357	0.826470*
	Item 34	46466	0.0125	0.037890	0.039640	-0.055290
OHS training	Item 5	46466	0.0125	0.083947	0.019643	0.085000
	Item 12	46466	0.0125	0.019210	0.064643	0.051765
	Item 22	46466	0.0125	0.199740*	0.209640*	0.205000*
Risk management	Item 31	46466	0.0125	0.031840	-0.096070	0.092057
	Item 33	46466	0.0125	-0.001316	0.185714*	0.162647*
Work practices	Item 2	46466	0.0125	0.051316	0.031071	0.056471
	Item 8	46466	0.0125	0.478684*	0.367500*	0.421588*
	Item 13	46466	0.0125	0.167630*	0.121790*	0.173420*
Periodic plan	Item 6	46466	0.0125	0.005263	0.032500	0.024710
	Item 28	46466	0.0125	0.005000	0.023929	0.016471
Continuous improvement	Item 10	46466	0.0125	0.005789	0.946430*	0.091471
	Item 15	46466	0.0125	0.112368*	0.053571	0.086765
Injury avoidance	Item 3	46466	0.0125	0.186580*	0.217140*	0.262940*
	Item 23	46466	0.0125	0.197110*	0.207140*	0.187350*
	Item 26	46466	0.0125	0.039211	0.068930	0.013820
Emergency plan	Item 19	46466	0.0125	0.216842*	0.263214*	0.255941*
	Item 27	46466	0.0125	0.140263*	0.224286*	0.188529*
Health care	Item 1	46466	0.0125	0.049740	0.013214	0.006180
	Item 18	46466	0.0125	0.031840	0.017857	0.006180

*indicates average change in output above 0.10 for ±10% change in input

The items showing average change in output above 0.10 for ±10% change in input are listed and ranked in descending order in Table 4.3 and 4.4 for OHS performance such as, injury level and material damage respectively. It can be observed from Table 4.3 that eight items such as, Item 19, Item 23, Item 29, Item 18, Item 27, Item 24, Item 31, and Item 28 are common items that contribute largely for improvement in injury level in all types of industries considered in this study. Similarly, it is obvious from

Table 4.4 that seven items, such as Item 8, Item 19, Item 22, Item 23, Item 3, Item 13, and Item 27, are common items that contribute largely for improvement in material damage in all types of industries. Of course, other items, apart from items mentioned above, contribute to OHS performance in specific industrial sector. For example, four items, such as Item 12, Item 26, Item 10, and Item 8 are other items, in addition to eight common items, contribute towards improvement of injury level in refractory industries. Similarly, six more items such as Item 12, Item 26, Item 15, Item 5, Item 21, and Item 10, in addition to eight common items contribute for improvement of injury level in steel industries. It is to be noted that steel industry needs more number of items for improving injury level because perception of risk in this sector is comparatively high. Secondly, in the steel sector, being mostly public enterprises and possessing organized workforce, formal OHS practices exist as per international guidelines. Further, the prioritization of items widely varies across industries for improvement of injury level. For example, Item 19 is most prioritized item for construction and refractory industries whereas Item 12 is the highest ranked item in steel sector (Table 4.3). The variation in prioritization of items reflects the present work practices, perception of OHS, policies operational at present, and the work environment. It is to be noted that, eight items are absolutely essential for improving safety perception with regard to injury level irrespective of type of industries. The minimum number of items may be increased if more industry types are considered. However, eight items are minimum number of items to instill a positive safety attitude among the work force. Such factors must be emphasized in safety policy formulation irrespective of organized or unorganized workforce. Recently, administrators are planning to extend insurance and social security system to unorganized workforce and enforce a law in this regard.

Table 4.3 Ranking of items (Injury level)

Construction		Refractory		Steel	
Item 19	0.431050[1]	Item 19	0.577464[1]	Item 12	0.615000
Item 23	0.239210[2]	Item 12	0.412500	Item 19	0.543530[1]
Item 29	0.183158[3]	Item 26	0.313929	Item 26	0.295882
Item 18	0.148684[4]	Item 23	0.311070[2]	Item 15	0.257941
Item 27	0.147632[5]	Item 10	0.295000	Item 24	0.257650[6]
Item 24	0.145530[6]	Item 28	0.287857[8]	Item 23	0.248240[2]
Item 31	0.116840[7]	Item 24	0.274640[6]	Item 28	0.238824[8]
Item 28	0.101316[8]	Item 29	0.244286[3]	Item 29	0.227941[3]
		Item 8	0.236790	Item 18	0.173824[4]
		Item 18	0.184643[4]	Item 27	0.166471[5]
		Item 31	0.168930[7]	Item 31	0.134410[7]
		Item 27	0.166071[5]	Item 5	0.126470
				Item 21	0.102940
				Item 10	0.102059

The superscript numbers indicate common items.

As shown in Table 4.4, seven items have been identified as common items that contribute largely so far as improvement in material damage in all types of industries is concerned. In addition to these items, there are some other items that contribute to OHS performance in specific industrial sector. For example, two items, such as Item 29 and Item 15 in construction and three items, such as Item 10, Item 33 and Item 24 in refractory industries are other items (in addition to seven common items) that contribute for improvement of material damage. Similarly, three more items, such as Item 29, Item 33, and Item 24 are other items that contribute for improvement of material damage in steel industries. It is to be noted that refectory and steel industries need more number of items for improving material damage because both types of industries use specialized production processes and needs better work practices, training, and clear visualization on occupational health. Prioritization of items widely varies across industries for improvement of material damage. For example, Item 29 is the most prioritized item for construction and steel industries whereas Item 10 is highest ranked item in refractory sector (Table 4.4). It is to be noted that, minimum number of common items for improving material damage is less than that for injury level. It indicates that all key players in the system are more concerned with health and safety than material damage.

Table 4.4 Ranking of items (Material damage)

Construction		Refractory		Steel	
Item 29	0.484210	Item 10	0.946430	Item 29	0.826470
Item 8	0.478684[1]	Item 8	0.367500[1]	Item 8	0.421588[1]
Item 19	0.216842[2]	Item 19	0.263214[2]	Item 3	0.262940[5]
Item 22	0.199740[3]	Item 27	0.224286[7]	Item 19	0.255941[2]
Item 23	0.197110[4]	Item 3	0.217140[5]	Item 22	0.205000[3]
Item 3	0.186580[5]	Item 22	0.209640[3]	Item 27	0.188529[7]
Item 13	0.167530[6]	Item 23	0.207140[4]	Item 23	0.187350[4]
Item 27	0.140263[7]	Item 33	0.185714	Item 13	0.173420[6]
Item 15	0.112368	Item 24	0.184.36	Item 33	0.162647
		Item 13	0.121790[6]	Item 24	0.129412

The superscript numbers indicate common items.

4.6 Conclusions

This study has given a classification and prediction model based on soft computing techniques (ANN) suitable for analyzing occupational injuries. The major contribution of this chapter is providing a systematic integrated approach for modeling safety officers' and workers' perceptions on occupational health and safety in the Indian industries. As safety is a sensitive issue in all kind of industrial setting, it is extremely important to find a base on which safety policy formulation can be made. The work environment in three sectors considered in this study is generally viewed as hazardous compared to other sectors due to usage of heavy equipment, unsafe and primitive tools, injurious materials and dust produced during processing. All of them increase the potential for serious occupational health and hazard issues. Therefore, it is evident that a focused effort towards occupational health is needed in these sectors. It can be inferred from the survey that the management, safety officers and workers have the opportunity as well as responsibility to influence the sense of safety and the quality of work environment. In this chapter the influence of each item of the valid instrument is judged through sensitivity analysis using artificial neural network (ANN). A construct suitable for improving OHS in these sectors has been developed and sector-wise perception of safety norms has been identified so that policy formulation and implementation become easier. The study reveals that item 19 (Firm has systems to identify risks in all job positions) for the outcome “injury level” and item 8 (Workers are sufficiently trained while entering firm, changing jobs or using new technique) for the outcome “materials damage” are most sensitive items to be dealt carefully. The incidence of serious or fatal occupational injuries occurs due to lack of knowledge, correct procedures, technical expertise, and inability of the internal actors to implement changes. The workers often are overexposed to occupational injury because they are concentrated in very high-risk industries and they know little or nothing about their rights, duties, and/or about the prevention methods available to them. Therefore, cultural adaptation of OHS measures must be promoted through commitment by both employers and employees.

CHAPTER 5

FRAMEWORK FOR SYSTEM DESIGN REQUIREMENT

5.1 Introduction

Today, the prime challenge for any organization (manufacturing or services) is to continually emphasize on the quality to cope with global competition. Therefore, various strategies need to be implemented for designing the product or services through adequate planning process. Occupational health and safety (OHS) is an important workplace behavior that can prevent injury, illness, material damage and death at work. For the above requirements, all organizations should establish and maintain a safe and healthy working environment, which will facilitate improve physical and mental health of employees. Improved OHS training and practice will assist the management to reduce cost and make the workplace safer for everyone. Therefore, it is of prime importance for socially responsible administrators to prioritize the system design requirements that bears in its ability to satisfy the internal customers (employees) through social marketing principles. To address this issue, the administrators must identify the system design requirements for safe environment to be improved through exhaustive analysis of apposite data related to safety issues. Increasing speed and volume of work, pressure for flexibility in organizations and people, and the slimming of organizations lead to strains and stresses on the staff of organizations. These have implications for the health of the work force and conditions at the workplace.

The success of an industry is evaluated based on the organization's performance on cost, time and quality constraints. However, with the extensive amount of work force employed, safety issues have become more important since some industries like construction, refractory and steel still have exhibited highest fatality and accident rates. The researchers have been focusing on improving the safety performance, both project based and industry based. Within the context of this chapter, the discussion focuses on managing parameters that minimize injury level discussed in Chapter 4. It has been demonstrated that eight items such as Item 19, Item 23, Item 29, Item 18, Item 27, Item 24, Item 31, and Item 28 are common items for three types of industries considered in this work. This chapter proposes the idea of building an injury minimizing OHS performance model using the concept of Quality Function Deployment (QFD) that can provide a more structured and organized way to analyze solution to the OHS management concern. Further, this chapter proposes a model for interpreting interrelation of system design requirements through Interpretive Structural Modelling (ISM).

The outline of the present chapter is as follows. Section 5.2 articulates the brief introduction of Quality Function Deployment (QFD) and Interpretive Structural Modeling

(ISM). Interrelationship of Design Requirements is elaborately described in section 5.3. Further the chapter describes the application of QFD and ISM in the competitive environment. The analysis of results is presented in section 5.4. Conclusions from the present study are summarized in section 5.5.

5.2 Quality function deployment (QFD) as a planning tool

Quality Function Deployment (QFD) facilitates the translation of a prioritized set of subjective customer requirements into a set of system level requirements during system conceptual design. A similar approach may be used to subsequently translate the system level requirements into a more detailed set of requirements at each stage of the design and development process. QFD is customer driven and translates customer needs into appropriate technical requirements in products and services. Sometimes this process of translation is referred to as the voice of the customer (VOC). Designers' need means implementing customer requirements into designs [205]. QFD is a highly effective and a structured planning tool to deal with customer needs more systematically and each translation uses a chart on the basis of House of Quality (HoQ) framework. The HoQ typically contains information on "what to do" (performance characteristic), "how to do" (engineering characteristics), and the integration of this information and the relevant benchmarking data [206]. The house of quality (HoQ) illustrated in Figure 5.2 shows how QFD is used to accomplish this. The left wall on the HoQ contains a listing of customer requirements. The roof on the HoQ is the technical/design requirements or the voice of engineering (VOE).

QFD was first conceptualized in the late 1960s [207]. In 1972, QFD was implemented successfully at the Kobe shipyards of Mitsubishi Heavy Industries Ltd. inspiring other industries to implement the technique throughout Japan. It remained a Japanese tool until the early 1980s. Following the article by Kogure and Akao and through Ford Motor Company and the Cambridge Corporation, QFD has entered the borders of the US and has started to play an important role at companies such as General Motors, Chrysler, Digital Equipment, Hewlett-Packard, AT and T, Procter and Gamble, and Baxter Healthcare [208,209]. There are two major organizations as sources of QFD viz. American Supplier Institute (ASI) and GOAL/QPC (a non-profit institution with the mission to help organizations and communities to grow and prosper since 1978) that developed their own models having many similarities to each other. The ASI employs a basic four-matrix method developed by Macabe, a Japanese reliability engineer, while GOAL/QPC uses a multiple matrix developed by Akao that incorporates many disciplines into a less structured format consisting of a matrix [209]. The technique of QFD is also extensively used in service sectors. Early applications of QFD in service organizations in Japan by Ohfuji, Noda and Ogino in 1981 applied for a shopping mall, a sports complex, and variety retail store [210]. Kaneko has been integrating QFD, reliability and quality circle activities in hotels, shopping centers and hospitals [211,212].

The QFD methodology begins with the accumulation of the voice of customer (customer requirements). To satisfy customers, it is necessary to understand their requirements and how well these requirements affect the satisfaction level of the customers. The relationships between the customer requirements and their satisfaction have been explained in Kano's model of quality consisting of three types of customer requirements such as normal requirements, expected requirements and exciting requirements as depicted in Figure 5.1 [2].

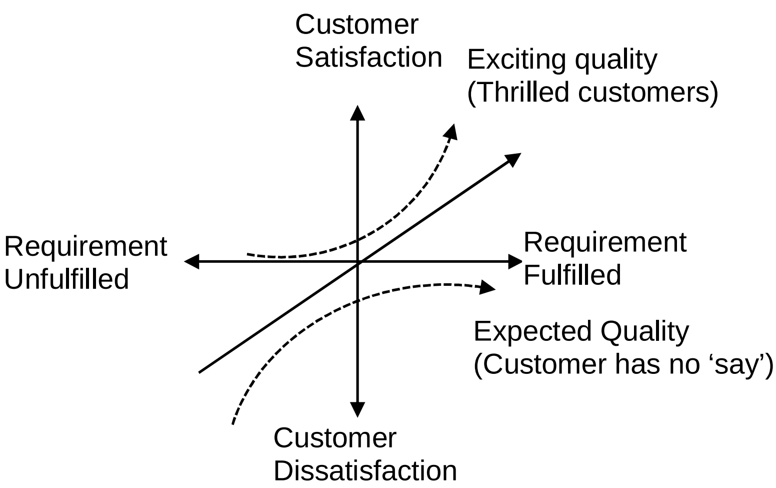


Figure 5.1 Kano's model of quality

The basic idea of QFD is to transform the above stated customer requirements into specific design requirements. QFD analysis starts by obtaining the customer requirements (CR_i) with respect to the product being designed. These requirements are commonly referred to as the 'whats' and can be derived through the interview/questionnaire survey. Once the 'whats' are established, the QFD team then determines the mechanism that would satisfy the 'whats'. These mechanisms are commonly referred to as 'hows'. The 'hows' comprises the list of technical descriptions of the product from the customer perspective. The technical descriptions (TD_j) might be linked with other elements of the product life cycle process including design activities (DA_j). Next, the QFD team establishes relationships between them. They assign a strength value of very weak, weak, moderate or strong to each relationship. Furthermore, the team will also assess each TD_j with respect to its interaction with the other TD_j to determine if there is positive, negative or no correlation. The product features are then related to themselves in the roof of the diagram using correlation symbols such as strong, moderate, weak and very weak. The strength values lie between 0 and 1. The QFD team incorporates all the information on a graphical display known as 'House of Quality'. This house provides a framework that guides the team through the QFD process. It is a matrix that identifies the 'whats' and 'hows', the relationship between them and criteria for deciding which of the 'hows' will provide the greatest customer satisfaction. The peak of the house identifies the interrelationships between the 'hows'. When the house of quality is complete, the QFD team can then analyze and use it to achieve a product/service realization that will allow the organization to enjoy greater customer and employee satisfaction, improved product/service performance and enhanced profitability [213]. Enhancements to the QFD process include adding importance measures to the customer requirements including target values for product design features and relating product design features to part and mechanism characteristics. Figure 5.2 shows a typical QFD matrix (house of quality) that is the foundation of QFD practices. The rows of the matrix in Figure 5.2 are the customer requirements i.e. what the customer wants in the product. The columns of the matrix shows what the manufacturer does to ensure the quality of the product. The right side of the matrix contains the planning information i.e. the importance rating, competitive analysis, target value, amount of scaling up necessary and the sales points. The relationships between customer requirements and design requirements are categorized in the body of the matrix. The important goal of QFD is to turn the design requirements into the detailed design activities. A full implementation of the QFD concept allows the customer requirements (CR_i) to be cascaded down through the technical descriptions (TD_j) and functional descriptions (FD_j) to design activities (DA_j) as illustrated in Figure 5.3.

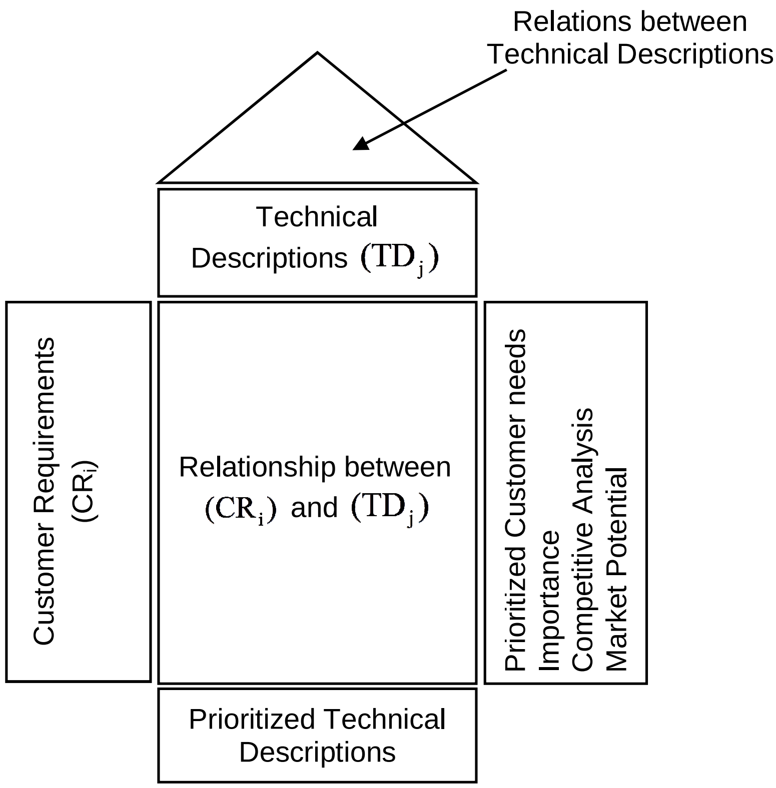


Figure 5.2 House of quality (QFD matrix)

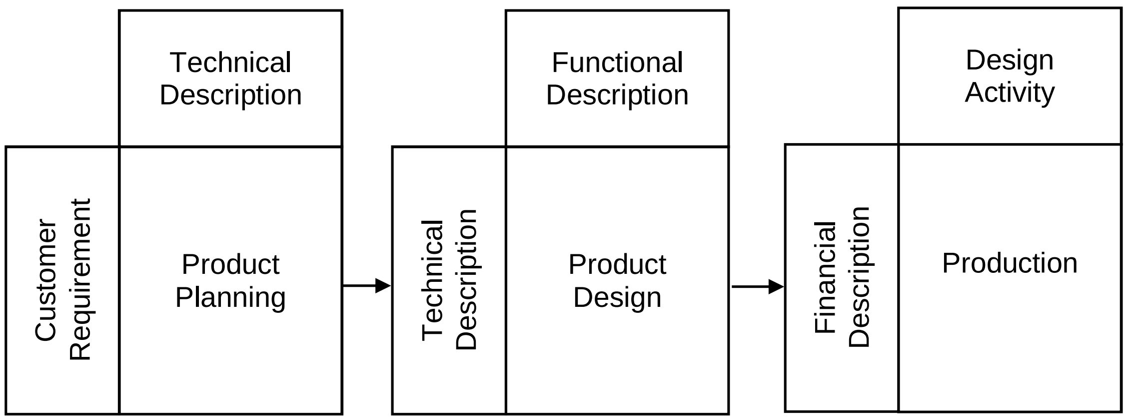


Figure 5.3 Phases of QFD

QFD's fundamental objectives are to:

(i) identify the customer

(ii) identify what the customer wants;

(iii) identify how to fulfil the customer's wants [214].

It can be employed to address almost any business situation requiring decision-making involving a multitude of criteria, requirements, or demands.

5.2.1 Application of QFD in the competitive environment

A review of the relevant literature reveals that significant gaps exist in implementing policy framework on OHS to reduce work place related injury. The goal of QFD is to translate often subjective quality criteria into objective ones that can be quantified and measured and which can then be used to design and manufacture the product. It is a complimentary method for determining how and where priorities are to be assigned in product development. The intent is to employ objective procedures in increasing detail throughout the development of the product [215]. QFD provides a framework for integrating customer's voice with engineering characteristic [216]. Lu and Kuei [217] applied QFD concept in strategic marketing planning and identified that QFD approach maximizes benefits for both customers and companies in the long run by determining the customer's needs, and then translating these needs into corporate goals and marketing objectives. Aungst et al. [218] has proposed integrating marketing models using QFD. Kotler [179] have applied tools like QFD, analytic hierarchy process (AHP) and competitive benchmarking to address managerial decision making process. Sahney [219] has applied QFD and ISM to identify performance indicators critical to success of online retailing. Lee et al. [220] established a product family that can satisfy various market needs and share design elements. They applied QFD to understand the correlation between customer needs and product design. The priority sequence and correlation of these design elements will be determined using the interpretive structure model.

Lee and Lin [221] used QFD to facilitate the new product development (NPD) process from product conceptualization to production requirements. Then, Fuzzy Delphi method is adopted to select the critical factors, and fuzzy interpretive structural modelling is applied to determine the relationships among the critical factors. The results are then used to construct houses of quality for QFD, which is incorporated by fuzzy analytic network process. Mahapatra and Khan [222] proposed a measuring instrument known as EduQUAL for evaluation of quality in Technical Education System (TES).

Factor analysis has been carried out on responses obtained through cross-sectional questionnaire survey on various items. Neural network models have been proposed to assess the degree of satisfaction of various stakeholders in TES. Finally, the QFD method is used to provide guidelines for administrators of the institutions to prioritize improvement policies needs to be implemented. Dikmen et al. [223] examined the applicability of QFD as a strategic decision-making tool after the construction stage of a housing project to determine the best marketing strategy to make a comparison between the performances of different competitors and to transfer the experience gained from the current project to the forthcoming projects. Buyukozkan and Berkol [224] studied sustainable supply chain management (SSCM) and provides economic, social and environmental requirements in material and service flows occurring between suppliers, manufacturers and customers by applying quality function deployment (QFD). Wang et al. [225] studied to establish a licensor selection model based on a hybrid model that embeds fuzzy logic within QFD for the patent transaction platform. Zohrabi and Nikzad [226] proposed a comprehensive framework in order to formulate strategy in educational organizations. The approach is based on Malcolm Baldrige National Quality Award (MBNQA) Education Criteria for selecting competitive strategies. Liu and Tsai [227] proposed to provide a prevention and improvement technique against occupational hazards in the construction industry using a fuzzy risk assessment method and two-stage quality function deployment (QFD), which represents the relationships among construction items, hazard types and hazard causes.

5.2.2 Application of QFD on OHS practices

Having found out important eight items of OHS practices on social marketing through neural approach (Chapter 4), it is necessary to design a system which fulfils the requirements and prioritization of the system design requirements so that proactive measures can be taken. The goal of QFD is to translate often subjective quality criteria into objective ones that can quantify and measures, and which can then be used to design a system for minimizing injury level. It is a complimentary method for determining how and where the priorities are to be assigned in a system design. QFD uses a series of matrices to document information collected and represent the QFD team’s plan for a customer need and system design requirements.

The House of Quality (HoQ) (matrix) is the most recognized form of QFD. HoQ is constructing from six major components as explain below.

- Customer needs (WHATs): A structured list of requirements derived from experts feedback
- Design requirements (HOWs): A structured set of relevant and measurable services/ characteristics which are required for fulfilling WHATs.
- Planning matrix (Left matrix): Gives customer/expert perceptions observed in surveys. It includes the relative importance of requirements.
- Interrelationship matrix (Centre matrix): Gives the expert's perceptions of interrelationships between design requirements and customer needs. An appropriate scale is applied and illustrated using symbols or figures. Filling this portion of the matrix involves discussions.
- Design correlation (Top) matrix: Used to identify where design requirements support or impede each other in the system or product design.

The eight common deficient safety items (injury level), such as Item 19, Item 23, Item 29, Item 18, Item 27, Item 24, Item 31, and Item 28, found in the neural network model are treated as customer needs. Keeping in view of the customer needs, the followings nine system design requirements are considered. These design requirements are placed at the top of HoQ (Figure 5.4) and they represent the activities to cope up with customer needs.

1. Regularity in preventive maintenance work
2. Regular consultation of management with employees on safety issues
3. Management committee and reward system
4. Safety committee and reward system
5. Up-gradation of safety knowledge through continuous assessment and re-training
6. Adequate training for organising materials and human resources quickly to response any emergency
7. Analysis of possible hazards and preventive measures in the process environment
8. Regular inspection of resources and up-gradation of safety tools and equipment
9. Compliance of safety rules and regulations and conduct safety audit

The various steps involved in QFD methodology:

Step 1: This step identifies eight items of safety performance from the results of neural networks i.e. customer needs (WHATs). The items are entered into HoQ in the room called voice of customers shown in Figure 5.4.

Step 2: Prioritise the customer needs (safety performance items) using a number that reflects the importance of each requirement of workers in the industry.

Step 3: An exhaustive analysis to assess the relationship between each item of the customer needs. The interrelation are typically defined as strong ($\omicron$ = 0.8), moderate (θ = 0.6), weak (Δ = 0.4) and very weak ($\bullet$ = 0.2). The interrelationship matrix is attached to left side of the HoQ.

Step 4: Keeping in view of stated items of safety performance for implementation of injury level, the nine system design requirements are considered through literature reviews and discussions with experts from the industry.

Step 5: A correlation matrix is formed, which indicates how the system designs are related to one another. The scale, used in step 3, is used here for describing the same and is entered on the top of HoQ which forms the top matrix of the house. It is called the interrelation between HOWs.

Step 6: Determine relationships between WHATs and HOWs. Construct the matrix using the intersection of each row (what) with each column (how), which represents the strength of relationship between each what and each how.

Step 7: A revised rating is determined from the left matrix of Figure 5.4 using equation 5.1 and is placed at right side of HoQ.

$$\text{Rating}_i = Z_i + \frac{1}{n-1} \sum_{j \neq 1}^{n} B_{ij} Z_j \qquad (5.1)$$

where Z_i is the initial customer rating for customer need i and B_{ij} denotes the interrelationship between customers' needs i and j.

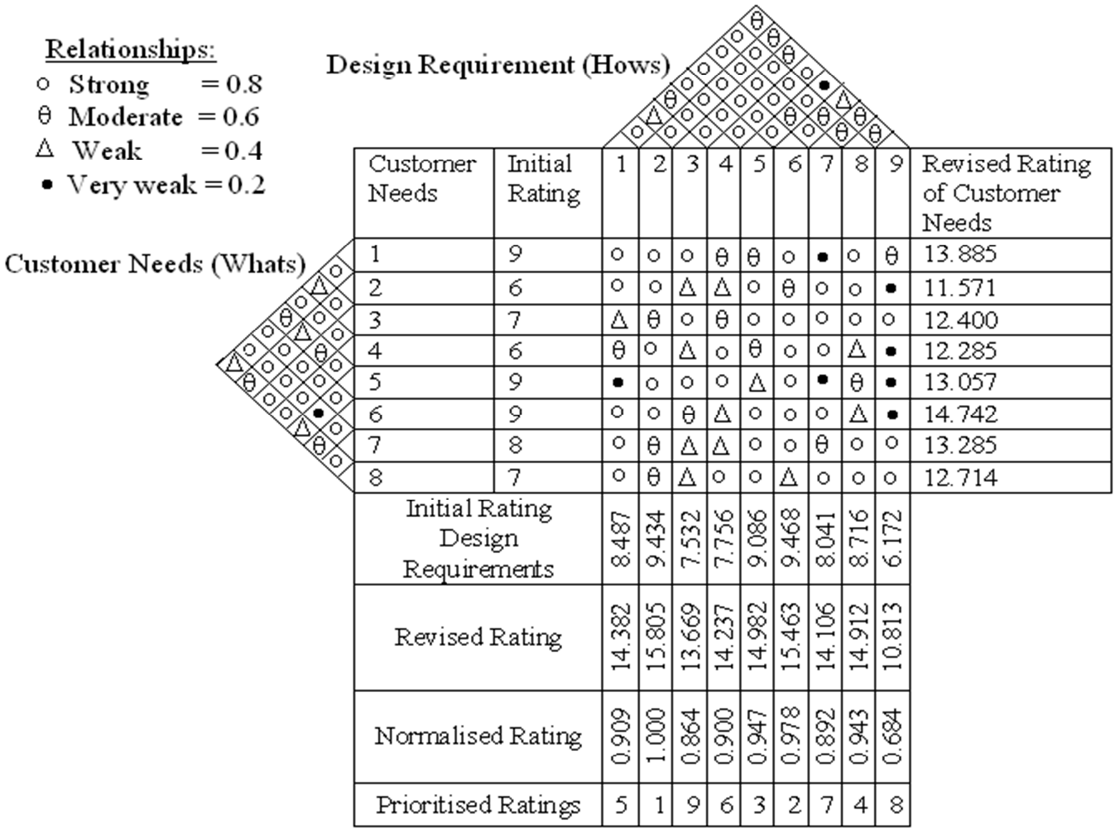
Step 8: The individual rating for each design requirement is calculated using equation (5.2) and placed at the bottom row 1 of the HoQ.

$$\text{Individual Rating}_i = \sum_j^{n} A_{ij} X_j \qquad (5.2)$$

where A_{ij} and X_j denote the relative importance of the i^{th} characteristic with respect to the j^{th} customer need in the relationship matrix and the importance of the j^{th} customer need perceived by the customer i.e. the customer rating and n is the number of customer needs.

Step 9: A revised rating for each design requirement is determined as for requirement (customer) needs using equation 5.1 and is entered in row 2 at bottom of HoQ.

Step 10: The final ratings of design requirements are normalized by dividing each rating with maximum available rating. The final ratings are tabulated in row 3 at bottom of HoQ. Using final ratings, the design requirements are prioritized as per their importance.



Customer Needs	Initial Rating	1	2	3	4	5	6	7	8	9	Revised Rating of Customer Needs
1	9	○	○	○	θ	θ	○	•	○	θ	13.885
2	6	○	○	Δ	Δ	○	θ	○	○	•	11.571
3	7	Δ	θ	○	θ	○	○	○	○	○	12.400
4	6	θ	○	Δ	○	θ	○	○	Δ	•	12.285
5	9	•	○	○	○	Δ	○	•	θ	•	13.057
6	9	○	○	θ	Δ	○	○	○	Δ	•	14.742
7	8	○	θ	Δ	Δ	○	○	θ	○	○	13.285
8	7	○	θ	Δ	○	○	Δ	○	○	○	12.714
Initial Rating Design Requirements		8.487	9.434	7.532	7.756	9.086	9.468	8.041	8.716	6.172	
Revised Rating		14.382	15.805	13.669	14.237	14.982	15.463	14.106	14.912	10.813	
Normalised Rating		0.909	1.000	0.864	0.900	0.947	0.978	0.892	0.943	0.684	
Prioritised Ratings		5	1	9	6	3	2	7	4	8	

Figure 5.4 OHS House of Quality

The revised rating for each design requirement is calculated for the customer needs using equation 5.2. The final rating of design requirements are normalized by dividing each rating with the maximum available rating. The final ratings are shown in Figure 5.4. Using the normalized ratings, the design requirements are prioritised as per their importance of design requirements. It is shown that design requirement 2 (Regular consultation of management with employees on safety issues) is the most prioritised design requirement whereas design requirement 3 (Management committee and reward system) is least prioritised design requirement.

5.3 Interpretive structural modelling (ISM) and interrelationship of design requirements

Interpretive Structural Modeling was proposed by Warfield 1974a, 1974b, 1976) as a computer assisted methodology [1,228,229]. It is used to derive an understanding of the interrelationships amongst complex elements, and allows a set of different and directly related elements to be structured into a comprehensive systemic model [230]. Therefore, this chapter applies ISM to build a relation map to identify the independence or dependence of all criteria. The theory of ISM is based on discrete mathematics, graph theory, social sciences, group decision-making, and computer assistance [231-234]. The first step of ISM is to identify the variables relevant to the problems or issues by calculating a binary matrix, called relation matrix. It then extends with a group problem-solving technique. A structural self-interaction matrix (SSIM) is then developed based on a pair-wise comparison of variables. The SSIM is formed by asking questions such as, "Does criterion e_i affect criterion e_j?". If the answer is yes, then $\pi_{ij} = 1$; otherwise, $\pi_{ij} = 0$. Transitivity is considered to calculate a reachability matrix next. Finally, the operators of the Boolean multiplication and addition are applied to obtain a final reachability matrix, which can reflect the convergence of the relationship among the elements. The ISM process transforms unclear, poorly articulated mental models of systems into visible and well-defined models useful for many purposes. It is a method for developing hierarchy of system enablers to represent the system structure. ISM is an interactive learning process in which a set of different and directly related elements are structured into a comprehensive systematic model. After having the house of quality model of nine design requirements, it is necessary to find a reachability and antecedent using Interpretive Structural Modelling (ISM).The basic idea of ISM is to decompose a complicated system into several subsystems (elements) by using practical experience of experts and their knowledge [235].

SSIM can be described as below:

$$D = \begin{matrix} & \begin{matrix} e_1 & e_2 & \cdots & e_n \end{matrix} \\ \begin{matrix} e_1 \\ e_2 \\ \vdots \\ e_m \end{matrix} & \begin{bmatrix} 0 & \pi_{12} & \cdots & \pi_{1n} \\ \pi_{21} & 0 & \cdots & \pi_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \pi_{m1} & \pi_{m2} & \cdots & 0 \end{bmatrix} \end{matrix} \quad (5.3)$$

The e_i means the i^{th} element. The π_{ij} means the interrelationship between the i^{th} and the j^{th} elements. D is an SSIM. After establishing the SSIM, we can then convert it into a reachability matrix. Its transitivity is then checked with Equations. (5.4) and (5.5) [228,236]:

$$M = D + I \qquad (5.4)$$

$$M = M^k = M^{k+1}, k > 1 \qquad (5.5)$$

where I is the unit matrix, k denotes the powers, and M^* is the reachability matrix. Note that the reachability matrix is under the operations of the Boolean multiplication and addition (i.e. $1 \cdot 1 = 1,\ 1 + 1 = 1,\ 1 \cdot 0 = 0,\ 1 + 0 = 0 + 1 = 1,\ 1 \cdot 0 = 0 \cdot 1 = 0$). For example:

$$M = \begin{bmatrix} 1 & 0 \\ 1 & 1 \end{bmatrix},\ M^2 = \begin{bmatrix} 1 & 0 \\ 1 & 1 \end{bmatrix}$$

The important characteristics of ISM are as follows:

- This methodology is interpretive as the judgment of the group decides whether and how the different elements are related.
- It is structural on the basis of mutual relationship; an overall structure is extracted from the complex set of elements.
- It is a modelling technique, since specific relationships and overall structure are portrayed in a digraph model.
- It helps to impose order and direction on the complexity of relationships among various elements of a system.

5.3.1 Application of Interpretive Structural Modelling (ISM)

Interpretive Structural Modelling (ISM) has been applied in various fields, and some recent works are presented below in Table 5.1.

Table 5.1 Application of ISM

Authors	Theories or Applications
Bolanos et al. [237]	To purposed the clarification of the perceptions of different individuals in a managerial group in order to improve strategic group decision-making process using ISM.
Sahney et al. [238]	To proposed an integrated framework for quality in education by applying SERVQUAL, quality function deployment, ISM and path analysis.
Agarwal et al. [1]	To understand the characteristics and interrelationship of

	variables in an agile supply chain.
Thakkar et al. [239]	To develop a balanced scorecard (BSC) framework using cause and effect analysis, ISM and ANP for performance measurement.
Faisal et al. [240]	To employed ISM to identify various information risks that could impact a supply chain and to present a risk index to quantify information risks.
Kannan and Haq [241]	To understand the interactions of criteria and sub-criteria that is used to select the supplier for the built-in-order to supply chain environment.
Qureshi et al. [242]	To modeled the logistics outsourcing relationship variables to enhance shippers' productivity and competitiveness in logistical supply chain.
Singh et al. [243]	To construct a structural relationship of critical success factors for implementing advanced manufacturing technologies.
Upadhyay et al. [244]	To use content analysis, nominal group technique (NGT) and ISM to develop a hierarchy framework for quality engineering education.
Thakkar [245]	To propose an integrated mathematical approach based on ISM and graph theoretic matrix for evaluating buyer-supplier relationships.
Yang et al. [246]	To study the relationships among the sub-criteria and use integrated fuzzy MCDM techniques to study the vendor selection problem.
Wang et al. [247]	To analyze the interactions among the barriers to energy-saving projects in China.
Chidambaranathan et al. [248]	To develop the structural relationship among supplier development factors and to define the levels of different factors based on their dependence power and mutual relationships.
Mukherjee and Mondal [249]	To examined relevant issues in managing the remanufacturing technology for an Indian company.
Lee et al. [220]	To determine the interrelationship among the critical factors for technology transfer of new equipment in high technology industry and apply the FANP to evaluate the technology transfer performance of equipment suppliers.
Lee et al. [250]	To determine the interrelationship among the criteria in a conceptual model to help analyze suitable strategic products for photovoltaic silicon thin-film solar cell power industry.
Lee et al. [251]	To propose an integrated model, this applies ISM to understand the interrelationship among criteria, for evaluating various technologies for a flat panel manufacturer.
Luthra et al. [252]	To identify the barriers to implement Green Supply Chain Management (GSCM) in Indian automobile industry and to prioritize them. The structured model developed will help to understand interdependence of the barriers. The classification of barriers has been carried out based upon dependence and driving power with the help of MICMAC analysis and Interpretive Structural Modelling (ISM).

5.3.2 Application of ISM in OHS

Keeping in view the contextual relationships in nine elements (design requirements), the existence of a relationship between two elements, (i and j) and the associated direction of relationship has been identified. The procedural steps for ISM are listed as follows:

1. Identification of variables: On the basis of prioritisation of nine design requirements from the house of quality, the variables are identified.
2. Contextual Relationship: From the identified elements in step 1, a contextual relationship is identified among them with respect to whom pairs of variables would be examined. After resolving the system design requirement set under consideration and the contextual relation, a structural self-interaction matrix (SSIM) is prepared. Four symbols are used to denote the direction of relationship between the criterion (i and j):

   V - for the relation from element i to element j and not in both directions

   A - for the relation from element j to element i and not in both directions

   X - for both the directional relations from element i to element j and j to i

   O - if the relation between the elements did not appear valid

Based on the experts' judgements, interaction among the various elements is established using the contextual relationships and the SSIM matrix for 1 to 9 design requirements are described in Table 5.2. The relation V means design requirement 1 (Regular consultation of management with employee's safety issues) helps to achieve design requirement 8 (Compliance of safety rules and regulations and conduct safety audits). The meaning of A shows that design requirement 9 (Management commitment to safety and enforcement policy) helps to achieve design requirement 1 (Regular consultation of management with employee's safety issues). Similarly, the relation X in design requirement 1 (Regular consultation of management with employee's safety issues) and 6 (Safety committee and reward system) that both design requirement helps to each other, in addition to relation O shows the relation between the design requirement are not valid. Again, to adequate training for organizing material and human resources quickly to respond any emergency is refer as design requirement 2 and design requirement 8 (Compliance of safety rules and regulations and conduct safety audits).

Table 5.2 Structural self-interaction matrix (SSIM)

Sl. No.	Variables	9	8	7	6	5	4	3	2
1	Regular consultation of management with employee's safety issues.	A	V	V	X	A	V	V	V
2	Adequate training for organizing material and human resources quickly to respond any emergency.	V	O	A	X	A	V	V	
3	Up-gradation of safety knowledge through continuous assessment and re-training.	A	V	A	V	A	V		
4	Regular inspection of resources and up-gradation of safety tools and equipment.	A	O	A	A	A			
5	Regularity in preventive maintenance work.	V	V	V	V				
6	Safety committee and reward system.	X	V	V					
7	Analysis of possible hazards and preventive measures in the process environment.	A	O						
8	Compliance of safety rules and regulations and conduct safety audits.	A							
9	Management commitment and reward system.								

3. Initial Reachability matrix: The design requirements of the system in the SSIM is transformed into a binary matrix called the initial reachability matrix by substituting V, A, X, O with 1 and 0 using the following the following four substitution of 1's and 0's are:

   - If the $(i,\ j)$ entry in the SSIM is V, then the $(i,\ j)$ entry in the reachability matrix becomes 1 and the $(j,\ i)$ entry becomes 0.
   - If the $(i,\ j)$ entry in the SSIM is A, then the $(i,\ j)$ entry in the reachability matrix becomes 0 and the $(j,\ i)$ entry becomes 1.
   - If the $(i,\ j)$ entry in the SSIM is X, then the $(i,\ j)$ entry in the reachability matrix becomes 1 and the $(j,\ i))$ entry also becomes 1.
   - If the $(i,\ j)$ entry in the SSIM is O, then the $(i,\ j)$ entry in the reachability matrix becomes 0 and the $(j,\ i)$ entry also becomes 0.

The above rules applied in the initial reachability matrix for the design requirements shown in Table 5.3.

Table 5.3 Initial reachability matrix

Design requirements	1	2	3	4	5	6	7	8	9
1	1	1	1	1	0	1	1	1	0
2	0	1	1	1	0	1	0	0	1
3	0	0	1	1	0	1	0	0	1
4	0	0	0	1	0	0	0	0	1
5	1	1	1	1	1	1	1	1	1
6	1	1	0	1	0	1	1	1	1
7	0	1	1	1	0	0	1	0	0
8	0	0	0	0	0	0	0	1	0
9	1	0	1	1	0	1	1	1	1

4. Final Reachability Matrix: The reachability matrix obtained in step 3 is converted into the final reachability matrix by scrutinizing it for transitivity. If the transitivity rule is not found to be satisfied, the SSIM is reviewed and modified by the specific feedback about transitive relationship from the experts. From the revised SSIM, the reachability matrix is again worked out and tested for the transitivity rule. The transitivity of the contextual relation is a basic assumption in ISM which states that if element A is related to B and B is related to C, then A is related to C. After checking transitivity, the final reachability matrix is shown in Table 5.4.

Table 5.4 Final reachability matrix

Design requirements	1	2	3	4	5	6	7	8	9	Driver power
1	1	1	1	1	0	1	1	1	1*	8
2	1*	1	1	1	0	1	1*	1*	1	8
3	1*	1*	1	1	0	1	1*	1	1*	8
4	1*	0	1*	1	0	1*	1*	1*	1	7
5	1	1	1	1	1	1	1	1	1	9
6	1	1	1*	1	0	1	1	1	1	8
7	0	1	1	1	0	1*	1	1*	1*	7
8	0	0	0	0	0	0	0	1	0	1
9	1	1*	1	1	0	1	1	1	1	8
Dependence	7	7	8	8	1	8	8	9	8	

5. Level Partition Reachability Matrix: The reachability and antecedent set for each element is found out from final reachability matrix. The reachability set includes criteria itself and others which it may help to achieve and antecedent set consists of itself and other criterion which helps in achieving it. Subsequently, the intersection set is derived and the variable having reachability and intersection

set same is given top level in ISM hierarchy. Table 5.5 shows the first iteration where element 3 and 8 are found to exist in level I.

Table 5.5 Iteration 1

Design requirements	Reachability	Antecedent set	Interaction	Level
1	1,2,3,4,5,6,7,8,9	1,5,6,9	1,6,9	
2	1,2,3,4,6,7,9	1,2,3,5,6,7,9,	1,2,3,4,6,7,9	
3	1,2,3,4,6,7,9	1,2,3,4,5,6,7,9	1,2,3,4,6,7,9	I
4	1,3,4,6,7,8,9	1,2,3,4,5,6,7,9	1,2,3,4,6,7,9	
5	1,2,3,4,5,6,7,8,9	5	5	
6	1,2,3,4,6,7,8,9	1,2,3,4,5,6,7,9	1,2,3,4,6,7,9	
7	2,3,4,6,7,8,9	1,2,3,4,5,6,7,9	2,3,4,6,7,9	
8	8	1,2,3,4,5,6,7,8,9	8	I
9	1,2,,34,6,7,8,9	1,2,3,4,5,6,7,9	1,2,3,4,6,7,9	

The top level element in the hierarchy would not help to achieve any other element above its own level. Once the top level element is found out, it is separated from other elements. Similar iteration process is repeated to find the criteria in the next level and is continued till the level of each element is found (Table 5.6 and 5.7).

Table 5.6 Iteration 2

Design requirements	Reachability	Antecedent set	Interaction	Level
1	1,2,4,6,7,9	1,2,4,5,6,9	1,2,4,6,9	
2	1,2,4,6,7,9	1,2,5,6,7,9	1,2,6,7,9	
4	1,4,6,7,9	1,2,4,5,6,7,9	1,4,6,7,9	II
5	5	1,2,4,5,6,7,9	5	II
6	1,2,4,6,7,9	1,2,4,5,6,7,9	1,2,4,6,7,9	II
7	2,4,6,7,9	1,2,4,5,6,7,9	2,4,6,7,9	II
9	1,2,4,6,7,9	1,2,4,5,6,7,9	1,2,4,6,7,9	II

Table 5.7 Iteration 3

Design requirements	Reachability	Antecedent set	Interaction	Level
1	1,2	1,2	1,2	III
2	1,2	1,2	1,2	III

6. Development of ISM Model: Figure 5.5 shows the Interpretive Structural Modelling. After having the levels of the design requirements identified, the relation between the design requirements is drawn with the help of an arrow. The diagraphs, thus drawn are complex in nature. The diagraph gives information about hierarchy between the design requirements for successful implementation

OHS in Indian industry which helps the internal marketing of the organizations. It is shown that two design requirements are most sensitive for minimizing injury level in the organization, design requirements 1 (Regular consultation of management with employee's safety issues) and design requirements 2 (Adequate training for organizing materials and human resources quickly to respond any emergency).

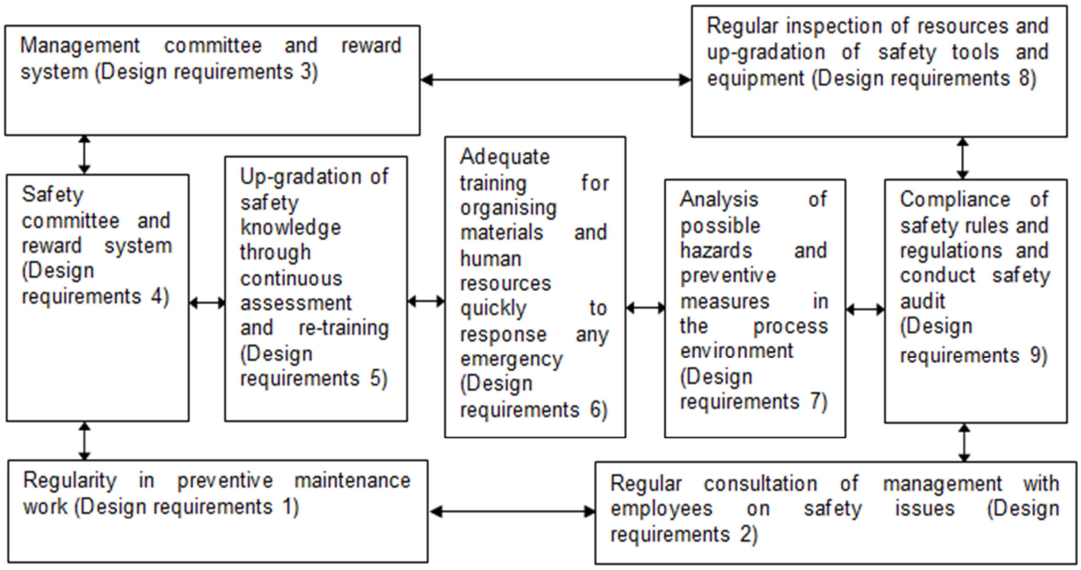


Figure 5.5 ISM based model for safety performance

The MICMAC analysis has been done by drawing a simple two dimensional graph (Figure 5.6). The objective of the MICMAC analysis is to analyze the driver power and dependence power of variables. The design requirements of OHS implementation in the social marketing are classified into four clusters. The first cluster consists of autonomous variables that have weak driver power and weak dependence. These variables are disconnected from the system, with which they have only a few but strong links because not a single item loaded. The second cluster consists of the dependent variable that has weak driver power but strong dependence with one item loaded (design requirements 8). The third cluster has the linkage variables that have strong driving power and also strong dependence. These variables are unstable in that any action on these variables will have an effect on others and also feedback effect on themselves. Here, seven items are loaded (design requirements 1, design requirements 2, design requirements 3, design requirements 6, design requirements 9, design requirements 4 and design requirements 7). The fourth cluster includes the independent variables having strong driving power but weak dependence having one item loaded (design requirements 5). It is observed that variables with very strong driving power are called the key variables, fall into the category of independent variables. The driving power and the dependence of each of the variables are calculated.

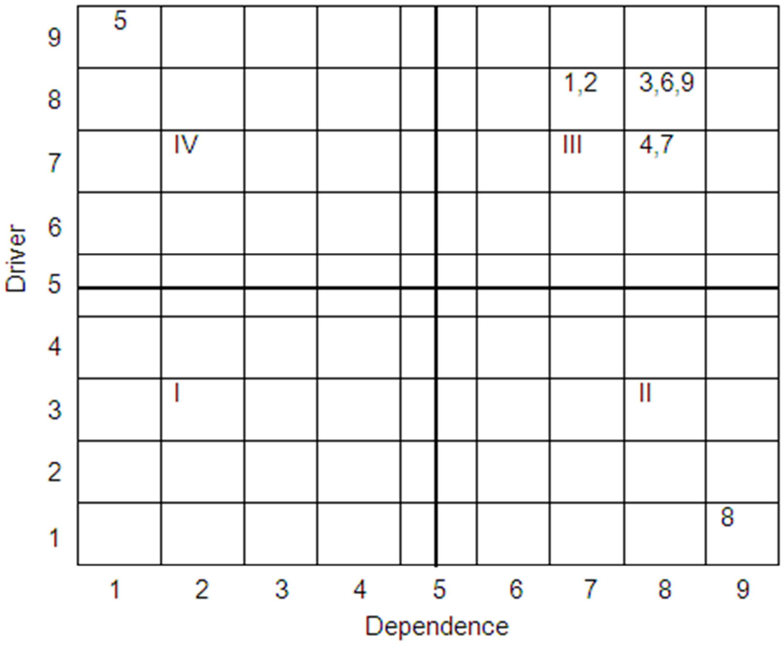


Figure 5.6 Driving power and dependence diagram

5.4 Results and discussions

This chapter has outlined a comprehensive methodology for the occupational health and safety management in an emerging context in social marketing of business succession using QFD and ISM approach. The methodology offers the potential and feasibility for application within a real business environment because of its simple structure. The results and findings of the research proposed above can serve as bases for the design and implementation of an effective social marketing program targeted at construction, refractory and steel industry workers in India. After factor analysis of thirty four items, twenty three items are considered under nine factors. To get the most prioritized items for minimizing injury levels, eight most sensitive items are emphasized using back propagation module of neural network. Having resolved at eight prioritized items of OHS practices through neural network, it is necessary to address the system design requirements (HOWs) which will fulfill the requirements of overcoming these deficient items using QFD. It is seen that design requirement 2 (Regular consultation of management with employees on safety issues) is the most prioritized item while design requirement 3 (management committee and reward system) is least prioritized design requirement. Reachability and antecedent of system design requirements are depicted in the form of a hierarchy through diagraph using Interpretive Structural Modelling (ISM) for the ease of managers while considering safety policy formulation. The concepts of internal marketing can be implemented by addressing the important issues of OHS for improving motivation and satisfaction level of internal customers. This research helps to influence the effectiveness of social marketing and improve workplace safety. Directing more attention towards the practice of social marketing can enhance the effectiveness of campaigns to reduce workplace injuries.

5.5 Conclusions

The study provides a generic framework on social marketing in the light of technological advances, global competition, re-alignment of organizational processes with the markets for dealing new rules of corporate strategy and outsourcing in order to access or extend organizational capabilities. Specifically, it describes how marketing strategy is evolving within the context of social marketing in a competitive and organizational environment. A widespread problem faced in the field on occupational injury prevention. There is apparent pressure on the part of management to achieve results on short-term basis leading to suppression of the long-term strategies within the context of a broad strategic plan. It is recommended that a more long-term and strategic view is needed to adequately identify and address the barriers on implementation of OHS policies. The study not only captures the voice of internal customers to reduce injury level but also proposes a methodology as to how to improve the system requirements. The hierarchical structure of design requirements helps the managers to resolve the complex issues of OHS policy implementation.

CHAPTER 6

PREDICTION OF ACCIDENTS USING FUZZY LOGIC

6.1 Introduction

Despite the fact that a large number of studies on occupational accidents, risk assessment, or safety practices have been published, only a few studies utilize a reliable methodology for prediction of different types of accidents [71,81,86,253]. In this chapter, a fuzzy logic approach (FIS- Fuzzy Inference System) has been proposed to predict accidents in three types of industries. Assimilating past data, subjective judgment and site inspections, types of accident are determined. A fuzzy expert system for prediction of accidents in Indian industries has been designed. The related parameters are described using fuzzy linguistic variables and a fuzzy rule-based structure has been used to deal with uncertain causal relationships between these parameters and accidents per annum. The methodology may serve as a robust control system for continuous assessment and improvement of safety performance. The importance of this study stems from the current lack of formal integrated methodologies for interpreting and evaluating accident rate and expenses incurred on safety planning in an industry. This approach is an efficient tool for safety professionals since it facilitates the prediction of different types of occupational accidents with reasonable accuracy.

In the rapidly globalized world, safety performance is a key issue for the industries to become a world class competitor. Occupational accidents may lead to permanent disabilities or deaths and/or economic losses or both. Death of employees or their permanent disability causes economic loss and social problems for employers, employees and their families. Occupational accidents can be reduced through effective preventive measures by investing on safety equipment’s, training, and educating the employees, process design, and machinery. In order to develop a good safety culture, attitude of the workers needs to be reoriented by adopting best practices, good housekeeping, change in work culture, and work practices. Occupational accidents are as common in India as in many other developing countries.

The responsibility for safety in an organizational context must be shared by employers, employees, trade unions, and related state authorities to determine the outcomes of present safety practices. To start with, employers should emphasize on the concept of occupational safety and invest in preventative measures. Further, employers and employees should receive awareness raising training so that employees are careful about occupational accidents and act responsibly. In the drastically change of climate, safety has always been a major concern in the Indian industrial setting. As safety performance is a sensitive issue involving of human life, the active resource in all aspects of life and its continuity must be ensured [99]. Safety evaluation (also called risk assessment) aims to identify and analyze risk factors existing in a system with the principles and methods of system safety engineering for the purpose of the realization of system safety. Safety evaluation determines the possibility and severity of accidents and occupational hazards in the system, which is useful to provide a scientific basis for the management and decisions of accident prevention.

Modern industries are generally large-scale ones involving, high-level automation and complex processes. An accident causes serious impact on the lives and health of employees, and manufacturing facilities may be damaged heavily. However, safety evaluation can assist to avoid or reduce to minimum the possibility and loss of an accident. Nowadays, safety management is less concerned with reacting to accidents when they happen; rather orientation is increasingly towards prevention. Prevention requires knowledge about how and where employees are exposed to hazardous situations, and in what ways, the risks are associated [254]. It has been suggested that the methods of risk and safety prediction should be developed along with injury and epidemiological studies.

6.2 Proposed methodology

The modeling of uncertainty in a risk exposure refers to the explicit quantification of probabilities and potential consequences based on all the information available about risks under consideration. In any project, uncertainties of risk events may be attributed to the randomness inherent in nature and to the lack of sufficient data related to the chances of their occurrence and potential consequences. As a result of such uncertainties, the accidents cannot be predicted with certainty. The experts with in-depth knowledge in such projects can provide a valuable opinion on uncertainties. Therefore, the opinion obtained from hundreds of experts with many years of experience needs to be utilized. Nonetheless, the quantification of their valuable knowledge to estimate the uncertainties is not an easy task. However, fuzzy set theory is a convenient mathematical tool that can process these linguistic terms. Thus, the fuzzy approach has been utilized to propose an efficient and systematic uncertainty modeling in this work.

6.2.1 Fuzzy logic modelling

The main idea of the fuzzy set theory is quite intuitive and natural. Instead of determining the exact boundary as in an ordinary set, a fuzzy set allows no sharply defined boundaries because of the generalization of a characteristic function to a membership function [255]. This technique, being part of decisional systems based on knowledge (Knowledge Based Processing), is widely applied in the field of risk analysis like assessment of the accident consequences arising due to frequency of dangerous substances transports [256,257].

6.2.2 Fuzzy inference system

Fuzzy inference is the process of formulating the mapping from a given input to an output using fuzzy logic. The mapping then provides a basis from which decisions can be made. The process of fuzzy inference involves fuzzification of crisp input by defining membership function, fuzzy logic operators, and if-then rules. Block diagram of a typical fuzzy logic system is presented in Figure 6.1. As outlined in Figure 6.1, a fuzzy rule based system consists of four parts: fuzzifier, knowledge base, inference engine, and defuzzifier. These four parts are described below:

- Fuzzifier: The real world input to the fuzzy system is applied to the fuzzzifier. In fuzzy literature, this input is called crisp input since it contains precise information about the specific information about the parameter. The fuzzifier converts this precise quantity to the form of imprecise quantity like 'low', 'medium', 'high' etc. with a degree of belongingness to it. Typically, the value ranges from 0 to 1.
- Knowledge base: The main part of the fuzzy system is the knowledge base in which both rule base and database are jointly referred. The database defines the membership functions of the fuzzy sets used in the fuzzy rules whereas the rule base contains a number of fuzzy if-then rules.
- Inference engine: The inference system or the decision-making unit performs the inference operations on the rules. It handles the way in which the rules are combined.
- Defuzzifier: The output generated by the inference block is always fuzzy in nature. A real world system will always require the output of the fuzzy system to the crisp or in the form of real world input. The job of the defuzzifier is to receive the fuzzy input and provide real world output. In operation, it works opposite to the input block.

Fuzzy inference is the process of formulating the mapping from a given input to an output using fuzzy logic. The mapping then provides a basis from which decisions can be made. The process of fuzzy inference involves fuzzification of crisp input by defining membership function, fuzzy logic operators, and if-then rules. Block diagram of a typical fuzzy logic system is presented in Figure 6.1.

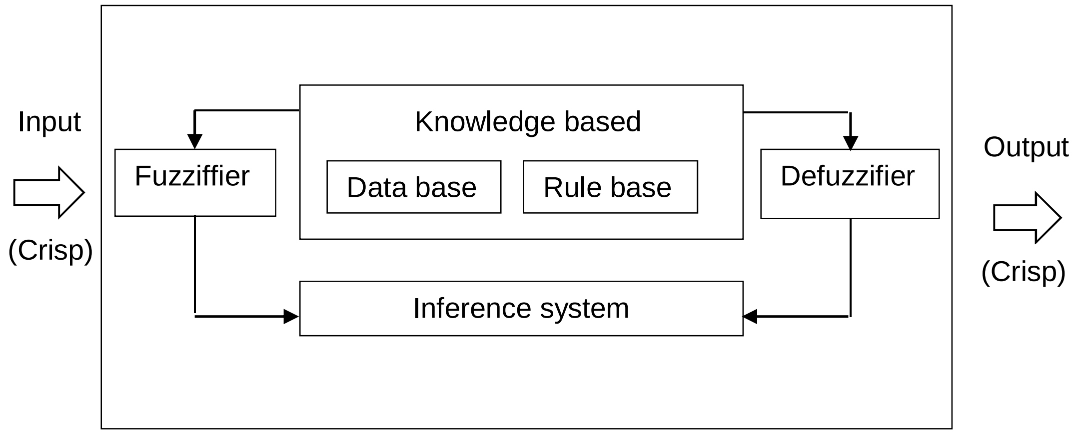


Figure 6.1 Fuzzy inference system

In general, two most popular fuzzy inference systems are available: Mamdani fuzzy model and Sugeno fuzzy model. The selection depends on the fuzzy reasoning and formulation of fuzzy IF-THEN rules. Mamdani fuzzy model is based on the collections of IF-THEN rules with both fuzzy antecedent and consequent. The benefit of this model is that the rule base is generally provided the experts and hence, to a certain degree, it is translucent to explanation and study. Because of its ease, Mamdani model is still most commonly used technique for solving many real world problems [258-260].

In the present study a fuzzy set A is represented by trapezoidal fuzzy number which is defined by the quadruplet (a, b, c, d) shown in Figure 6.2. Membership function $\mu_A(x)$ is defined as:

$$\mu_A(x) = 0,\ x < a,$$

$$= \frac{x-a}{b-a}, a \le x \le b,$$

$$= 1, b \le x \le c$$

$$\frac{d-x}{d-c}, c \le x \le d,$$

$$= 0, x > d \qquad (6.\ 1)$$

If $b = c$, the function is called triangular membership function as shown in Figure 6.3. The Mamdani implication method is employed for the rules definition.

For a rule R_i : If x_1 is A_{1i} and x_2 is A_{2i} …… x_s is A_{si} then y_i is C_i, $i = 1,2,\ldots, M$

where M is total number of fuzzy rule, $x_j = (j = 1, 2, \ldots, s)$ are input variables, y_i are the output variables, and A_{ji} and C_i are fuzzy sets modeled by membership functions $\mu_{A_{ji}}(x_j)$ and $\mu_{c_i}(y_i)$, respectively. The aggregated output for the M rules is:

$$\mu_{c_i}(y_i) = \max\{\min_i[\mu_{A_{1i}}(x_1), \mu_{A_{2i}}(x_3)]\}, \; i = 1, 2, \ldots, M \qquad (6.2)$$

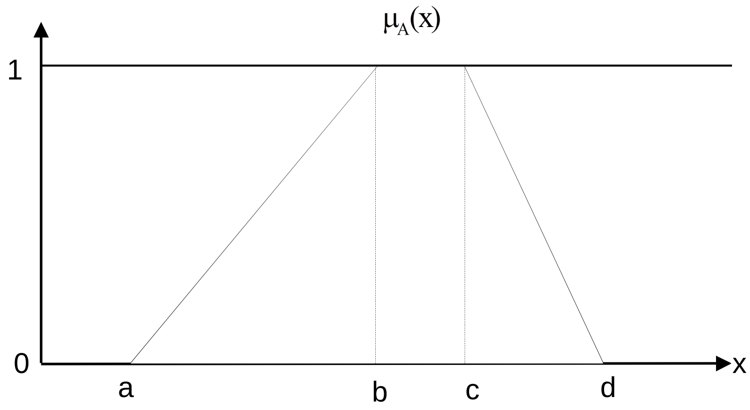


Figure 6.2 Trapezoidal fuzzy number

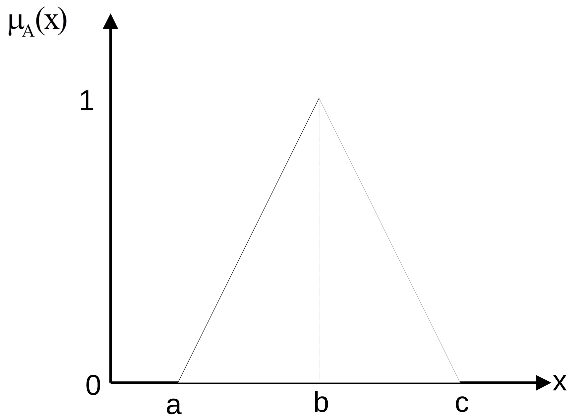


Figure 6.3 Triangular fuzzy number

Using a defuzzification method, fuzzy values can be combined into one single crisp output value. The center of gravity, one of the most popular methods for defuzzifying fuzzy output functions, is employed in the study. The formula to find the centroid of the combined outputs $\hat{y}_i$ is given by:

$$\hat{y}_i = \frac{\int y_i \mu_{c_1}(y_i)dy}{\int \mu_{c_1}(y_i)dy} \tag{6. 3}$$

6.3 Input-output parameter selection

In order to select input and output parameters for the model, visit to various industries has been made to assess on-the-spot safety norms being adopted at present. The safety issues have been discussed with the safety officers and managers of the organizations. A thorough literature review has been made to identify the items relevant to evaluate safety performance in generic sense but emphasis has been made on Indian context. Finally, data on several input and output parameters have been collected through field visits from thirty organizations (Table 6.1). A specially designed questionnaire was prepared to collect data from different organizations as shown in Appendix 6.1. The survey was conducted during July-September 2010. The input parameters are selected in such a manner that expenses on various items is likely to improve the safety performance in the industries. Each parameter is expressed as a percentage of total revenues of the annual budget averaged over last five years. These expenses include annual cost on health care, safety training, up-gradation of process tools and machinery, and safety instrument procured by the organizations.

The safety performance is measured by number of different categories of accidents occurring in a year averaged over five years. The occurrence of accidents is a random phenomenon and, many a times, difficult to assign any reason. However, safety performance can be improved through commitment from management, change in work practices, investment on safety tools, change in equipment and machinery, improving attitude and safety perception of employees, and training. It is assumed that more than one type of accidents is unlikely to occur at the same time. As far as output is concerned, number of different types of accidents (fatal and non-fatal) occurring per year in an organization averaged over last five years is recorded as shown in Table 6.2. The reciprocal of each output parameter is treated as the safety performance measure because accidents are unfavorable for an organization. In order to present a generic scenario of safety performance, three categories of industries such as construction, refractory, and steel have been selected. Organizations are labeled as C_1 to C_{10} represent construction, R_{11} to R_{20} belong to refractory, and S_{21} to S_{30} refer steel industries of eastern region of the country.

Table 6.1 Inputs and output parameters for safety performance

Inputs	I_1	Expenses in health care
	I_2	Expenses in safety training
	I_3	Expenses in up-gradation of process related tools, instruments, machines, materials leading to safe and healthy environment
	I_4	Expenses on safety equipment and tools
Outputs	ACC-O_1	Accident that do not cause any disability and do not involve any lost work days
	ACC-O_2	Accident that do not cause any disability but involve lost work days
	ACC-O_3	Accident that cause temporary disability
	ACC-O_4	Accident that cause permanent partial disability
	ACC-O_5	Accident that cause permanent full disability or fatality

Note: I = Input ACC-O = Accident Output

6.4 Results and discussions

The objective of the study is to develop a valid model for prediction of safety performance using fuzzy rule-based system in different categories of Indian Industries. The reciprocal of different types of accidents occurring per year in three categories of industries is shown in Table 6.2. The first column of the table represents the type of selected organizations i.e. C_1 to C_{10} refers to construction, R_{11} to R_{20} represents refractory, and S_{21} to S_{30} represents steel sector. The first category of accidents is the accident that do not cause any disability and do not involve any lost work days (ACC-O_1), second category is accident that do not cause any disability but involve lost work days (ACC-O_2), third category is accident that cause temporary disability (ACC-O_3), fourth category is accident that cause permanent partial disability (ACC-O_4) and fifth category is accident that cause permanent full disability or fatality (ACC-O_5). The inputs to the fuzzy inference system are the expenses expressed in percentage of annual budget on health care, safety training, up-gradation of process tools and machinery, and safety instrument procured by the organizations. Both input and output are fuzzified as explained below. A multi input and output (MIMO) Mamdani-type fuzzy model is shown in Figure 6.4. Each input to the model is nothing but expenses possibly responsible for improving in safety performance is expressed as three fuzzy membership functions (low, medium, high) to account for uncertainty. The four types of input parameters are shown in Figures 6.5, 6.6, 6.7, and 6.8 for expenses in health care, expenses in safety training, expenses in up-gradation of process related tools, instruments, machines, materials leading to safe and healthy environment and expenses on safety equipment and tools respectively.

Table 6.2 Distribution of reciprocal of fatal and non-fatal accidents in a year

Sl. No.	ACC-O_1	ACC-O_2	ACC-O_3	ACC-O_4	ACC-O_5
C_1	1.00	0.20	0.25	0.12	0.29
C_2	1.00	1.00	0.21	0.10	0.35
C_3	0.80	0.58	0.12	0.16	0.50
C_4	1.00	0.29	0.13	0.10	1.00
C_5	1.00	1.00	0.14	1.00	1.00
C_6	0.36	0.29	1.00	1.00	0.12
C_7	0.35	0.20	1.00	0.34	0.35
C_8	0.14	0.20	0.48	0.11	0.37
C_9	0.40	0.20	0.12	0.20	0.38
C_{10}	0.35	0.19	0.10	0.12	0.12
R_{11}	0.50	0.38	0.10	0.37	0.32
R_{12}	0.60	0.38	0.14	0.37	0.12
R_{13}	1.00	0.25	0.11	0.24	0.35
R_{14}	0.50	0.25	0.12	0.22	1.00
R_{15}	0.90	0.14	0.11	0.12	0.70
R_{16}	1.00	0.30	0.90	0.11	1.00
R_{17}	1.00	0.14	0.49	0.24	0.12
R_{18}	1.00	0.14	1.00	0.14	0.10
R_{19}	0.75	0.80	0.28	0.12	0.33
R_{20}	1.00	0.90	0.25	0.18	0.35
S_{21}	1.00	0.42	0.25	0.21	0.32
S_{22}	0.95	0.16	0.40	0.10	1.00
S_{23}	1.00	0.26	1.00	0.10	0.12
S_{24}	0.37	0.20	0.13	0.15	0.23
S_{25}	1.00	0.37	0.08	0.13	0.14
S_{26}	0.60	0.36	0.10	0.24	0.10
S_{27}	1.00	0.32	0.10	0.26	0.25
S_{28}	0.44	0.14	0.11	0.30	0.25
S_{29}	0.56	0.34	0.10	0.41	0.27
S_{30}	0.70	0.25	0.08	0.40	0.20

Note: C= Construction, R=Refractory, S=Steel

By taking into account the data gathered on pattern of expenditure for improving safety performance and combining subjective judgment of experts, linguistic variables are employed to develop fuzzy membership functions for inputs to the model. Fuzzy linguistic variables are extensions of numerical variables in the sense that they are able to represent the condition of an attributes at a given interval by taking fuzzy sets as their values [261]. The position of the element is described by the membership function (μ) that has a value of one (μ=1) if the element belongs completely to the set, a value of zero (μ=0) if the element does not belong to the fuzzy set and value between zero and one (0<μ<1) when the element belongs partially to the fuzzy set. The order to define the fuzzy membership functions of inputs is defined as low, medium and high. Low define as minimum expense per annum, medium describe as average expenses per annum and high known as high level of expenses per annum (Table 6.3). The membership function range in I_1 (expenses in health care) is 2 to 6.9, I_2 (expenses in safety training) is 2 to 6.2, I_3 (expenses in up-gradation of tool) is 2 to 8.5 whereas I_4 (expenses in safety equipment) is 2 to 4.5.

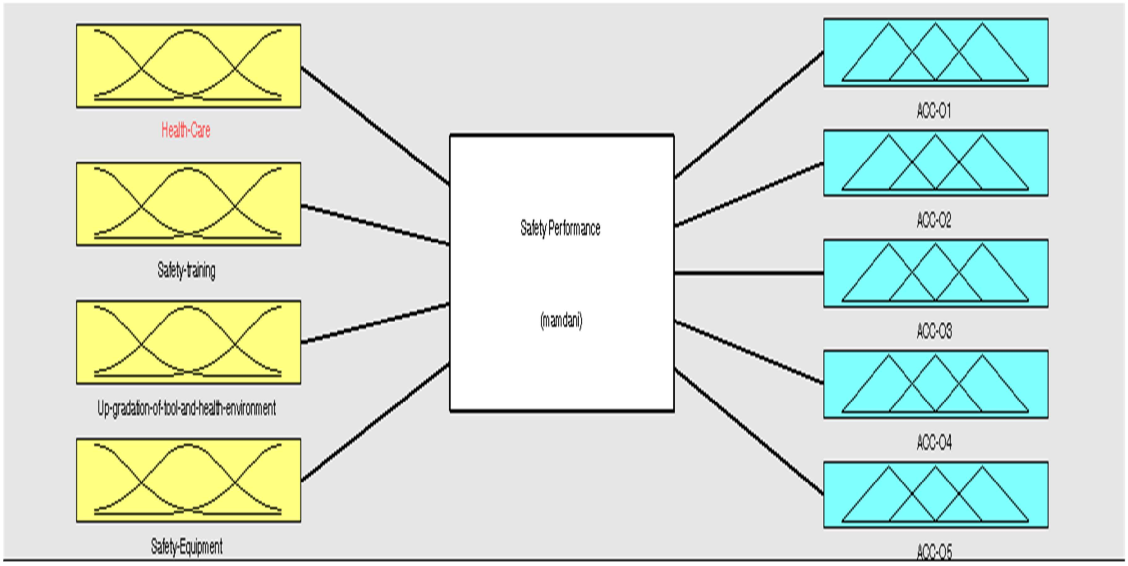


Figure 6.4 MIMO system for evaluating safety performance

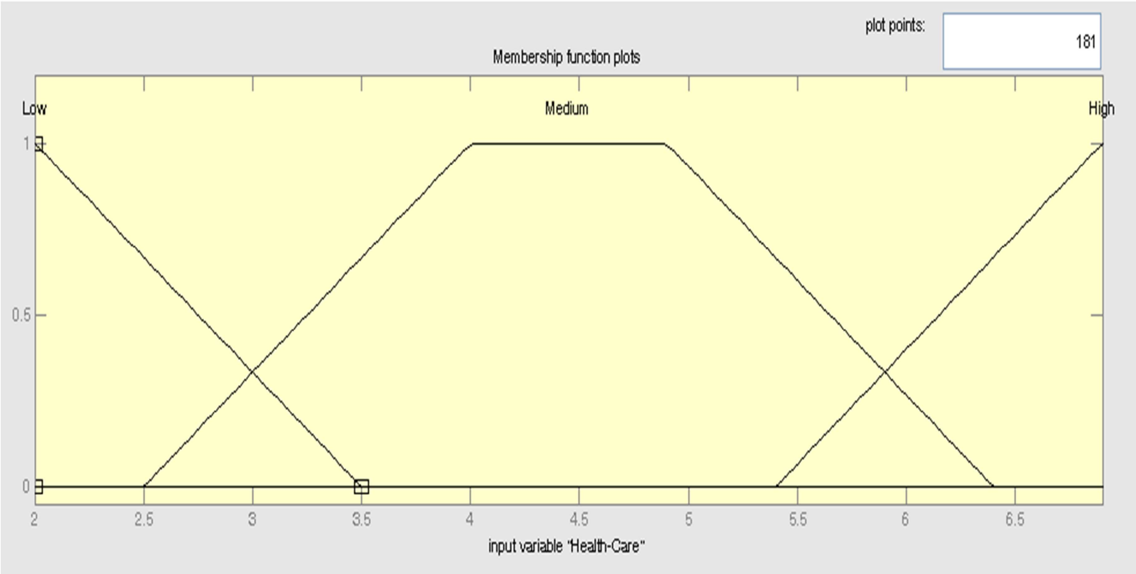


Figure 6.5   Membership functions for expenses in health care

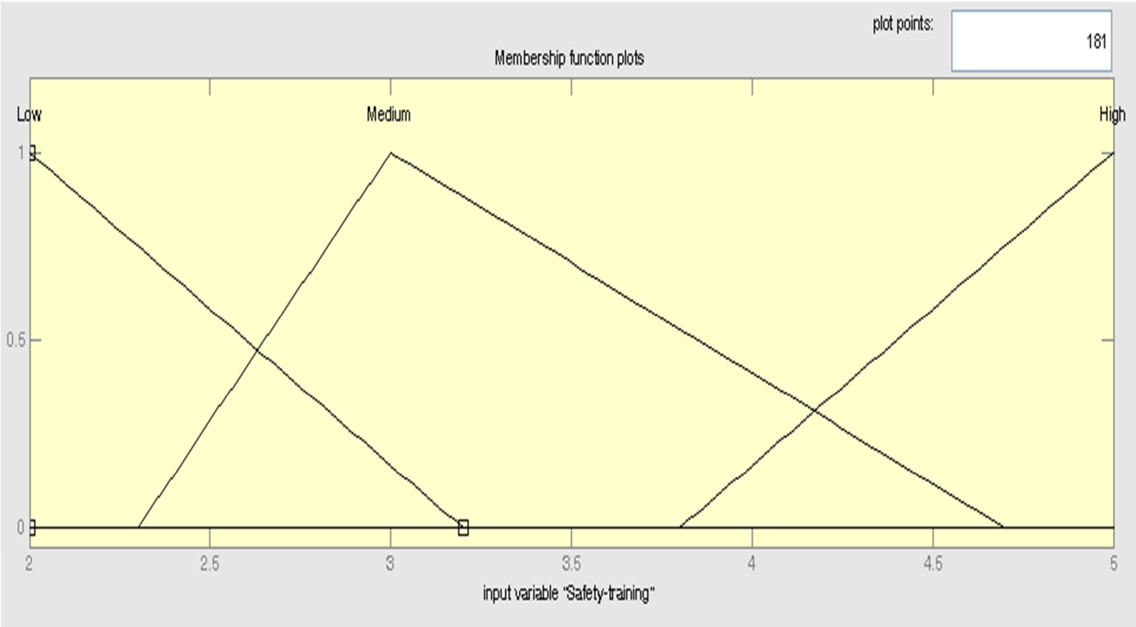


Figure 6.6   Membership function for expenses in safety training

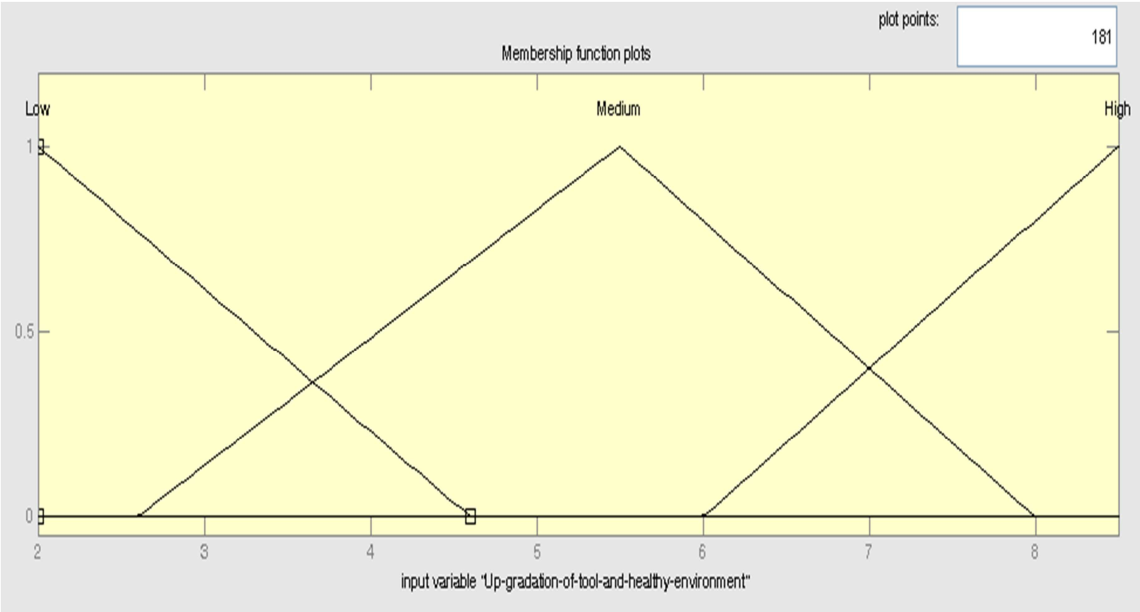


Figure 6.7 Membership function for expenses in up-gradation of process related tools, instruments, machines, materials leading to safe and healthy environment

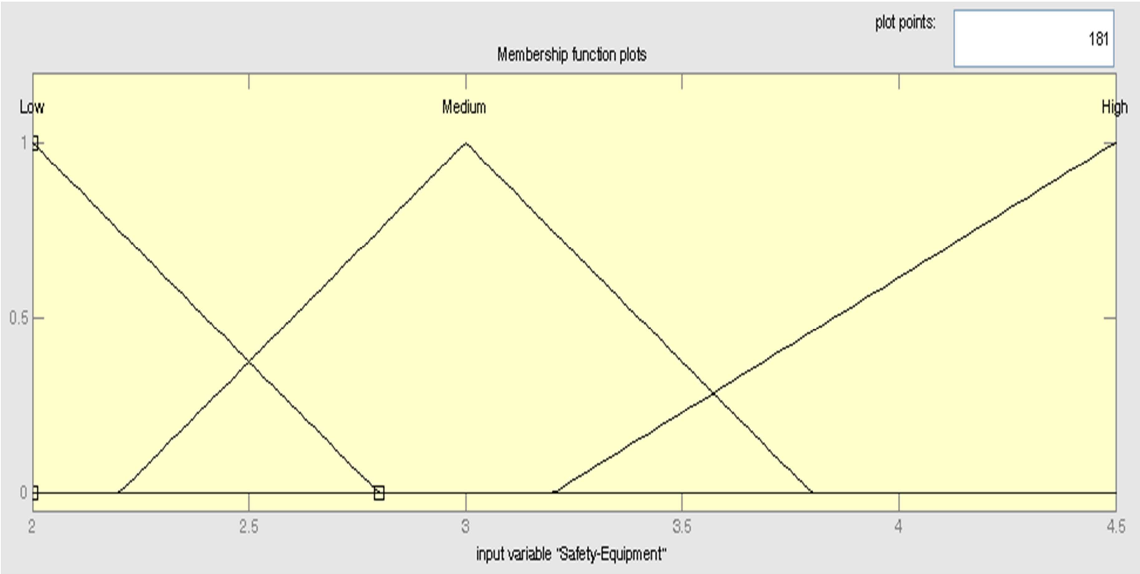


Figure 6.8 Membership function for expenses on safety equipment and tools

Table 6.3 Linguistic variables for the input fuzzy triangular and trapezoidal membership functions value

Linguistic value	Definition	Expenses in health care (I_1)	Expenses in safety training (I_2)	Expenses in up-gradation of tool (I_3)	Expenses in safety equipment (I_4)
Low	Minimum investment exit per annual expenditure	2, 2, 3.5	2, 2, 3.2	2, 2, 4.6	2, 2, 2.8
Medium	Average investment exit per annual expenditure	2.5, 4, 4.9, 6.4	2.3, 3, 4.7	2.62, 5.52, 8.02	2.2, 3, 3.8
High	High level of investment exit per annual expenditure	5.4, 6.9, 6.9	3.8, 5, 6.2	6, 8.5, 8.5	3.2, 4.5, 4.5

Similarly, each output parameter is expressed as five fuzzy membership functions denoted in linguistic terms such as extremely unsafe, very unsafe, unsafe, safe and highly safe as shown in Figure 6.9. The membership functions in a linguistic expression for extremely unsafe to highly safe uses value between 0 to1. These membership functions are commonly used to describe the parameters in assessment of safety performance [262]. Fuzzy accident types set definitions is shown in Table 6.4. Fuzzy sets are defined as extremely unsafe, very unsafe, unsafe, safe and highly safe according to the types of accident. For example, very high accident is extremely unsafe, high accident is very unsafe, lower than high accident is unsafe, low accident is safe and negligible accident is highly safe.

The inputs and outputs are combined by matching them against rule base, evaluated with Mamdani-type inference system, and then defuzzified to assess various nature of accidents at the job site. By this approach, imprecise, ambiguous, qualitative information and qualitative data can be handled in a convenient manner.

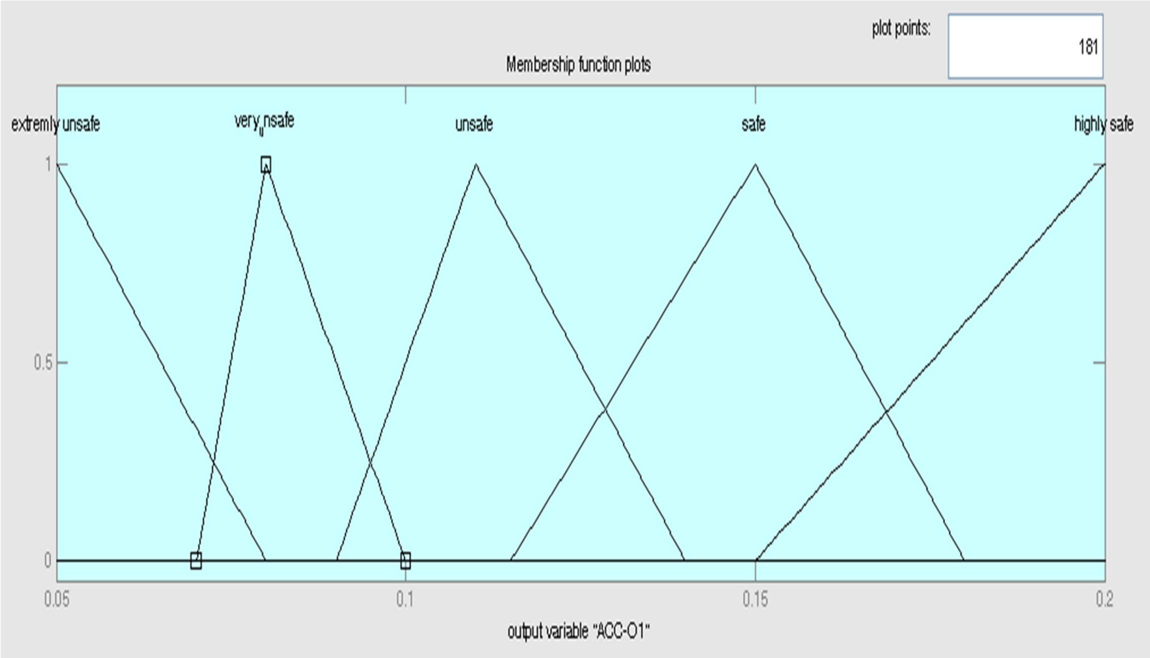


Figure 6.9 Output membership function (Accident types) function of safety performance

Table 6.4 Linguistic variables for the output fuzzy triangular membership functions value

Linguistic value	Definition	ACC-O_1	ACC-O_2	ACC-O_3	ACC-O_4	ACC-O_5
Extremely unsafe	Very high accident	0.05, 0.05, 0.08	0.09, 0.09, 0.182	0.1, 0.1, 0.18	0.12, 0.12, 0.296	0.22, 0.22, 0.476
Very unsafe	High accident	0.07, 0.08, 0.1	0.1513, 0.182, 0.2433	0.1533, 0.18, 0.2333	0.2373, 0.296, 0.4133	0.3907, 0.476, 0.6467
Unsafe	Lower than high accident	0.0904, 0.11, 0.14	0.2127, 0.274, 0.366	0.2067, 0.26, 0.34	0.3547, 0.472, 0.648	0.561, 0.732, 0.988
Safe	Low accident	0.115, 0.15, 0.18	0.2893, 0.3967, 0.4887	0.2733, 0.3667, 0.4467	0.5013, 0.7067, 0.8827	0.7447, 1.073, 1.329
Highly safe	Negligible accident	0.15, 0.2, 0.2	0.3967, 0.55, 0.55	0.3667, 0.5, 0.5	0.7067, 1, 1	1.073, 1.5, 1.5

6.4.1 Fuzzy rule-base for safety performance

Many practical approaches can be used to gather information and knowledge required in deriving fuzzy rules and four of the most commonly used techniques are statistical data and information analysis, expert experience and engineering knowledge analysis, concept mapping and fuzzy modelling. These techniques are not mutually exclusive and a combination of them is often the most effective way to create a rule-based system [71]. The process of fuzzification of the inputs, evaluation of the rules and aggregation of all the required rules is known as fuzzy inference. The mathematical foundations of fuzzy logic and the fuzzy inference can be found in many resources [263-267]. Mamdani-type inference is a type of fuzzy inference in which the fuzzy sets from the consequent of each rule are combined through the aggregation operator and the resulting fuzzy set is defuzzified to yield the output of the system. The fuzzy rules represent the logical correlations between the input and output variables and normally deduced from past data and/or from the experience of the analysts. The fuzzy rules are of a decisional type "IF-THEN" i.e. the consequences occur only if the premises are real. The logical operator between the terms can either be an OR logic or an AND logic. Therefore, the number of rules of a fuzzy model depends on the number of input variables, number of sub-sets of the input variables and number of logical operaters adopted in order to correlate them [264]. The fuzzy system that describes a Mamdani model with the characteristics is explained in Table 6.5.

Table 6.5 Characteristics of the Mamdani model [268]

Operation	Operator	Norm	Formula
Union (OR)	MAX	T-conorm	$\mu_c(x) = \max(\mu_A(x),\mu_B(x))=\mu_A(x)\vee\mu_B(x)$
Intersection (AND)	MIN	T-norm	$\mu_c(x) = \min(\mu_A(x),\mu_B(x))=\mu_A(x)\wedge\mu_B(x)$
Implication	MIN	T-norm	$\mathrm{Max}(\min(\mu_A(x), \mu_B(x)))$
Aggregation	MAX	T-conorm	
Defuzzification methodology	Center of mas (area) of the surface		$COA = Z^* = \frac{\int Z\mu_c(z)dz}{\int \mu_c(z)dz}$

An important contribution of the fuzzy system theory is that it provides a systematic procedure for transforming a knowledge map into non-linear mapping. A fuzzy IF-THEN rule is an IF-THEN statement in which some words are characterised by continuous membership functions. In the proposed approach, seventeen rules for the fuzzy rule-based system (Figure 6.10) are determined by the combination of statistical accident data and expenses in safety performance in various organisatons. The total seventeen fuzzy IF-THEN rules that are used in the study and are given as follows:

R1: IF Expenses in healthcare is High and Expenses in safety training is High and Expenses in upgradation of tool is Low and Expenses in equipment is High then ACC-O_1 is Very unsafe and ACC-O_2 is Safe and ACC-O_3 is Extremely unsafe and ACC-O_4 is Very unsafe and ACC-O_5 is Very unsafe.

R2: If Expenses in healthcare is Medium and Expenses in safety training is Medium and Expenses in safety tool is Medium and Expenses in safety equipment is Medium then ACC-O_1 is Unsafe and ACC-O_2 is Safe and ACC-O_3 is Extremely unsafe and ACC-O_4 is Extremely unsafe and ACC-O_5 is Safe.

R3: If Expenses in healthcare is Medium and Expenses in safety training is High and Expenses in safety tool is Medium and Expenses in safety equipment is High then ACC-O_1 is Unsafe and ACC-O_2 is Extremely safe and ACC-O_3 is Unsafe and ACC-O_4 is Highly safe and ACC-O_5 is Safe.

R4: If Expenses in healthcare is Medium and Expenses in safety training is Medium and Expenses in safety tool is Medium and Expenses in safety equipment is Low then ACC-O_1 is Unsafe and ACC-O_2 is Unsafe and ACC-O_3 is Unsafe and ACC-O_4 is Extremely unsafe and ACC-O_5 is Unsafe.

R5: If Expenses in healthcare is High and Expenses in safety training is Medium and Expenses in safety tool is Low and Expenses in safety equipment is Medium then ACC-O_1 is Extremely unsafe and ACC-O_2 is Safe and ACC-O_3 is Extremely unsafe and ACC-O_4 is Highly safe and ACC-O_5 is Very unsafe.

R6: If Expenses in healthcare is Medium and Expense in safety training is Medium and Expenses in safety tool is High and Expenses in safety equipment is Low then ACC-O_1 is Unsafe and ACC-O_2 is Safe and ACC-O_3 is Extremely safe and ACC-O_4 is Highly safe and ACC-O_5 is Safe.

R7: If Expenses in healthcare is Low and Expenses in safety training is Medium and Expenses in safety tool is High and Expenses in safety equipment is Low then ACC-O_1 is Unsafe and ACC-O_2 is Highly safe and ACC-O_3 is Extremely unsafe and ACC-O_4 is Highly safe and ACC-O_5 is Safe.

R8: If Expenses in healthcare is Medium and Expenses in safety training is High and Expenses in safety tool is Medium and Expenses in safety equipment is Medium then ACC-O_1 is safe and ACC-O_2 is Very unsafe and ACC-O_3 is Unsafe and ACC-O_4 is Extremely unsafe and ACC-O_5 is Safe.

R9: If Expenses in healthcare is Medium and Expenses in safety training is Medium and Expenses in safety tool is Low and Expenses in safety Equipment is Medium then ACC-O_1 is Extremely unsafe and ACC-O_2 is Safe and ACC-O_3 is Extremely unsafe and ACC-O_4 is Extremely unsafe and ACC-O_5 is Very unsafe.

R10: If Expenses in healthcare is Medium and Expenses in safety training is Low and Expenses in safety tool is Medium and Expenses in safety equipment is Low then ACC-O_1 is Unsafe and ACC-O_2 is Extremely unsafe and ACC-O_3 is Highly safe and ACC-O_4 is Highly safe and ACC-O_5 is Safe.

R11: If Expenses in healthcare is Medium and Expenses in safety training is Medium and Expenses in safety tool is Low and Expenses in safety equipment is Low then ACC-O_1 is unsafe and ACC-O_2 is Safe and ACC-O_3 is Extremely unsafe and ACC-O_4 is Highly safe and ACC-O_5 is Safe.

R12: If Expenses healthcare is Medium and Expenses in safety training is Medium and Expenses in safety tool is High and Expenses in safety equipment is Low then ACC-O_1 is Unsafe and ACC-O_2 is Safe and ACC-O_3 is Extremely unsafe and ACC-O_4 is Highly safe and ACC-O_5 is Safe.

R13: If Expenses in healthcare is Low and Expenses in expenses in safety training is Medium and Expenses in safety tool is Medium and Expenses in safety equipment is Low then ACC-O_1 is Safe and ACC-O_2 is Extremely unsafe and ACC-O_3 is Extremely unsafe and ACC-O_4 is Very unsafe and ACC-O_5 is Extremely unsafe.

R14: If Expenses in healthcare is Medium and Expenses in safety training is Medium and Expenses in safety tool is High and Expenses in safety equipment is

Medium then ACC-O_1 is unsafe and ACC-O_2 is Safe and ACC-O_3 is Extremely unsafe and ACC-O_4 is Highly safe and ACC-O_5 is Safe.

R15: If Expenses in healthcare is Low and Expenses in safety training is Low and Expenses in safety tool is Medium and Expenses in safety equipment is Medium then ACC-O_1 is Unsafe and ACC-O_2 is Safe and ACC-O_3 is Extremely unsafe and ACC-O_4 is Highly safe and ACC-O_5 is Safe.

R16: If Expenses in healthcare is Medium and Expenses in safety training is Medium and Expenses safety tool is High and Expenses in safety equipment is High then ACC-O_1 is Safe and ACC-O_2 is Extremely unsafe and ACC-O_3 is Unsafe and ACC-O_4 is Highly safe and ACC-O_5 is Safe.

R17: If Expenses in healthcare is Low and Expenses in safety training is Medium and Expenses in safety tool is Low and Expenses in safety equipment is Low then ACC-O_1 is Highly safe and ACC-O_2 is Extremely unsafe and ACC-O_3 is Unsafe and ACC-O_4 is Extremely unsafe and ACC-O_5 is Very unsafe.

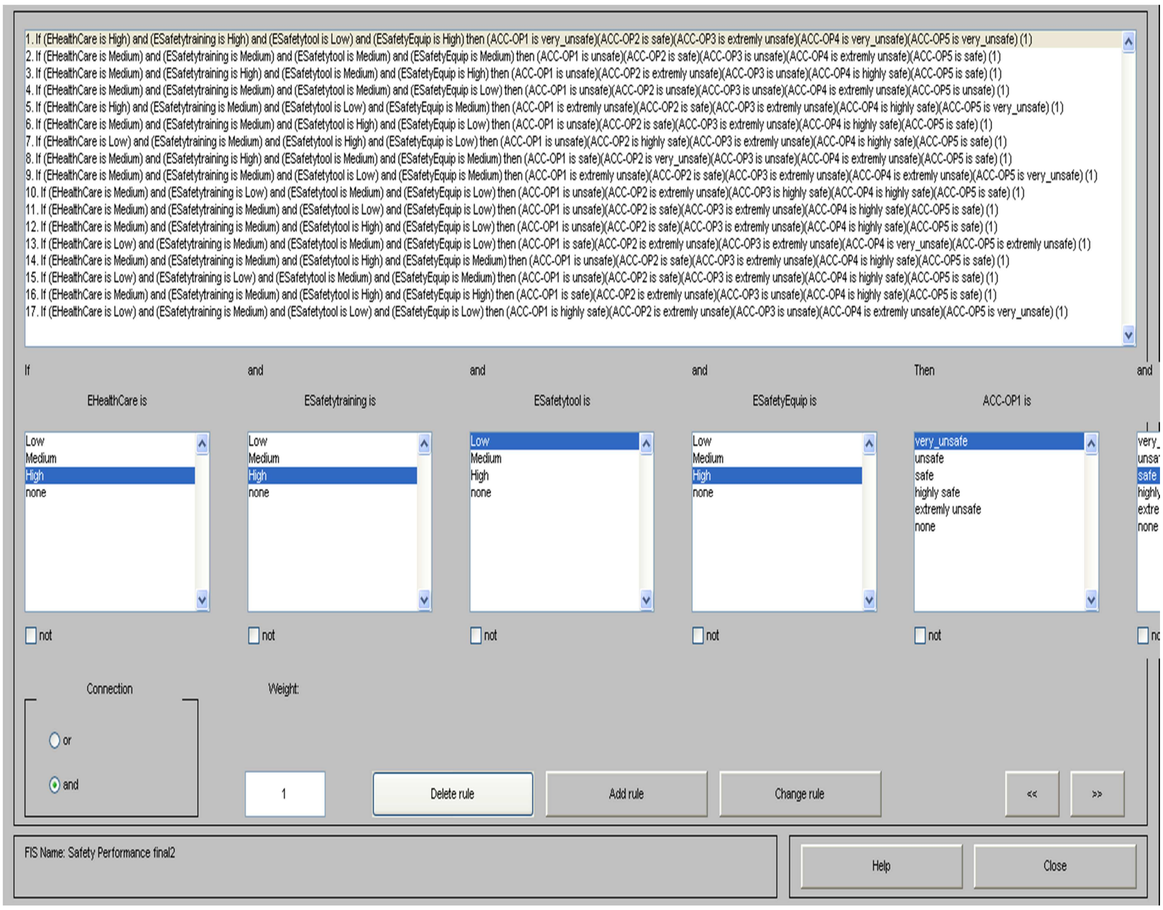


Figure 6.10 The rule-base of the model

All the rules that have any truth in their premises will contribute to the fuzzy risk level expression. Each single rule is fired to a degree that is a function of the degree to which the antecedent matches the input. This imprecise matching leads to an interpolation basis between possible input states and serves to minimise the number of rules for describing the input-output relation (Figure 6.11). Figure 6.12 shows a sample surface viewer of the model and it can be obsrved that seventeen rules are capable of covering the complete domain of inputs and outputs. The fuzzy responses generated by the rules are defuuzified using centriod method to produce the predicted value of different types of reciprocal of accidents in crisp manner. The predcietd values are shown in Table 6.6. In Table 6.6, for type of accident, the first column represents actual reciprocal of accident per year. The second column specifies the predicted value based on the fuzzy logic rule-based output. The third column shows the absolute percentage error. The fourth column indicates the residual i.e. actual minus predicted (A-P). From accident category 1 (ACC-OP$_1$), maximum absolute percentage error of 12.00 is obtained for refractory industry (serial no. R$_{11}$) whereas minimum absolute percentage error of 1.166 is observed for construction type of industry (serial no. C_6). For accident category 2 (ACC-O_2), maximum absolute percentage error of 13.586 is found in construction industry (serial no. C_3) whereas minimum absolute percentage error of 1.676 is found in steel sector (serial no. S_{29}). For accident category 3 (ACC-O_3), maximum absolute percentage error is 13.900 observed for refractory type organization (serial no. R_{11}) and minimum absolute percentage error is 0.744 found again in refractory (serial no. R_{16}). In accident category 4 (ACC-O_4), serial no. S_{23}, a steel type industry, shows maximum absolute percentage error of 14.200 whereas minimum absolute percentage error of 3.636 is found in serial no. C_8. Serial no. R_{18} shows maximum absolute percentage error of 13.700 whereas serial no. C_3 shows minimum absolute percentage of error of 1.600 in accident category (ACC-OP_5). In all cases, maximum absolute percentage error is 14.200 and minimum absolute percentage is 0.744. The residuals for all the cases are plotted in Figure 6.13 and it is noted that the residuals are distributed around the mean line i.e. zero. Hence, it is said that model can predict the value with sufficient accuracy. The correlation graph shown in Figure 6.14 indicate that a high correlation coefficient of 0.993 exist between actual and predicted values.

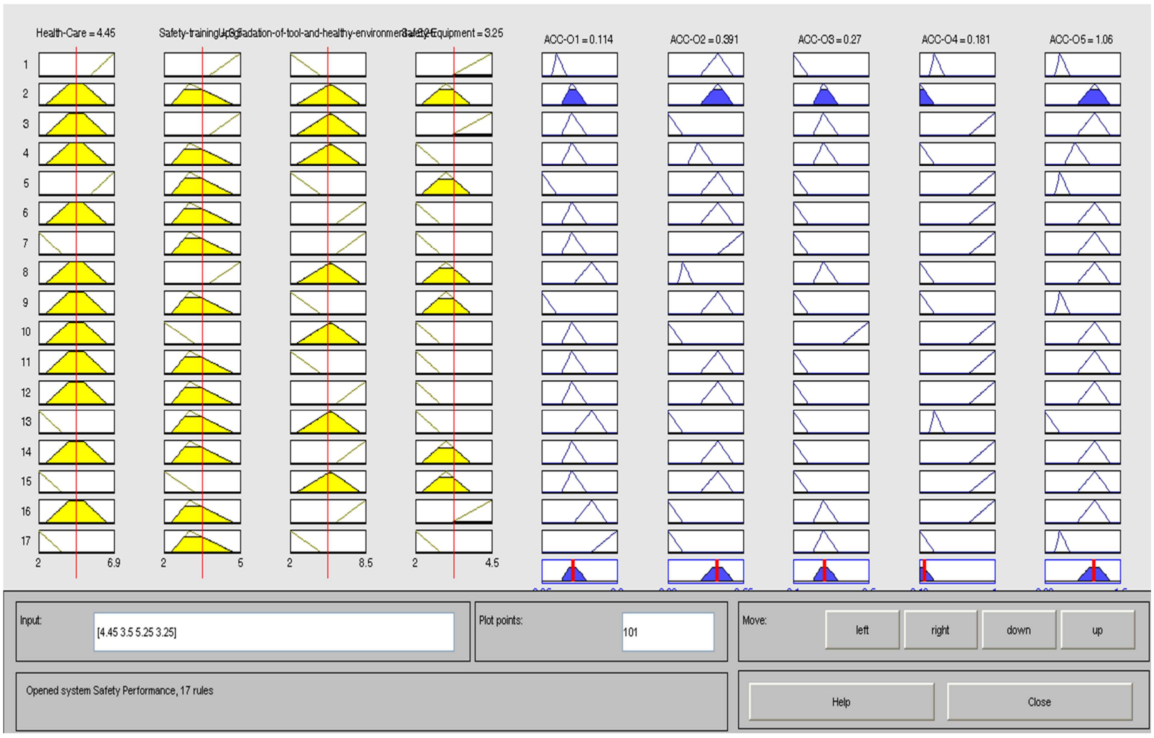


Figure 6.11 MATLAB rule base obtained after the cognitive interventions

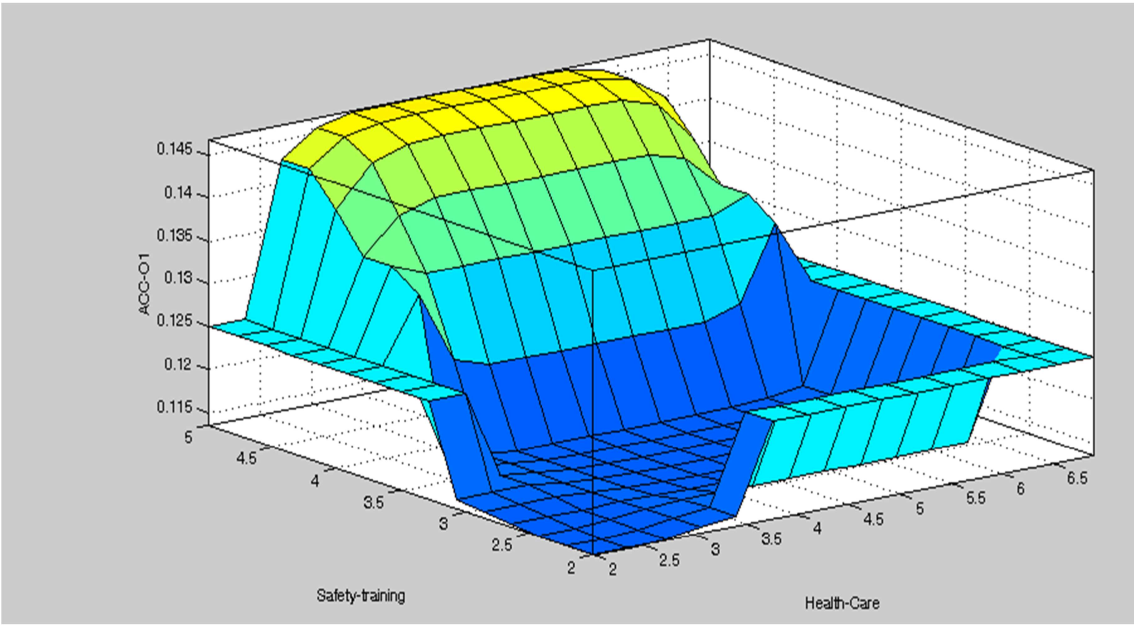


Figure 6.12 A Surface viewer

Table 6.6 Predicted values of reciprocal of accidents per year

	Accident that do not cause any disability and do not involve any lost work days				Accident that do not cause any disability but involve lost work days				Accident that cause temporary disability				Accident that cause permanent partial disability				Accident that cause permanent full disability or fatality			
Sl. No.	Actual (A) ACC1	Predicted (P)	Abs. %age error	(A-P) Resid ual	Actual (A) ACC2	Predicted (P)	Abs. %age error	(A-P) Residual	Actual (A) ACC3	Predicted (P)	Abs. %age error	(A-P) Residual	Actual (A) ACC4	Predicted (P)	Abs. %age error	(A-P) Residu al	Actual (A) ACC5	Predicted (P)	Abs. %age error	(A-P) Resid ual
C1	1.00	1.057	5.720	0.057	0.20	0.191	4.750	-0.010	0.25	0.270	7.920	0.020	0.12	0.114	5.000	-0.010	0.29	0.265	8.483	-0.020
C2	1.00	1.058	5.820	0.058	1.00	0.899	10.090	-0.100	0.21	0.220	4.952	0.010	0.10	0.114	14.200	0.014	0.35	0.391	11.770	0.041
C3	0.80	0.813	1.575	0.013	0.58	0.501	13.586	-0.080	0.12	0.128	6.917	0.008	0.16	0.144	10.190	-0.020	0.50	0.508	1.600	0.008
C4	1.00	1.055	5.520	0.055	0.29	0.251	13.310	-0.040	0.13	0.133	2.615	0.003	0.10	0.114	13.500	0.014	1.00	1.026	2.640	0.026
C5	1.00	1.056	5.550	0.056	1.00	0.893	10.670	-0.110	0.14	0.131	6.143	-0.010	1.00	1.056	5.580	0.056	1.00	0.894	10.560	-0.110
C6	0.36	0.356	1.166	-0.000	0.29	0.318	9.655	0.028	1.00	1.057	5.740	0.057	1.00	1.055	5.520	0.055	0.12	0.131	8.750	0.011
C7	0.35	0.391	11.830	0.041	0.20	0.191	4.750	-0.010	1.00	1.058	5.750	0.058	0.34	0.321	5.500	-0.020	0.35	0.390	11.510	0.040
C8	0.14	0.125	10.790	-0.020	0.20	0.178	10.950	-0.020	0.48	0.513	6.833	0.033	0.11	0.114	3.636	0.004	0.37	0.390	5.459	0.020
C9	0.40	0.390	2.450	-0.010	0.20	0.189	5.400	-0.010	0.12	0.114	5.083	-0.010	0.20	0.182	9.000	-0.020	0.38	0.391	2.974	0.011
C10	0.35	0.391	11.600	0.041	0.19	0.176	7.526	-0.010	0.10	0.094	5.800	-0.010	0.12	0.136	13.000	0.016	0.12	0.123	2.417	0.003
R11	0.50	0.560	12.000	0.060	0.38	0.391	2.868	0.011	0.10	0.114	13.900	0.014	0.37	0.391	5.649	0.021	0.32	0.335	4.812	0.015
R12	0.60	0.554	7.683	-0.050	0.38	0.390	2.632	0.010	0.14	0.152	8.429	0.012	0.37	0.391	5.622	0.021	0.12	0.123	2.167	0.003
R13	1.00	1.057	5.730	0.057	0.25	0.259	3.560	0.009	0.11	0.114	3.727	0.004	0.24	0.269	12.210	0.029	0.35	0.341	2.600	-0.010
R14	0.50	0.508	1.500	0.007	0.25	0.231	7.560	-0.020	0.12	0.114	4.917	-0.010	0.22	0.200	9.318	-0.020	1.00	0.894	10.600	-0.110
R15	0.90	0.998	10.920	0.098	0.14	0.127	9.286	-0.010	0.11	0.099	9.818	-0.010	0.12	0.133	10.580	0.013	0.70	0.608	13.210	-0.090
R16	1.00	0.950	5.040	-0.050	0.30	0.265	11.530	-0.030	0.90	0.893	0.744	-0.010	0.11	0.105	4.182	-0.000	1.00	1.059	5.850	0.059
R17	1.00	0.927	7.270	-0.070	0.14	0.129	8.143	-0.010	0.49	0.548	11.760	0.058	0.24	0.230	4.125	-0.010	0.12	0.123	2.667	0.003
R18	1.00	1.058	5.820	0.058	0.14	0.129	7.929	-0.010	1.00	0.887	11.290	-0.110	0.14	0.132	5.714	-0.010	0.10	0.114	13.700	0.014
R19	0.75	0.776	3.453	0.026	0.80	0.883	10.380	0.083	0.28	0.269	3.857	-0.010	0.12	0.130	8.417	0.010	0.33	0.355	7.636	0.025
R20	1.00	1.059	5.890	0.059	0.90	0.878	2.422	-0.020	0.25	0.271	8.320	0.0210	0.18	0.172	4.722	-0.010	0.35	0.390	11.460	0.040
S21	1.00	1.057	5.650	0.057	0.42	0.391	6.905	-0.030	0.25	0.269	7.560	0.019	0.21	0.218	3.667	0.008	0.32	0.313	2.156	-0.010
S22	0.95	0.884	7.000	-0.070	0.16	0.179	11.940	0.019	0.40	0.449	12.180	0.049	0.10	0.114	13.500	0.014	1.00	1.057	5.730	0.057
S23	1.00	1.057	5.660	0.057	0.26	0.243	6.692	-0.020	1.00	1.056	5.580	0.056	0.10	0.114	14.200	0.014	0.12	0.133	10.580	0.013
S24	0.37	0.349	5.595	-0.020	0.20	0.184	8.250	-0.020	0.13	0.114	12.540	-0.020	0.15	0.130	13.270	-0.020	0.23	0.251	9.174	0.021
S25	1.00	1.056	5.580	0.056	0.37	0.390	5.459	0.020	0.08	0.084	4.625	0.004	0.13	0.114	12.540	-0.020	0.14	0.127	9.571	-0.010
S26	0.60	0.620	3.383	0.020	0.36	0.391	8.667	0.031	0.10	0.111	10.600	0.011	0.24	0.270	12.460	0.030	0.10	0.113	13.300	0.013
S27	1.00	0.888	11.190	-0.110	0.32	0.295	7.719	-0.020	0.10	0.113	13.400	0.013	0.26	0.231	11.310	-0.030	0.25	0.236	5.720	-0.010
S28	0.44	0.491	11.660	0.051	0.14	0.123	12.360	-0.020	0.11	0.114	3.727	0.004	0.30	0.270	10.070	-0.030	0.25	0.272	8.680	0.022
S29	0.56	0.621	10.860	0.061	0.34	0.346	1.676	0.006	0.10	0.114	13.700	0.014	0.41	0.390	4.805	-0.020	0.27	0.300	11.110	0.030
S30	0.70	0.621	11.310	-0.080	0.25	0.275	10.080	0.025	0.08	0.072	10.000	-0.010	0.40	0.430	7.375	0.030	0.20	0.221	10.300	0.021
Maximum absolute %age error Industry 11			12.000	Maximum absolute %age error Industry 3			13.586	Maximum absolute %age error Industry 11			13.900	Maximum absolute %age error Industry 23			14.200	Maximum absolute %age error Industry 18			13.700	
Minimum absolute %age error Industry 6			1.166	Minimum absolute %age error Industry 29			1.676	Maximum absolute %age error Industry 16			0.744	Maximum absolute %age error Industry 8			3.636	Maximum absolute %age error Industry 3			1.600	

Maximum %age error for 150 cases = 14.200 Minimum %age error for 150 cases = 0.744

C_1-C_{10} = Construction, R_{11}- R_{20} = Refractory, S_{21}-S_{30} = Steel Industry

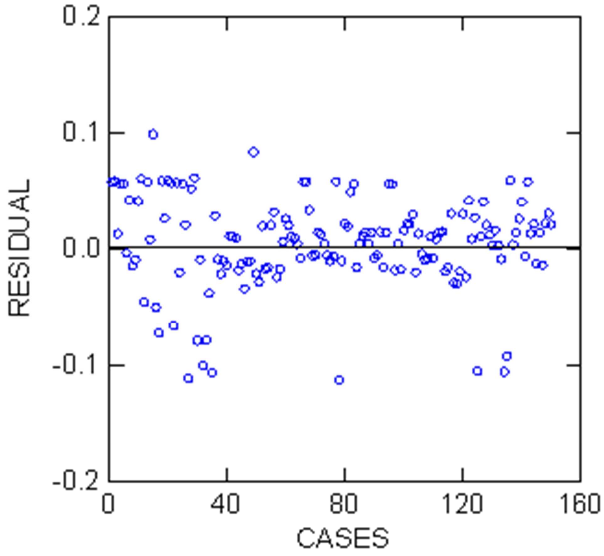


Figure 6.13 Distribution of residuals

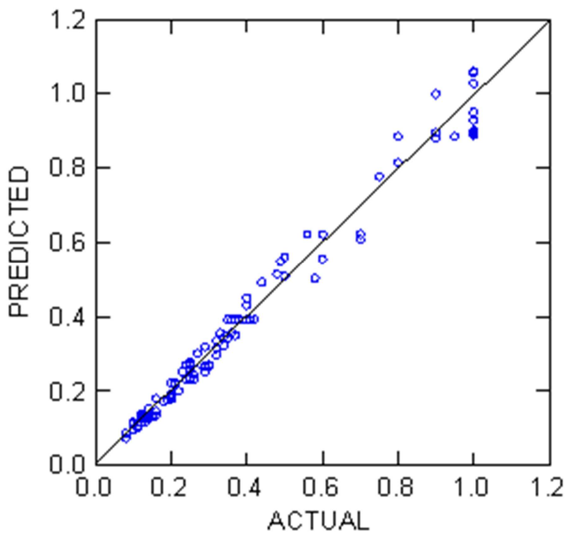


Figure 6.14 Comparison of actual and predicted values

6.5 Conclusions

This chapter has presented a classification and prediction model based on soft computing techniques i.e., Fuzzy Inference System (FIS), for assisting the managers in analyzing occupational injuries and planning for financial outlays in various expenses in order to improve safety performance. Although the methodology addresses the safety performance evaluation in few types of Indian industries, the model is quite generic in nature. The prediction model based on fuzzy logic can effectively handle impreciseness and uncertainty present in the system and avoid the requirement of large amount of data. The effectiveness of the model is judged from the observation of maximum absolute percentage error of 14.200. The residuals for all the cases considered in this study are distributed in both sides of the mean line. Hence, it is said that the model can predict the value with sufficient accuracy. The correlation coefficient between predicted and actual values is quite high (0.993). Occupational accidents may lead to permanent disabilities or deaths and/or economic losses or both causing social problems for employers, employees and their families. Occupational accidents can be reduced through effective preventative measures by investing on safety equipment's, training, and educating the employees, process design, and machinery. The prediction tool using simple linguistic variables can help the managers to generate scenario to study the pattern of investment in various categories of expenses to improve safety performance. In order to develop a good safety culture, attitude of the workers needs to be reoriented by adopting best practices, good housekeeping, change in work culture, and work practices. Therefore, qualitative factors responsible for improving safety performance can be easily incorporated in the fuzzy prediction model for improving accuracy. The major contribution of this paper is nothing but proposing a systematic integrated approach for modeling the accident analysis and their prediction so that occupational health and safety situation can be improved. As accidental hazards is a sensitive issue in all the industrial settings, Three sectors considered in this study are generally viewed as hazardous compared to other sectors due to usage of heavy equipment, unsafe and primitive tools, injurious materials and polluting gas producing units.

CHAPTER 7

SAFETY PERFORMANCE EVALUATION

7.1 Introduction

This chapter presents the assessment of safety performance of industrial settings using various types of accidents and annual expenses on safety measures through application of Data Envelopment Analysis (DEA). It addresses management's need for consistent benchmarking, target setting and designing focused on-site work environment in an attempt to identify and transfer best-practices. Depending on type of industry, demographic profile of employees and managerial commitment, perceived risk and hazard may vary from one organization to another. It is important to know best safety practices in same industrial sector or in others sector so that the concepts can be transplanted and implemented for improving safety performance of an organization. In order to thrive in today's competitive environment, many organizations have recognized benchmarking as strategically important in the drive for better performance and commitment to achieve a competitive advantage [269].

Recently, the comprehensiveness of neo-liberal restructuring in service as well as manufacturing sector has had impact not only on growth in economic terms but also on orientation towards social obligations and responsibility, commonly termed as corporate social responsibility (CSR). The industries ignoring such issues as environmental pollution, exploitation of labour, and occupational-related ailments and injuries find it difficult to survive in the marketplace due to huge social pressure and increased awareness of people. Now, safety and green environment are treated as two vital elements so as to develop or retain the goodwill in the marketplace. The industries normally use continuous improvement approach to progress in both the aspects as an image-building strategy so that competition may become easier. However, both the aspects are not only important for existence but also help to improve motivation level of employees resulting in higher productivity and profitability for the organization. This fact has been realized quite early in India and safety of working personnel in industries has become a major concern for management ever since the enactment of Factories Act, 1948. Bureau of Indian Standards has formulated an Indian Standard on Occupational Health and Safety Management Systems (OHSMS) known as IS 18001:2007 in accordance with international guidelines, OSHAS 18001 formulated by International Labor Organization (ILO). It is promoted in Indian industries considering the fact that Indian industry badly needs a comprehensive frame work. To uphold the organization in an adequate management system, a control review of activities is carried out within the organization. Two types of control can be distinguished - internal control and benchmarking techniques. Internal control is executed by means of an analysis of operations and working conditions, safety inspections, and audits through identification, investigation, and recording of events such as accidents, incidents of injury etc. that occur within the organization.

Benchmarking is a learning process based on the search for the best management system in the market, which will then serve as a reference to the firm for facilitating its efforts to perform better in control procedures, accident investigation techniques, ergonomically design of jobs, training programmes with other organizations from any sector, and self-assessment through identification of its strengths and weaknesses [270,271]. A safety management system can be viewed as a set of policies, strategies, practices, procedures, roles, and functions associated with safety and mechanisms that integrate with the whole organization so that hazards affecting employees' health and safety can be controlled effectively [272]. At the same time, the safety policies must be in compliance of current legislation of the land. In order to achieve such goals, employees' involvement is a crucial need along with strong commitment and support from management [174].

Usually, shared perceptions of employees about the value and importance of safety in the organization is called safety climate [116]. Safety climate has been linked to firm outcomes like compliance with safety policies, perceived workplace safety, safety knowledge and perceived ability to maintain safety in the workplace [273-277]. Workplace hazards may exist in any setting but they are most likely to be found in higher risk industries such as forest products, mining, transportation, and heavy manufacturing [278]. Despite the desire to improve safety, health and environment performance, accident rates for many industrial organizations is alarmingly high [167,279]. Knowledge of risks is not enough to bring about changes in unsafe behavior because man is hardly a rational decision-maker as far as safety issues are concerned. Mostly, decision making is influenced by feelings [280].

Hence, safety programs should be complemented with motivation oriented program elements such as performance feedback. Implementation of an effective occupational health and safety management system (OHSMS) should, however, primarily leads to a reduction of workplace illness and injury, and minimizes the costs associated with workplace accidents. To minimize the health hazards, it is necessary to have an occupational health and safety policy authorized by the organization's top management that clearly states overall OHS objectives and demonstrates a commitment to improve OHS performance. Management should establish a sound health and safety environment (HSE) and maintain a process to periodically monitor and audit the key characteristics of company operations and activities that can have significant impacts on people's health, workplace safety, and surrounding environment. Such a process helps to track company HSE performance and identify HSE weak points [281].

This study attempts to measure the relative efficiency of various types of organizations in eastern India. In doing so, it is possible to measure the degree of variation in efficiency across an industrial sector as a whole and to identify possible sources of inefficiency. The efficiency score has been calculated based on two scale of assumptions viz., CRS (Constant Return to Scale) and VRS (Variable return to scale). The comparison is made between the ranking of the organizations based on the efficiency scores using CRS and VRS assumptions. The contents in this chapter are organized as follows. The chapter encompasses sections 7.2 to 7.4 devoted to discussions related to DEA for benchmarking safety performance. Section 7.2 broadly discusses on the methodology and consists of three sub sections. Sub-section 7.2.1 begins with some preliminaries to pave the way for the mathematical formulation of DEA whereas section 7.2.2 and 7.2.3 describes the selections of DMUs and the DEA model for safety performance evaluation respectively. The third part of the chapter is Section 7.3, which encompasses 7.3.1 to 7.3.5. Sub-section 7.3.1 discusses the constant return to scale (CRS) assumption. Section 7.3.2 summarizes the CRS Model with comparisons between efficient and inefficient DMUs. Section 7.3.3 and 7.3.4 presents the comparisons of output parameter of CRS Model and variable return to scale assumption respectively.

7.2 Methodology

Data envelopment analysis (DEA), being a robust mathematical tool, has been employed to evaluate the safety performance of industries. DEA, basically, takes into account the input and output components of a decision making unit (DMU) to calculate technical efficiency (TE). TE is treated as an indicator for safety performance of DMUs and comparison has been made among them.

7.2.1 Data envelopment analysis (DEA)

Data Envelopment Analysis (DEA) is a methodology based upon linear programming based technique for measuring the performance efficiency of organizational units (DMUs) using multiple incommensurate inputs and outputs. The efficiency is the key measure in DEA, it is required to emphasize on efficiency measure in the context of DEA [282]. The efficiency can simply be defined as the ratio of output to the input.

$$\text{Efficiency} = \frac{\text{Output}}{\text{Input}} \tag{7.1}$$

A DMU is regarded as the entity responsible for converting inputs (i.e. resource, money etc.) into outputs (i.e. sales, profits etc.). In this chapter, a DMU refers to one from three types of industries (construction, refractory, and steel industry). Usually, the investigated DMUs are characterized by a vector of multiple inputs converting to multiple outputs making it difficult to directly compare them. In order to aggregate information about input and output quantities, DEA makes use of fractional programming problem (FPP) and corresponding Linear programming problem (LPP) together with their duals to measure the relative performance of DMUs [282-289]. The CCR model is a FPP model which measures the efficiency of DMUs by calculating the ratio of weighted sum of its outputs to the weighted sum of its inputs. The fractional programme is run for each DMU subjected to the condition that no DMU can have relative efficiency score greater than unity for that set of weights. Thus, the DEA model calculates a unique set of factor weights for each DMU. The set of weights has the following characteristics:

- It maximizes the efficiency of the DMU for which it is calculated
- It is feasible for all DMU
- Since DEA does not incorporate price information in the efficiency measure, it is also appropriate for non-profit organizations where price information is not available.

Since the efficiency of each DMU is calculated in relation to all other DMUs using actual input-output values, the efficiency calculated in DEA is called relative efficiency. In addition to calculating the efficiency scores, DEA also determines the level and amount of inefficiency for each of the inputs and outputs. The magnitude of inefficiency of the DMUs is determined by measuring the radial distance from the inefficient unit to the frontier.

The efficiency evaluation of a unit in presence of multiple inputs and outputs becomes difficult. The difficulties are further enhanced when the relationship between the inputs and outputs are complex and involve unknown tradeoff. Simple efficiency measure defined in equation (7.1) cannot be used in this situation. Therefore, efficiency score is calculated as the "weighted cost approach" in presence of multiple inputs and outputs as shown in equation (7.2).

$$\text{Efficiency} = \frac{\text{Weighted sum of output}}{\text{Weighted sum of input}} \tag{7.2}$$

The equation (7.2) can be mathematically expressed as

$$\text{Efficiency} = \frac{\sum_{r=1}^{n} v_r y_r}{\sum_{i=1}^{m} u_i x_i} \tag{7.3}$$

where y_r = quantity of output r

v_r = weight attached to output r

x_i = quantity of input i

u_i = weight attached to input i

r=1,2…,n = number of outputs

i=1,2…,m = number of inputs

The major drawback with this measure is that it assumes that all weights are uniform. In order to alleviate this drawback, Farrell introduced a new measure of efficiency called 'technical efficiency' (TE) which employs the efficient production function. To understand the concept of an efficient production function, we take the example of a set of firms employing two factors of production (inputs) to produce a single product (output) under conditions of constant returns to scale [289,290]. Considering the inputs and outputs for each firm, an isoquant diagram is drawn as shown in Figure 7.1. A constant return to scale means that increase in the inputs by a certain proportion results in a proportional increase in the output. An isoquant diagram is the one in which all firms producing the same output lie in the same plane. A point represents each firm in an isoquant diagram so that a set of firms yields a scatter of points. An efficient production function is a curve that joins all the firms in an isoquant diagram utilizing the inputs most efficiently.

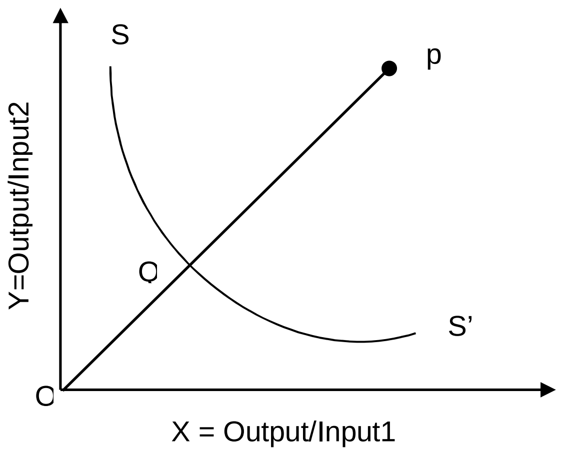


Figure 7.1 Representation of the production function

The point P represents an inefficient firm, as it is outside the isoquant SS'. It used two inputs per unit of output in a certain proportion. Since Q is on theisoquant curve, it represents an efficient firm producing same output as P but uses only a fraction of input (OQ/OP). This ratio is defined as the TE of firm P. Similarly, the TE of firm Q is OQ/OQ=1, which is an efficient firm. Adopting the idea from Farrell's TE that considers the relative performance of inputs and outputs, Charnes et al. [282] proposed a new methodology known as Data Envelopment Analysis (DEA) that can be used to measure the efficiency of a DMU relative to other DMUs in order to find the relative efficiency. In DEA, the efficiency of any DMU is obtained as the maximum of a ratio of weighted output to weighted input subjected to the condition that similar ratios for every DMU be less than or equal to unity. Usually a vector of multiple inputs and multiple outputs characterizes the investigated DMUs. Thus, direct comparison of DMUs is generally difficult. In order to aggregate information about input and output quantities, DEA makes use of fractional and corresponding linear programmes (together with their duals) to measure the relative performance of DMUs [283]. In addition to calculate the relative efficiency scores, DEA also determines the level and amount of inefficiency for each of the inputs and outputs. The magnitude of inefficiency of the DMUs is determined by measuring the radial distance from the inefficient unitto the production function SS'. Algebraically the DEA model can be written as:

The basic DEA model for $'n'$ DMUs with $'m'$ inputs and $'s'$ outputs proposed by CCR, the relative efficiency score of P^{th} DMU is given by:

$$\text{Max}Z_p = \frac{\sum_{k=1}^{s} v_k y_{kp}}{\sum_{j=1}^{m} u_j x_{jp}}$$

$$\text{Subject to} \quad \frac{\sum_{k=1}^{s} v_k y_{ki}}{\sum_{j=1}^{m} u_j x_{ji}} \le 1 \forall i \tag{7.4}$$

$$v_k, u_j \ge 0 \forall k, j$$

where $k = 1$ to s (no. of outputs)

$j = 1$ to m (no. of inputs)

$i = 1$ to n (no. of DMUs)

Z_p = Relative efficiency of the P^{th} DMU

y_{ki} = amount of output k produced by DMU_i

x_{ji} = amount of input j utilized by DMU_i

v_k = weight given to output k

u_j = weight given to input j

The fractional program equation (7.4) can be reduced to Linear Programming Problem (LPP) as follows:

$$\text{Max}Z_p = \sum_{k=1}^{s} v_k y_{kp}$$

$$\text{Subject to} \quad \sum_{i=1}^{m} u_j x_{jp} = 1$$

$$\sum_{k=1}^{s} v_k y_{ki} - \sum_{j=1}^{m} u_j x_{ji} \leq 0 \forall i \qquad (7.5)$$

$$v_k, u_j \geq 0 \forall k, j$$

The model is called CCR output-oriented maximization DEA model. The efficiency score of $'n'$ DMUs is obtained by running the above LPP $'n'$ times. The dual DEA model for the above LPP is used for benchmarking in DEA. For every inefficient DMU, DEA identifies a set of corresponding efficient units that can be utilized as benchmarks for improvement. The benchmarks can be obtained from the dual problem shown as equation (7.6) [290].

$$\text{Min } \theta$$

$$\text{Subject to } \sum_{i=1}^{n} \lambda_i x_{ji} - \theta x_{jjo} \leq 0 \forall j$$

$$\sum_{i=1}^{n} \lambda_i x_{rj} - y_{jj_0} \geq 0 \forall r \qquad (7.6)$$

$$\lambda_i \geq 0 \forall i$$

where θ = Efficiency Score

λ = Dual Variable

r = Number of output $= 1,2,\ldots, n$

i = Number of input $= 1,2,\ldots, m$

j = Number of DMUs

The main difference between the primal equation (7.5) and dual equation (7.6) model of DEA is that the number of constraints of primal depends upon the number of DMUs whereas in dual model the constraints depend upon the number of inputs and outputs. The DEA models may have any of the two-orientation viz. input orientation or output orientation. Input orientation means how much inputs can be reduced while maintaining the same level of output. But output orientation of DEA is characterized by how much output can be increased while keeping the level of inputs constant. The latter orientation is more relevant for many service providers where the objective is to maximize the output maintaining the same level of inputs. Another variation to a DEA model is the returns to scale (RTS) assumption. Constant, decreasing, increasing, and variable returns to scale assumptions may be employed. Constant Return to Scale (CRS) implies that doubling inputs will exactly double outputs. Decreasing return to scale implies that doubling inputs will less-than-double outputs. Increasing return to scale implies that doubling inputs will more-than-double outputs. Thus, Variable Return to Scale (VRS) allows for a combination of constant, increasing, and decreasing inputs and outputs. The DEA model shown in equation (7.5) and (7.6) assumes a Constant Return to Scale (CRS). The drawback with the CRS model is that it compares DMUs only based on overall efficiency assuming constant returns to scale. It ignores the fact that different DMUs could be operating at different scales. To overcome this drawback, Banker, Charnes and Cooper (BCC) developed a model which considers variable returns to scale and compares DMUs purely on the basis of TE [291]. The model can be shown as below.

$$\text{Min } \theta$$

$$\text{Subject to} \quad \sum_{i=1}^{n} \lambda_i x_{ji} - \theta x_{jj_0} \leq 0 \; \forall \; j$$

$$\sum_{i=1}^{n} \lambda_i y_{rj} - y_{jj_0} \geq 0 \; \forall \; r \qquad (7.7)$$

$$\lambda_i = 1 \; \forall \; i$$

The difference between the CRS model equation (7.6) and the VRS model equation (7.7) is that the λ_j is restricted to one. This has the effect of removing the constraint in the CRS model that DMUs must be scale efficient. Consequently, the VRS model allows variable returns to scale and measures only TE for each DMU. Thus, a DMU to be considered as CRS efficient, it must be both scale and technical efficient (TE). For a DMU to be considered VRS efficient, it only needs to be TE [292,154].

7.2.2 Selection of DMUs

In order to identify DMUs, thirty Indian industrial organizations from three sectors (where DMUs 1 to 10 represent construction, 11 to 20 belong to refractory and 21 to 30 refer steel industries) of eastern region have been considered, as shown in Table 7.1. The ranking of DMUs is made based on total score summed over perceptual score and factual score obtained from each DMU. The benchmarking of safety score considers four input and five output parameters. All the items are relevant for evaluating safety performance not only in Indian context but are quite generic to be adopted anywhere. The responses under each item are collected through field visits to all organizations. The input items are selected in such a manner that expenses on various items are likely to improve the safety performance of the industries. Each item is expressed as a percentage of total revenues of the annual budget averaged over last five years. These expenses include annual cost on health care, safety training, up-gradation of process tools and machinery, and safety instrument procured by the organizations.

The safety performance is measured by number of different categories of accidents occurring in a year. The occurrence of accidents is a random phenomenon and, many a times, difficult to assign any reasons. However, safety performance can be improved through commitment from management, change in work practices, investment on safety tools, change in equipment and machinery, improving attitude and safety perception of employees, and training. It is assumed that more than one type of accidents is unlikely to occur at the same time. As far as output is concerned, number of different types of accidents occurring per year in a DMU (Table 6.1 - Chapter 6) averaged over last five years is recoded. The reciprocal of each output item is used in DEA because accidents are unfavorable for a DMU.

Table 7.1 Selected DMUs

DMUs	Type of industry
DMU_1	Construction
DMU_2	Construction
DMU_3	Construction
DMU_4	Construction
DMU_5	Construction
DMU_6	Construction
DMU_7	Construction
DMU_8	Construction
DMU_9	Construction
DMU_{10}	Construction
DMU_{11}	Refractory
DMU_{12}	Refractory
DMU_{13}	Refractory
DMU_{14}	Refractory
DMU_{15}	Refractory
DMU_{16}	Refractory
DMU_{17}	Refractory
DMU_{18}	Refractory

DMU_{19}	Refractory
DMU_{20}	Refractory
DMU_{21}	Steel
DMU_{22}	Steel
DMU_{23}	Steel
DMU_{24}	Steel
DMU_{25}	Steel
DMU_{26}	Steel
DMU_{27}	Steel
DMU_{28}	Steel
DMU_{29}	Steel
DMU_{30}	Steel

7.2.3 The DEA model

For ranking of industries the following parameters and variables are considered in DEA model:

h = Relative efficiency

j = Number of DMUs = 30

r = Number of outputs = 5

i = Number of inputs = 4

y_{rj} = quality of r^{th} outputs of j^{th} DMU

x_{ij} = quality of i^{th} outputs of j^{th} DMU

u_r = weight of r^{th} output

v_i = weight of i^{th} input

Pictorially, the DEA model for safety performance can be presented as shown in Figure 7.2.

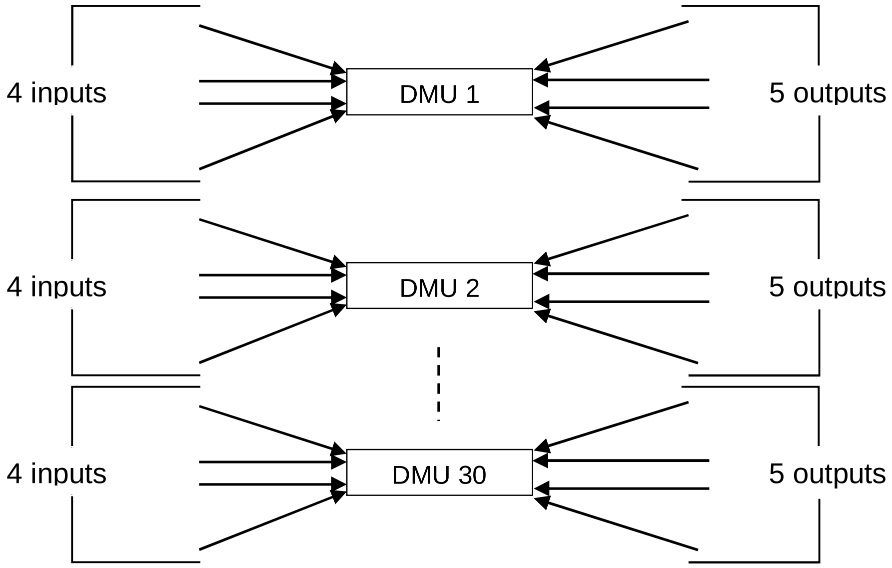


Figure 7.2 DEA model of safety performance

The relative efficiency of a target $\mathrm{DMU}(j_0)$ is given by maximizing the efficiency of $\mathrm{DMU}(j_0)$ subject to the efficiency (output/input) of all units being ≤1. or, output-input ≤ 0

Algebraically, the model can be written as,

$$\max h_{j_0} = \frac{\sum_{r=1}^{5} u_r y_{rj_0}}{\sum_{i=1}^{4} v_i x_{ij_0}}$$

$$\text{Subject to} = \sum_{r=1}^{5} u_r y_{rj_0} - \sum_{i=1}^{4} v_i x_{ij_0} \leq 0 \; j = 1,2,3,\ldots,30 \tag{7.8}$$

$$u_r, v_i \geq 0 \forall r, i$$

The fractional program in equation (7.8) can be reduced to Linear Programming Problem (LPP) as follows:

$$\max h_{j_0} = \sum_{r=1}^{5} u_r y_{rj_0}$$

$$\text{Subject to } \sum_{i=1}^{4} v_i x_{ij_0} = 1$$

$$\sum_{r=1}^{5} u_r y_{rj} - \sum_{i=1}^{4} v_i x_{ij} \le 0,\ j = 1,2,3,\cdots,30 \quad (7.9)$$

$u_r, v_i \ge 0 \forall r, i$

The variables of the above problem are the weights and the solution produces the weights most favorable to unit j_0 and also produces a measure of efficiency. The decision variables $u = (u_1, u_2, \ldots, u_r, \ldots, u_5)$ and $v = (v_1, v_2, \ldots, v_r, \ldots, v_5)$ are respectively the weights given to the five outputs and to the four inputs. The numerator of the objective function in equation (7.8) is the weighted sum of the output and the denominator is the weighted sum of input for $DMU(j_0)$ respectively. In the constraint part, we write the difference of weighted sum of outputs and weighted sum of inputs one by one for all the 30 DMUs. To obtain the relative efficiencies of all the units, the model is solved 30 times for one unit at a time.

7.3 Results and discussions

The main objective of the study is to develop a valid model for assessing safety performance of DMUs in different categories of Industries. Two types of models such as constant return to scale (CRS) and variable return to scale (VRS) are used.

7.3.1 DEA with CRS scale assumption

A DMU is regarded as a benchmark unit when its objective function (TE) becomes unity. The general input oriented maximization CCR-DEA model is used to obtain efficiency score. Data Envelopment Analysis Programme (DEAP version 2.1) has been used to solve the model. The results thus obtained are summarized in Table 7.2 (CRS model). The first column of the table represents the selected DMUs arranged in a sequential manner. The second column specifies the efficiency score of the corresponding DMUs. Based on the efficiency score, the DMUs are ranked as shown in the third column. The fourth column shows the peers or the benchmarking units for the corresponding DMU. The fifth column indicates the weight of each of the peers or the benchmarking unit. The last column shows the peer count of the DMUs. Ranking based on relative efficiency scores indicate that seven DMUs out of 30 DMUs have emerged as benchmarking units for the other 23 DMUs. The efficient or benchmarking units are listed as DMU_{12}, DMU_{16}, DMU_{17}, DMU_{22}, DMU_{25}, $DMU_{29,}$ and DMU_{30} as shown in Table 7.2. The efficiency score for these DMUs approach unity while that of DEA-inefficient DMUs show relative efficiency less than unity. The inefficient units can refer the DMUs listed in column 4 with corresponding peer weight given in column 5 for the improvement in safety performance. For example, DMU_1 having efficiency score of 0.877 can refer DMU_{16}, DMU_{12} and DMU_{25}. DMU_1 can assign a weightage of 0.341 to DMU_{16}, 0.277 to DMU_{12} and 0.382 to DMU_{25} to become a benchmark unit.

It is evident from column 4 that there are thirteen DMUs (DMU_1, DMU_2, DMU_4, DMU_9, DMU_{10}, DMU_{11}, DMU_{13}, DMU_{18}, DMU_{19}, DMU_{20}, DMU_{21}, $DMU_{23,}$ and DMU_{24}) consult three benchmarking organizations. Seven DMUs (DMU_3, DMU_6, DMU_7, DMU_8, DMU_{14}, DMU_{15}, and DMU_{28}) which can refer four different DEA-efficient units with varying degree of weightages. Two DMUs (DMU_{26} and DMU_{27}) which can refer five different DEA efficient units with the corresponding weightages whereas it is interesting to note that DMU_6 is the only DMU that has six reference units ($DMU_{17,}$ DMU_{12}, DMU_{29}, DMU_{22}, $DMU_{16,}$ and DMU_{25}). It is further observed that DMU_{12}, DMU_{16}, DMU_{17}, DMU_{22}, $DMU_{25,}$ and DMU_{29} have become peer units nineteen, twenty-three, nine, four, eighteen, and ten times respectively. It is to be noted that DMU_{16} is ranked as best first because it has efficiency score of one and more number of referring DMUs as far as safety performance is concerned whereas DMU_3 is ranked last one having efficiency score 0.694 denoted as most inefficient unit. It is important to note that not a single DMU from construction category has become efficient one. The overall efficiency score of thirty DMUs is found to be 0.898 meaning that there exists a large scope for improvement of safety performance in Indian industries. When mean efficiency scores of three industrial categories are compared, it reveals that construction sector (mean efficiency=0.856) perform worst in regard to safety performance and refractory sector (mean efficiency=0.921) is best in that respect. However, safety performance of steel sector (mean efficiency=0.916) lies in between them. The difference in mean efficiency score of steel and refractory units is marginal. Therefore, steel units can approach refractory sector with least resistance whereas construction sector must work hard to improve their safety performance through a broad based policy.

Table 7.2 Results of DEA (CRS) model

DMUs	Efficiency	Ranking by DEA	Peers	Peer weights	Peer count
DMU_1	0.877	12	16	0.341	0
			12	0.277	
			25	0.382	
DMU_2	0.876	13	25	0.117	0
			16	0.103	
			17	0.871	
DMU_3	0.694	24	25	0.092	0
			16	0.239	
			22	0.444	
			29	0.007	
DMU_4	0.861	15	12	0.247	0
			25	0.443	
			16	0.310	
DMU_5	0.918	5	17	0.073	0
			12	0.321	
			29	0.326	
			22	0.086	
			16	0.176	
			25	0.135	
DMU_6	0.840	19	17	0.059	0
			12	0.153	
			25	0.477	
			16	0.311	
DMU_7	0.834	20	16	0.178	0
			29	0.098	
			25	0.729	
			12	0.082	
DMU_8	0.940	3	17	0.197	0
			29	0.106	
			12	0.158	
			16	0.382	
DMU_9	0.893	10	12	0.307	0
			25	0.320	
			16	0.373	
DMU_{10}	0.832	21	16	0.028	0
			25	0.221	
			17	0.738	
DMU_{11}	0.844	18	12	0.462	0
			29	0.004	
			16	0.537	
DMU_{12}	1.000	1	12	1.000	19
DMU_{13}	0.847	17	16	0.707	0
			29	0.387	
			12	0.099	
DMU_{14}	0.907	7	25	0.459	0
			12	0.311	

			17	0.003	
			16	0.227	
DMU_{15}	0.857	16	16	0.003	0
			17	0.674	
			12	0.027	
			25	0.281	
DMU_{16}	1.000	1	16	1.000	23
DMU_{17}	1.000	1	17	1.000	9
DMU_{18}	0.910	6	12	0.339	0
			25	0.255	
			16	0.406	
DMU_{19}	0.980	2	29	0.718	0
			16	0.032	
			25	0.132	
DMU_{20}	0.867	14	16	0.378	0
			12	0.265	
			25	0.357	
DMU_{21}	0.883	11	12	0.297	0
			25	0.296	
			16	0.410	
DMU_{22}	1.000	1	22	1.000	4
DMU_{23}	0.896	8	16	0.266	0
			25	0.432	
			12	0.301	
DMU_{24}	0.894	9	12	0.004	0
			22	0.469	
			16	0.293	
DMU_{25}	1.000	1	25	1.000	18
DMU_{26}	0.810	22	25	0.217	0
			29	0.406	
			16	0.260	
			22	0.172	
			12	0.062	
DMU_{27}	0.757	23	29	0.145	0
			16	0.092	
			25	0.749	
			17	0.002	
			12	0.140	
DMU_{28}	0.924	4	12	0.180	0
			17	0.064	
			16	0.377	
			29	0.218	
DMU_{29}	1.000	1	29	1.000	10
DMU_{30}	1.000	1	30	1.000	0
Overall mean efficiency (DMU_1 to DMU_{30}) = 0.898					
Mean efficiency (DMU_1 to DMU_{10}) = 0.856					
Mean efficiency (DMU_{11} to DMU_{20}) = 0.921					
Mean efficiency (DMU_{21} to DMU_{30}) = 0.916					

*DMU_1 to DMU_{10} = Construction, DMU_{11} to DMU_{20} = Refractory, DMU_{21} to DMU_{30} = Steel

7.3.2 Comparison between efficient and inefficient DMU (CRS Model)

The comparisons between the average of inputs and outputs efficient and inefficient DMUs are mentioned in Table 7.3. It may be noted that efficient DMU spends less than its inefficient counterpart on safety. Still the efficient DMU records less number of accidents compared to inefficient DMU. It means that inefficient DMU is not effectively converting its committed resources into lower number of accidents. Therefore, the inefficient DMU needs to examine safety expenses properly and find cost minimization opportunity without impacting safety performance of the organization.

Table 7.3 Comparison of inputs and outputs between efficient and inefficient DMUs

	Efficient industry (DMU_{16})	Inefficient industry (DMU_3)
Inputs		
Expenses in health care	4.00%	4.00%
Expenses in safety training	2.00%	3.00%
Expenses in up-gradation of process related tools, instruments, machines, materials leading to safe and healthy environment	4.00%	4.50%
Expenses on safety equipment and tools	2.00%	3.50%
Outputs		
Accident that do not cause any disability and do not involve any lost work days	10.00	14.28
Accident that do not cause any disability but involve lost work days	7.14	9.09
Accident that cause temporary disability	2.00	5.55
Accident that cause permanent partial disability	1.00	5.00
Accident that cause permanent full disability or fatality	1.00	1.00

Although the model is quite capable of distinguishing performing and non-performing DMUs, it is prudent to analyze effect of changes in inputs on output. To this end, each input variable is changed by 10% from its base value in a systematic manner and output is noted down. As shown in Table 7.4, all the inputs are decreased by 10% for the most inefficient unit (DMU_3). It has been observed that DMU_3 becomes efficient after four steps.

Table 7.4 Changes in efficiency when all inputs of DMU_3 is decreased by 10%

DUM_3	I_1	I_2	I_3	I_4	Efficiency
Base value	4.0000	3.0000	4.50000	3.50000	0.694
Step1	3.6000	2.7000	4.05000	3.15000	0.771
Step2	3.2400	2.4300	3.64500	2.83500	0.856
Step3	2.9160	2.1870	3.28050	2.55150	0.952
Step4	2.6244	1.9683	2.95245	2.29635	1.000

*Note: I= Input

Next, effect of changes in each input on output is considered. Table 7.5 depicts the output when only one input, I_1 (Expenses in health care), is decreased from its base value by 10% systematically keeping other inputs at their base value for the most inefficient unit (DMU_3). It is evident from the table that DMU_3 becomes efficient in five steps.

Table 7.5 Changes in efficiency when input 1 (I_1) of DMU_3 is decreased by 10%

DUM_3	I_1	I_2	I_3	I_4	Efficiency
Base value	4.00000	3.0	4.5	3.5	0.694
Step1	3.60000	3.0	4.5	3.5	0.716
Step2	3.24000	3.0	4.5	3.5	0.782
Step3	2.91600	3.0	4.5	3.5	0.859
Step4	2.62244	3.0	4.5	3.5	0.943
Step5	2.36196	3.0	4.5	3.5	1.000

*Note: I= Input

Similarly, Table 7.6 shows that when expenses in safety training (I_2) is decreased by 10% from its base value keeping other inputs at their base level, DMU_3 becomes efficient in four steps.

Table 7.6 Changes in efficiency when input 2 (I_2) of DMU_3 is decreased by 10%

DUM_3	I_1	I_2	I_3	I_4	Efficiency
Base value	4.0	3.0000	4.5	3.5	0.694
Step1	4.0	2.7000	4.5	3.5	0.756
Step2	4.0	2.4300	4.5	3.5	0.833
Step3	4.0	2.1870	4.5	3.5	0.920
Step4	4.0	1.9683	4.5	3.5	1.000

*Note: I= Input

But decrease in inputs like expenses in up-gradation of process related tools, instruments, machines, materials leading to safe and healthy environment (I_3) and expenses on safety equipment and tools (I_4) requires six steps so that DMU_3 can become efficient (Table 7.7 and Table 7.8).

Table 7.7 Changes in efficiency when input 3 (I_3) of DMU_3 is decreased by 10%

DUM_3	I_1	I_2	I_3	I_4	Efficiency
Base value	4.0	3.0	4.5000000	3.5	0.694
Step1	4.0	3.0	4.0500000	3.5	0.733
Step2	4.0	3.0	3.6450000	3.5	0.778
Step3	4.0	3.0	3.2805000	3.5	0.844
Step4	4.0	3.0	2.9524500	3.5	0.913
Step5	4.0	3.0	0.6572050	3.5	0.986
Step6	4.0	3.0	2.3914845	3.5	1.000

*Note: I= Input

Table 7.8 Changes in efficiency when input 4 (I_4) of DMU_3 is decreased by 10%

DUM_3	I_1	I_2	I_3	I_4	Efficiency
Base value	4.0	3.0	4.5	3.5000000	0.694
Step1	4.0	3.0	4.5	3.1500000	0.710
Step2	4.0	3.0	4.5	2.8350000	0.766
Step3	4.0	3.0	4.5	2.5515000	0.831
Step4	4.0	3.0	4.5	2.2963500	0.902
Step5	4.0	3.0	4.5	2.0667150	0.976
Step6	4.0	3.0	4.5	1.8600435	1.000

*Note: I= Input

It is clearly evident from foregoing discussions that expenses in safety training (I_2) is relatively more sensitive for improving safety performance of the organization whereas expenses in health care (I_1) moderately influences safety performance. Other two inputs also help in improving safety performance but need a large reduction on expenses. Therefore, it implies that expenditure on safety related training should not be reduced at present and training related activities must not be discontinued. If the training is good enough, the work force learn and absorb the skills that reflects in causing reduction in accident rates.

7.3.3 Comparison of output parameters (CRS Model)

The five output parameters are divided into two categories. The first two outputs (accident that do not cause any disability and do not involve any lost work days; accident that do not cause any disability but involve lost work days) that hardly cause any disability are treated as category I output and three outputs (accident that cause temporary disability; accident that cause permanent partial disability; accident that cause permanent full disability or fatality) causing disability are treated as category II output. It is decided to study the model behavior on different categories of outputs and compare the results with base model results shown in Table 7.2. The model is run considering only category I outputs and the results are depicted in Table 7.9. It can be observed that four DMUs (DMU_{12}, $DMU_{17,}$ DMU_{25} and DMU_{29}) have come up as efficient in contrast to seven DMUs in the base model (Table 7.2). The overall efficiency score has been reduced from 0.898 to 0.786. The sector wise mean efficiency scores have also been reduced from the base model but interestingly safety performance of refractory sector happens to be efficient in both the models. The second best safety performing sector comes out to be construction sector in contrast to steel sector in the base model. This clearly indicates that minor accidents are caused irrespective of industrial sectors to some extent in all organizations. Therefore, the number of efficient units in terms of category I outputs has been reduced. Two DMUs (DMU_{25} and DMU_{29}) from steel sector turned out to be most efficient units whereas only one unit (DMU_{16}) from refractory sector is labeled as most efficient one in the base model depending on number of peer counts.

Table 7.9 Output 1 and Output 2 (Category I) (CRS Model)

DMUs	Efficiency	Ranking by DEA	Peers	Peer weights	Peer count
DMU_1	0.830	10	25	0.518	0
			12	0.262	
			29	0.084	
DMU_2	0.832	9	25	0.208	0
			27	0.821	
DMU_3	0.452	22	25	0.243	0
			29	0.229	
DMU_4	0.819	12	25	0.563	0
			12	0.235	
			29	0.077	
DMU_5	0.848	7	25	0.285	0
			12	0.314	
			29	0.419	
DMU_6	0.788	15	25	0.589	0
			12	0.178	
			29	0.099	
DMU_7	0.440	23	25	0.100	0
			29	0.550	
DMU_8	0.795	14	17	0.153	0

			12	0.247	
			29	0.268	
DMU_9	0.840	8	25	0.470	0
			12	0.289	
			29	0.091	
DMU_{10}	0.819	12	25	0.246	0
			17	0.725	
DMU_{11}	0.736	17	25	0.075	0
			12	0.508	
			29	0.208	
DMU_{12}	1.000	1	12	1.000	17
DMU_{13}	0.717	19	12	0.172	0
			29	0.658	
			25	0.078	
DMU_{14}	0.862	4	25	0.542	0
			12	0.310	
			29	0.043	
DMU_{15}	0.856	5	12	0.028	0
			17	0.673	
			25	0.282	
DMU_{16}	0.957	3	25	0.286	
			29	0.357	
DMU_{17}	1.000	1	17	1.000	6
DMU_{18}	0.851	6	25	0.422	
			12	0.318	
			29	0.098	
DMU_{19}	0.967	2	29	0.775	0
			25	0.050	
DMU_{20}	0.819	12	25	0.509	0
			12	0.246	
			29	0.098	
DMU_{21}	0.829	11	25	0.463	0
			12	0.273	
			29	0.105	
DMU_{22}	0.488	20	25	0.186	0
			29	0.307	
DMU_{23}	0.851	6	29	0.057	0
			25	0.534	
			12	0.294	
DMU_{24}	0.394	24	25	0.156	0
			29	0.209	
			12	0.022	
DMU_{25}	1.000	1	25	1.000	23
DMU_{26}	0.718	18	29	0.536	0
			25	0.426	
DMU_{27}	0.474	21	29	0.611	0
			25	0.079	
DMU_{28}	0.784	16	17	0.027	0
			12	0.265	

			29	0.376	
DMU_{29}	1.000	1	29	1.000	23
DMU_{30}	0.804	13	17	0.601	0
			29	0.012	
			12	0.262	
Overall mean efficiency (DMU_1 to DMU_{30}) = 0.7860					
Mean efficiency (DMU_1 to DMU_{10}) = 0.7463					
Mean efficiency (DMU_{11} to DMU_{20}) = 0.8765					
Mean efficiency (DMU_{21} to DMU_{30}) = 0.7342					

*DMU_1 to DMU_{10} = Construction, DMU_{11} to DMU_{20} = Refractory, DMU_2 to DMU30= Steel

Again, the model is run considering only category II outputs and the results are shown in Table 7.10. It can be observed that six DMUs (DMU_{12}, DMU_{16}, DMU_{17}, DMU_{22}, DMU_{25} and DMU_{29}) have come up as efficient in contrast to seven DMUs in the base model and four DMUs when only category I output is considered. The overall efficiency score has been reduced from 0.898 to 0.752 whereas this value is 0.786 if only category I outputs are considered. It is to be noted that mean efficiency of steel sector is higher compared to other two types of sector. The second best safety performing sector comes out to be refractory sector which is the best performing sector in base model and the model with category I outputs. This implies that major accidents are less in steel sector as compared to other industrial sectors. Only one DMU (DMU_{16}) from refractory sector becomes most efficient unit which is also most efficient one in the base model.

Table 7.10 Output 3, Output4 and Output 5 (Category II) (CRS Model)

DMUs	Efficiency	Ranking by DEA	Peers	Peer weights	Peer count
DMU_1	0.720	15	12	0.040	0
			16	0.960	
DMU_2	0.481	23	17	0.279	0
			29	0.233	
			16	0.105	
DMU_3	0.682	18	22	0.465	0
			16	0.302	
DMU_4	0.803	7	12	0.176	0
			16	0.535	
			25	0.289	
DMU_5	0.745	12	16	0.294	0
			22	0.471	
DMU_6	0.790	8	12	0.068	0
			16	0.553	
			25	0.379	
DMU_7	0.812	5	16	0.248	0
			12	0.089	
			25	0.663	

DMU_8	0.555	20	16	0.482	0
			29	0.064	
DMU_9	0.814	4	12	0.209	0
			16	0.664	
			25	0.128	
DMU_{10}	0.430	24	29	0.038	0
			17	0.355	
			16	0.127	
DMU_{11}	0.783	9	12	0.087	0
			16	0.913	
DMU_{12}	1.000	1	12	1.000	12
DMU_{13}	0.697	16	22	0.183	0
			16	0.725	
DMU_{14}	0.804	6	12	0.179	0
			16	0.620	
			25	0.201	
DMU_{15}	0.405	25	22	0.045	0
			16	0.125	
			17	0.307	
DMU_{16}	1.000	1	16	1.000	24
DMU_{17}	1.000	1	17	1.000	3
DMU_{18}	0.769	10	16	1.000	
DMU_{19}	0.549	21	12	0.043	0
			22	0.063	
			16	0.191	
DMU_{20}	0.824	3	12	0.211	0
			16	0.542	
			25	0.247	
DMU_{21}	0.747	11	12	0.041	0
			16	0.959	
DMU_{22}	1.000	1	22	1.000	7
DMU_{23}	0.733	13	12	0.098	0
			16	0.886	
			25	0.015	
DMU_{24}	0.894	2	16	0.294	0
			22	0.471	
DMU_{25}	1.000	1	25	1.000	8
DMU_{26}	0.688	17	22	0.445	0
			16	0.260	
			29	0.143	
DMU_{27}	0.726	14	25	0.658	0
			16	0.196	
			12	0.146	
DMU_{28}	0.572	19	16	0.547	0
			29	0.022	
DMU_{29}	1.000	1	29	1.000	6
DMU_{30}	0.539	22	29	0.414	0
			16	0.331	
Overall mean efficiency (DMU_1 to DMU_{30}) = 0.7520					

Mean efficiency (DMU_1 to DMU_{10}) = 0.6832
Mean efficiency (DMU_{11} to DMU_{20}) = 0.7831
Mean efficiency (DMU_{21} to DMU_{30}) = 0.7899

*DMU_1-DMU_{10} = Construction, DMU_{11}-DMU_{20} = Refractory, DMU_{21}-DMU_{30} = Steel

7.3.4 DEA with VRS scale assumption

The result of VRS-DEA model is shown in Table 7.11. In contrast to CRS model, fourteen DMUs (DMU_1, DMU_2, DMU_3, DMU_4, DMU_6, DMU_9, DMU_{10}, DMU_{11}, DMU_{14}, DMU_{15}, DMU_{18}, DMU_{20}, DMU_{21}, and DMU_{23}) with corresponding efficiency scores are found to be the DEA-inefficient units in VRS model. The inefficient units can make adjustments in their inputs/outputs looking into their peer groups to become efficient unit. These units may adopt either input-oriented strategy or output-oriented strategy to become efficient. The input-oriented strategy emphasizes on achieving current level of output using less inputs than the current level whereas output-oriented strategy rests on achieving higher level of output by same level of inputs. The latter strategy is not only preferred but also suitable for safety performance in Indian industries. The relative efficiency scores indicate that fourteen DMUs out of 30 DMUs have emerged as inefficient units for the other sixteen DMUs.

It is to be noted that sixteen DMUs are efficient units listed as DMU_5, DMU_7, DMU_8, DMU_{12}, DMU_{13}, DMU_{16}, DMU_{17}, DMU_{19}, DMU_{22}, DMU_{24}, DMU_{25}, DMU_{26}, DMU_{27}, DMU_{28}, DMU_{29}, and DMU_{30} as shown in column two (Table 7.11). The efficiency score for these DMUs approach unity while that of DEA-inefficient DMUs show relative efficiency less than unity. The inefficient units can refer the DMUs listed in column 4 with corresponding peer weight given in column 5 for the improvement in safety performance. It is evident from column 4 that there are eight DMUs (DMU_1, DMU_2, DMU_4, DMU_9, DMU_{18}, DMU_{20}, DMU_{21}, and DMU_{23}) which can refer three different DEA-efficient units. Five DMUs (DMU_3, DMU_6, DMU_{10}, DMU_{14}, and DMU_{15}) consult four benchmarking organizations whereas DMU_{11} which can refer two different DEA efficient units with the corresponding weightages. The last column indicates that DMU_{12} and DMU_{25} become the peer units for twelve times, DMU_{16} become the peer units of thirteen times, DMU_{17} become the peer units of five times and DMU_{29} become the peer unit for two times. The overall efficiency score of all DMUs is found to be 0.942 which happen to be more than that of CRS-model. Based on the efficiency scores obtained from CRS and VRS model, it is interesting to note that fourteen DMUs (DMU_1, DMU_2, DMU_3, DMU_4, DMU_6, DMU_9, DMU_{10}, DMU_{11}, DMU_{14}, DMU_{15}, DMU_{18}, DMU_{20}, DMU_{21}, and DMU_{23}) have become inefficient units in both CRS and VRS model. When mean efficiency scores of three industrial categories are compared, it reveals that safety performance of steel sector (mean efficiency=0.977) is best whereas construction sector (mean efficiency=0.908) perform worst in regard to safety performance. Mean efficiency of refractory sector (mean efficiency=0.939) lies between them. In order to check for existence of significant difference between safety performance scores calculated using the two models (CRS and VRS) a paired sample t-test for means is carried out [293]. The hypothesis set is as follows:

Null Hypothesis: H_0: TE from DEA (CRS) = TE from DEA (VRS)

Alternate Hypothesis: H_1: TE from DEA (CRS) ≠ TE from DEA (VRS)

The t-test is conducted using SYSTAT VERSION 12 software. The result shows a p-value of 0.002 allowing us to reject the null hypothesis with anα (probability of type I error) value as low as 0.05. This allows us to accept the alternate hypothesis that there is a significant difference between efficiency scores obtained through CRS and VRS models. The test indicates that a DEA model can produce results significant different based on assumption of scale. The manager must study the behavior of input and output variables before making any assumption on scale.

Table 7.11 Results of DEA (VRS Model)

DMUs	Efficiency	Ranking by DEA	Peers	Peer weights	Peer count
DMU_1	0.877	8	12	0.277	0
			25	0.382	
			16	0.341	
DMU_2	0.943	2	12	0.035	0
			17	0.704	
			30	0.261	
DMU_3	0.825	15	25	0.261	0
			22	0.157	
			29	0.157	
			16	0.426	
DMU_4	0.861	11	25	0.443	0
			12	0.247	
			16	0.310	
DMU_5	1.000	1	5	1.000	0
DMU_6	0.840	14	17	0.059	0
			25	0.477	
			12	0.153	
			16	0.311	
DMU_7	1.000	1	7	1.000	0

DMU_8	1.000	1	8	1.000	0
DMU_9	0.893	6	12	0.307	0
			25	0.320	
			16	0.373	
DMU_{10}	0.841	13	17	0.709	0
			16	0.004	
			29	0.042	
			25	0.245	
DMU_{11}	0.846	12	12	0.500	0
			16	0.500	
DMU_{12}	1.000	1	12	1.000	12
DMU_{13}	1.000	1	13	1.000	0
DMU_{14}	0.907	4	25	0.459	0
			17	0.003	
			12	0.311	
			16	0.277	
DMU_{15}	0.865	10	16	0.024	0
			17	0.680	
			25	0.273	
			12	0.023	
DMU_{16}	1.000	1	16	1.000	13
DMU_{17}	1.000	1	17	1.000	5
DMU_{18}	0.910	3	25	0.255	0
			12	0.339	
			16	0.409	
DMU_{19}	1.000	1	19	1.000	0
DMU_{20}	0.867	9	25	0.357	0
			12	0.265	
			16	0.345	
DMU_{21}	0.883	7	12	0.295	0
			25	0.296	
			16	0.410	
DMU_{22}	1.000	1	22	1.000	1
DMU_{23}	0.896	5	25	0.432	0
			12	0.301	
			16	0.266	
DMU_{24}	1.000	1	24	1.000	0
DMU_{25}	1.000	1	25	1.000	12
DMU_{26}	1.000	1	26	1.000	0
DMU_{27}	1.000	1	27	1.000	0
DMU_{28}	1.000	1	28	1.000	0
DMU_{29}	1.000	1	29	1.000	2
DMU_{30}	1.000	1	30	1.000	1

Overall mean efficiency (DMU1 to DMU30) = 0.942
Mean efficiency (DMU_1 to DMU_{10}) = 0.908
Mean efficiency (DMU_{11} to DMU_{20}) = 0.939
Mean efficiency (DMU_{21} to DMU_{30}) = 0.977

*DMU_1-DMU_{10} = Construction, DMU_{11}-DMU_{20} = Refractory, DMU_{21}-DMU_{30} = Steel

7.4 Conclusions

This chapter attempts to provide a framework for assessing safety performance of three industrial sectors based on DEA approach. The methodology helps to identity benchmarking units in same or other sectors so that the best practices of peers can be implemented to become efficient one. It also quantifies how much efficiency score needs to be improved so as to reach at referring unit's score.

The genesis of the work is based on the fact that safety performance can be improved through adequate allocation of annual budget of the firm in different safety activities. Therefore, the percentage of annual budget on various safety activities is considered as inputs to DEA model. The number of accidents of different nature occurring in a unit are treated as outputs of the model and signify the safety performance of a firm. DEA approach helps to identify the benchmarking organizations which can be referred by inefficient units to become efficient one. Two approach of DEA known as CRS and VRS are considered to obtain efficiency of DMUs. Seven units out of thirty are found to be efficient in CRS model whereas sixteen units are found to be efficient in VRS model. Fourteen DMUs (DMU_1, DMU_2, DMU_3, DMU_4, DMU_6, DMU_9, DMU_{10}, DMU_{11}, DMU_{14}, DMU_{15}, DMU_{18}, DMU_{20}, DMU_{21}, and DMU_{23}) have become inefficient units in both CRS and VRS model based on their efficiency scores. The efficiency scores obtained by CRS and VRS models are compared using a paired sample t-test. It has been demonstrated that statistically significant difference exists on ranking of units in both models. Therefore, managers must be cautious regarding the use of scale assumption. A thorough understanding of behavior of input and output variables is needed while assuming scale. Seven units have resulted as efficient in DEA-CRS model. They are three (DMU_{12}, DMU_{16} and DMU_{17}) from refractory and four (DMU_{22}, DMU_{25}, DMU_{29} and DMU_{30}) from steel industries. It is to be noted that, not a single unit from construction sector is eligible to be considered as efficient one. In case of DEA-VRS model, 53% of the selected DMUs under this study are DEA-efficient. The average mean score of efficiency indicates that construction sector must strengthen its efforts to improve the safety performance. The original DEA-CRS model is considered as base model and model bahaviour, specifically sensitivity analysis of inputs and outputs on efficient frontier, is studied. When inputs are reduced by ten percent in a systematic manner, it is observed that an expense in safety training is relatively a more sensitive factor for improving safety performance of the organizations. The outputs are categorized into two groups. One group of outputs considers accidents that do not lead to disability whereas other group considers accidents that lead to disability. The results obtained from both categories of outputs are compared with the base model. The number of efficient units with the model considering outputs of category I is much less than the base model. It implies that accidents of minor nature do occur in all organization irrespective of industrial sectors. However, refractory units show better performing organizations as far as safety is concerned considering the mean efficiency score both in base model and model with category I outputs. When output category II is considered, it is observed that steel units perform better as compared to other sectors.

An excellent utilization for the result of this study is programs like US Malcolm Baldridge National Quality Award and the UK Department of Trade and Industry Business-to-Business Exchange Program [294]. These programs aim at improving the performance of particular industries. Of course, UK Department of Trade and Industry Business-to-Business Exchange Program offers visits to UK best practicing organizations in manufacturing and service industries. The goal of these visits helps to transfer best across interested organizations for the purpose of improving their performance. Therefore, the deployment of the DEA methodology makes it possible for programs like the ones described above to utilize the results and target industry leaders in order to publicize their strategies and procedures for the benefits of the whole organization. The construction industry currently lacks any readily available safety performance measure to assess performance. To judge safety performance, the industry currently relies on the segregated reported number of the different types of accidents. As such, the DEA approach is well suited to fill this gap and assesses industry safety performance. The DEA approach presented in this paper can be utilized by a particular industry to gauge its own safety performance over time. With data available for several numbers of years, every year might be considered as a single DMU. By conducting such analysis industry would be able to quantitatively determine whether or not the safety performance of the firm is getting better over time. Even though the results in this chapter is based on data collected from three industrial sectors of eastern region of India, the methodology would suggest a much broader geographical applicability on evaluating safety performance in all sectors in India. Clearly, to gain insight into the problem, both, a large sample size and a large scope of data collection, are essential. The factors, such as organizational safety policy, safety training, safety equipment, safety inspection, safety incentives and penalties, and workers' attitude towards safety, must be considered for improving safety performance in a specific context.

CHAPTER 8

EXECUTIVE SUMMARY AND CONCLUSIONS

8.1 Introduction

The study mainly revolves around issues of occupational health and safety (OHS) and their assessment in the context of injury prevention social marketing. However, assessment and measurement of OHS practices largely depends on perceptions of manager, safety officers and workers because they are directly involved in OHS policy implementation in an organization. In addition, type and size of the organization and internal and external factors influence safety performance to a large extent. Therefore, it becomes practically difficult to set the standards and procedures for maintenance, measurement and evaluation of OHS practices from social marketing perspective. As OHS is a sensitive issue, the industries are reluctant to share the accident data at least in Indian environment to gain insight into the problem and propose corrective measures. Because of paucity of field data, the study undertakes a questionnaire survey to assess the safety culture in industrial settings. Although the survey uses many safety items (or characteristics), it finds that the items and number of items widely differ across the types of industries, size and location of organizations. However, attempt has been made to propose an instrument consisting of OHS dimensions and items under each dimension for assessment OHS practices systematically in a variety of industrial settings. The study also contributes in providing an integrated approach for modeling perceptions of manager, safety officers and workers to find deficient safety items in different kinds of organizations and in proposing an appropriate construct to benchmark OHS performance in Indian industrial setting. The benchmarking study helps to highlight deficiencies and evolve appropriate strategies to improve the performance. The work environment in three sectors such as construction, refractory and steel considered in this study is generally viewed as hazardous due to usage of heavy equipment, unsafe and primitive tools, injurious materials and dust produced during operation. There are many other sectors such as fishing, agriculture, nuclear installations, electricity generating plants, mining etc. where safety is of prime importance. However, the study area covers such industries where size in manpower and investment varies, both organized and unorganized workforce exist, both public and private enterprises exist and level of sophistication of tools, methods, and work environment is poor.

The instrument proposed for assessment OHS practices in industrial sectors is used to identify the pattern of influence of input parameters on outputs such as injury level and material damage, which otherwise would have been difficult to establish, possibly due to existence of some nonlinear relationship among them. Injury level is an aggregate measure of severity and frequency of accidents caused due to prevailing safety norms adopted in the work field. Material damage is the aggregate measure of damage caused to equipment, machinery, raw materials, consumables, accessories etc. due to prevailing practice of safety culture. Both the measures are difficult to assess quantitatively because relationship between inputs and the outputs of the system is not well understood. Although safety policy significantly influences material damage and injury level, but it is not a measurable quantity. Therefore, perceptions of manager, safety officers and workers on various safety items are extracted and their impact on both the measures is assessed. The usefulness of the study in real practice has been explained in the following sections. Various methods used in this work provide some important guidelines on OHS implementation in different types of industries. These guidelines are also useful while formulating OHS policy in a specific situation. Therefore, in this research work, an attempt has been made to provide a general framework for designing the OHS instrument suiting to some important industry categories (construction, refractory and steel) and an evaluation methodology for identification of injury prevention social marketing blockages existing in the system.

8.2 Summary of the findings

The important findings of this thesis are summarized as follows:

- The study presents evidence that occupational health and hazard perception in Indian industrial settings can be reliably measured with twenty three items loaded on nine factors such as Preventive procedures, OHS training, Risk management, Work practices, Periodic plans, Continuous improvement, Injury avoidance, Emergency plans, and Health care.
- It is to be noted that Injury Avoidance happened to be most important factor with percentage of variance 12.136 whereas Risk Management is least important factor with percentage of variance 5.561.
- Three group Linear Discriminant analysis (LDA) shows that “Standards of action or work procedures are elaborated on the basis of risk evaluation” (Item 23) differ significantly in refractory and steel industries under “Injury avoidance” (factor 1). Significant difference exists in construction and steel industries for “Pre-determined plans and actual steps are frequently compared to identify gaps” (item 29) contained in “Preventive procedure” (factor 3). Significant difference is found in “Workers are sufficiently trained while entering firm, changing jobs or using new technique” (Item 8) under “Work practices” (factor 4) for construction

and steel industries. As far as “Health care” (factor 8) is concerned, significance difference exists in refractory and steel industries on “Workers are informed about risks associated with their work and how to prevent accidents through written circulars and meetings” (item 18). Significance difference exists in “Firm’s accident rates are regularly compared with those of other organizations from same sectors using similar production processes” (item 33) under Risk management (factor 9) in refractory and steel industries. It is to be noted that not a single item in “OHS training” (factor 2), “Periodic plans” (factor 5), “Continuous improvement” (factor 6) and “Emergency plan” (factor 7) shows statistically significant difference industry wise.

- Neural network approach is adopted to carry out sensitivity analysis. It is found that eight items such as Item 19 (Firm has systems to identify risks in all job positions), Item 23 (Standards of action or work procedures are elaborated on the basis of risk evaluation), Item 29 (Pre-determined plans and actual steps are frequently compared to identify gaps), Item 18 (Workers are informed about risks associated with their work and how to prevent accidents through written circulars and meetings), Item 27 (All workers are informed about emergency plan), Item 24 (Prevention plans are circulated among all workers), Item 31 (Systematic inspections are conducted periodically to ensure effective functioning of whole system), and Item 28 (Periodic checks are conducted on execution of prevention plans and compliance level of regulations) are most sensitive common items largely contributing for prevention of injury level in all types of industries. Similarly, seven items like Item 8 (Workers are sufficiently trained while entering firm, changing jobs or using new technique), Item 19 (Firm has systems to identify risks in all job positions), Item 22 (Prevention plans clearly specify person responsible for carrying out action), Item 23 (Standards of action or work procedures are elaborated on the basis of risk evaluation), Item 3 (A format on functions of commitment, participation and responsibilities is established on all safety aspects and available to all organization members), Item 13 (OHS training actions are carried out during working day), and Item 27 (All workers are informed about emergency plan) are most sensitive common items largely contributing for reduction of material damage in all types of industries. Item 19 (Firm has systems to identify risks in all job positions) is the most prioritized item for construction and refractory industries whereas Item 12 (Training plan is decided jointly with workers or their representatives) is highest ranked item in steel sector for prevention of injury level. It is found that Item 29 (Pre-determined plans and actual steps are frequently compared to identify gaps) is the most prioritized item for construction and steel industries whereas Item 10 (Training actions are continuous and periodic and are integrated in formally established training plan) is highest ranked item in refractory sector for minimization of material damage. In addition to eight common items, four other items contribute for prevention of injury level in refractory industry. Similarly, six more items are other items in addition to eight common items contributing for minimization of injury level in steel industries. In addition to seven common items contributing for minimization of material damage, two items in construction, three items in refractory and three in steel are other items.

- The eight deficient common items (or sensitive items) contributing largely for minimizing injury level in three types of industries are used as voice of customers and nine design requirements (1. Regularity in preventive maintenance work, 2. Regular consultation of management with employees on safety issues, 3. Management commitment and reward system, 4. Safety committee and reward system, 5. Up-gradation of safety knowledge through continuous reduction and re-training, 6. Adequate training for organising materials and human resources quickly to response any emergency, 7. Analysis of possible hazards and preventive measures in the process environment, 8. Regular inspection of resources and up-gradation of safety tools and equipment, 9. Compliance of safety rules and regulations and conduct safety audit) needed to develop a safe system) are considered in QFD analysis. It is found that design requirement 2 is the most prioritized item while design requirement 3 is least prioritized design requirement.
- To find the interrelationship of design requirements, Interpretive Structural Modeling (ISM) method is used. To analyze the driver power and dependence power of variables, MICMAC analysis has been carried out. MICMAC analysis is classified into four clusters. The first cluster consists of autonomous variables that have weak driver power and weak dependence but not a single design requirement is loaded in this cluster. The second cluster consists of the dependent variable that have weak driver power but strong dependence. In this cluster, design requirement 8 is loaded. The third cluster has the linkage variables that have strong driving power and also strong dependence. In this cluster, seven design requirements (1, 2, 3, 6, 9, 4 and 7) are loaded. Fourth

cluster includes the independent variables having strong driving power but weak dependence having design requirement 5.

- A fuzzy logic approach has been proposed to predict accidents under three industry categories. Assimilating past data, subjective judgment and site inspections, five categories of accidents ($ACC\text{-}OP_1$: Accident that do not cause any disability and do not involve any lost work days, $ACC\text{-}OP_2$: Accident that do not cause any disability but involve lost work days, $ACC\text{-}OP_3$: Accident that cause temporary disability, $ACC\text{-}OP_4$: Accident that cause permanent partial disability, $ACC\text{-}OP_5$: Accident that cause permanent full disability or fatality) and four types of expenses (I_1: Expenses in health care, I_2 :Expenses in safety training, I_3 : Expenses in up-gradation of process related tools, instruments, machines, materials leading to safe and healthy environment, I_4 : Expenses on safety equipment and tools) are considered as inputs and outputs of the model respectively. Seventeen fuzzy IF-THEN rules are used in a Mamdani type fuzzy inference system. The residuals for industry categories are plotted and it is noted that the residuals are distributed around the mean line i.e. zero. Hence, it is said that the model can predict the output with sufficient accuracy. A high value of correlation coefficient (0.993) exists between actual and predicted values.
- Benchmarking of OHS performance helps to highlight deficiencies and possible strategies can be evolved to improve the performance of non-performing units using Data Envelopment Analysis (DEA). DEA CRS (constant return to scale) model shows that seven DMUs are efficient out of thirty DMUs. DMU_{16} in the refractory category is ranked first because it has more number of referring DMUs as far as safety performance is concerned whereas DMU_3 in construction category is ranked last having efficiency score of 0.694. When mean efficiency scores of three industrial categories are compared, it reveals that construction sector (mean efficiency=0.856) perform worst in regard to safety performance and refractory sector (mean efficiency=0.921) is best in that respect. However, safety performance of steel sector (mean efficiency=0.916) lies in between them.

8.3 Contribution of the research work

The contributions of this thesis in light of above summary and findings have been discussed as follows:

- An instrument has been proposed to assess OHS practices in three major industrial settings which are characterized by disorganized and unsafe work environment. Although internal guidelines and Government legislation is being practised in these industries, the work practices seems to below average.
- The instrument is useful for improving morale of the workers and their satisfaction in regard to safety issues. The instrument has been tested using statistical tool and can be used for comparative evaluation of safety practices within and/or among organizations. Using the instrument, comparison of various industrial settings has been made using discriminant analysis.
- Using the instrument, an approach based on Artificial Neural Network (ANN) model has been proposed to identify deficient safety items in various industrial settings. The tool, being a simple one, can be adopted at any organization. A common minimum number of safety items suiting to all industrial settings considered in this study have been identified. These common items are minimum safety issues that must be resolved to improve the safety performance. Also common minimum items necessary to reduce material damage resulting due to safety concern has also been identified.
- In order to design the organization with prime concern for safety, system design requirements have been proposed in this work using Quality Function Deployment (QFD). A pictorial representation of interaction of system design requirements has been developed using Interpretative Structural Modelling (ISM) approach. The study enables the managers to design a safe system.
- A predictive methodology based on fuzzy logic approach has been proposed to predict injury level and material damage. The fuzzy logic helps the manager to deal with incomplete, imprecise and uncertain environment to predict the safety outcome. As fuzzy inference system uses minimum mathematics and based on rule bases, normally obtained through expert judgment, it can be conveniently used by the manager for prediction purpose.
- Benchmarking of safety practices is an important issue for improving safety performance. An extensive study on benchmarking based on Data Envelopment Analysis (DEA) has been demonstrated with the help of examples for acceptance of the managers.

- The study helps to promote OHS through appropriate work culture, work organization and support for social cohesion.
- The study attempts to reduce health care costs of injuries, diseases and illnesses caused by a combination of occupational, environmental, life style and social health determinants.

8.4 Limitations of the study

In spite of advantages obtained through proposed study, the following may be treated as limitations of the study since they have not been addressed in this study:

- The safety instrument that has been developed can be tested on a real life case study.
- The sampling design for the data collection and number of respondents adopted in the study might have been increased to reduce social and demographic bias.
- The study is confined to three sectors and needs to be extended to other industry types. A comparison of safety performance in public and private sector industries can be useful for the managers.
- The fuzzy inference system can be extended using other fuzzy membership functions and performance of models could have been compared. In addition, the results of fuzzy inference system can be compared with other predictive tools.
- Data Envelopment Analysis (DEA) method can be extended to take care of assurance region.

8.5 Scope for future work

The present work leaves a wide scope for future investigations to explore OHS issues with special reference to injury prevention social marketing. Some recommendations for future research include:

- To generalize the results, this study needs to be replicated with a large sample.
- The study may be extended to other industrial sectors and a comparison of safety issues in product and service based sectors may be useful.
- For proving the robustness, a broad based instrument increasing the number of samples can be developed through cross-sectional survey.
- Efforts should be directed to propose a comprehensible National Policy on OHS for all sectors of the economy through multilateral consultations.

- Benchmarking studies can be carried out considering more number of DMUs with other industrial categories and also increasing number of input and output parameters.
- Future research should consider DEA model with assurance region.
- In future, the study can be extended to use different types of membership functions in fuzzy inference system for prediction of OHS performance.
- In order to improve OHS understanding and its relevance to workplace, there is need to undertake substantial strengthening of safe work procedures, code of best practices, prevention of identified hazards, and public awareness on OSH.
- To overcome the weaknesses in the enforcement of the statutes, wherever applicable, a comprehensive enforcement strategy and guidelines on OHS aspects should be developed at the national level.

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Appendix 3.1

A Sample Questionnaire for Measuring Perception on Occupational Health and Safety (OHS)

We are conducting a survey to assess occupational health and safety on social marketing and the related work environment in Indian organization. The Study is purely of academic nature. Your identity will not be disclosed and the data will be kept confidential. We request you to spare some of your valuable time in answering the questionnaire. Please read the following statements carefully and respond to all the statements. Each statement has five possible responses. Please circle the response you feel is the most appropriate for your organization by choosing from the following alternatives.

Strongly disagree	Disagree	Neither disagree nor agree	Agree	Strongly Agree
1	2	3	4	5

The figures in the box indicate rating values in Likert scale

Sl. No.	Items	Ratings				
1	Firm is committed to well-being of the workers through its health and safety policies along with other HR policies.	1	2	3	4	5
2	A written declaration reflecting management's concern for safety, principles of action and objectives to achieve is available to all workers.	1	2	3	4	5
3	A format on functions of commitment, participation and responsibilities is established on all safety aspects and available to all organization members.	1	2	3	4	5
4	Safety policy promotes commitment to continuous improvement and attempts to improve objectives already achieved.	1	2	3	4	5
5	Incentives are frequently offered to workers to put in practice the principles and procedures of action (e.g., correct use of protective equipment).	1	2	3	4	5
6	Periodical meetings between managers and workers are held to take decisions affecting organization of work.	1	2	3	4	5
7	Teams made up of workers from different parts of organization are frequently used to resolve specific problems relating to working conditions.	1	2	3	4	5
8	Workers are sufficiently trained while entering firm, changing jobs or using new technique.	1	2	3	4	5
9	Follow-up of training needs and repercussion of training previously given is regularly done.	1	2	3	4	5
10	Training actions are continuous and periodic and are integrated in formally established training plan.	1	2	3	4	5
11	Specific training are planed taking into account firm's particular characteristics and job positions.	1	2	3	4	5

12	Training plan is decided jointly with workers or their representatives	1	2	3	4	5
13	OHS training actions are carried out during working day.	1	2	3	4	5
14	Firm helps workers for OHS training in-house.	1	2	3	4	5
15	Instruction manuals or work procedures are elaborated to aid in preventive action.	1	2	3	4	5
16	Rules and principles are effectively communicated in meetings, campaigns and oral presentations.	1	2	3	4	5
17	When starting in new job position, workers are provided written information about procedures and correct way of doing tasks.	1	2	3	4	5
18	Workers are informed about risks associated with their work and how to prevent accidents through written circulars and meetings.	1	2	3	4	5
19	Firm has systems to identify risks in all job positions.	1	2	3	4	5
20	System is in place to evaluate risks detected in all job positions.	1	2	3	4	5
21	Prevention plans are formulated on the basis of information provided by evaluation of risks in all job positions.	1	2	3	4	5
22	Prevention plans clearly specify person responsible for carrying out action.	1	2	3	4	5
23	Standards of action or work procedures are elaborated on the basis of risk evaluation.	1	2	3	4	5
24	Prevention plans are circulated among all workers.	1	2	3	4	5
25	Prevention plans are periodically reviewed and updated when job are conditions modified or worker's health is affected.	1	2	3	4	5
26	Firm has elaborated emergency plan for serious risks.	1	2	3	4	5
27	All workers are informed about emergency plan.	1	2	3	4	5
28	Periodic checks are conducted on execution of prevention plans and compliance level of regulations.	1	2	3	4	5
29	Pre-determined plans and actual steps are frequently compared to identify gaps.	1	2	3	4	5
30	Procedures to check achievement of objectives are allocated to managers.	1	2	3	4	5
31	Systematic inspections are conducted periodically to ensure effective functioning of whole system.	1	2	3	4	5
32	Accidents and incidents are reported, investigated, analyzed and recorded.	1	2	3	4	5
33	Firm's accident rates are regularly compared with those of other organizations from same sectors using similar production processes.	1	2	3	4	5
34	Firm's techniques and management practices are regularly compared with those of other organizations from all sectors to obtain new ideas about management of similar problems.	1	2	3	4	5
Overall safety performance of the organization						
1	Personal injuries in the organization are very low.	1	2	3	4	5
2	Material damage is low in the organization.	1	2	3	4	5

Thank you for your cooperation.

Appendix 3.2

Principal Component Factor Analysis

The prime applications of factor analysis techniques are to reduce the number of variables and to detect structure in the relationships between variables, i.e. to classify variables. Therefore, factor analysis is applied as a data reduction or structure detection method.

Terminologies of Factor Analysis

Factor Loadings, $L_i(j)$

It is the matrix representing the correlation between different combinations of variables and factors. $L_i(j)$ is the factor loading of the variable j on the factor i,

Where $i = 1,2,3,\ldots,n$ and $j = 1,2,3,\ldots,n$.

Communality, h_i^2

It is the sum of squares of the factor loadings of the variable I on all factors:

$$h_i^2 = \sum_{j=1}^{n} L_{ij}^2$$

Eigenvalue

It is the sum of squares of the factor loadings of all variables on a factor.

$$\text{Eigenvalue of the factor } j = \sum_{i=1}^{n} L_{ij}^2$$

Note: The sum of the eigenvalues of all factors (if no factor is dropped) is equal to the sum of the communalities of all variables.

Factor Rotation

Since the original loadings may not be readily interpretable, the usual practice is to rotate them until a ‘simple structure’ is achieved. A simple structure means that each variable has very high factor loadings (as high as 1) on one of the factors and very low factor loadings (as low as 0) on the other factors. The communalities of each variable before and after factor rotation will be the same.

Significant Number of Factors

The main objective of factor analysis is to group the given set of input variables into minimal number of factors with the maximum capability of extracting information with the reduced set of factors. There are basically two criteria to determine the number of factors to be retained for future study:

Minimum Eigenvalue Criterion

If the eigenvalue (sum of squares of the factor loadings of all variables on a factor) of a factor is more than or equal to 1, then that factor is to be retained; otherwise, that factor is to be dropped.

Scree Plot Criterion

It is a plot of the eigenvalues of the factors by taking the factor number on X-axis and the eigenvalues on Y-axis. Then, identify the factor number at which the slope of the line connecting the points changes from steep to a gradual trailing off towards the right of the identified factor number. Such change in slope in the graph is known as ‘scree’ and the point is known as ‘scree point’. The factors which are marked up to the right of the scree point are to be dropped from the study.

Factor Scores

Though a factor is not visible like an original input variable, it is still a variable which can be used to find the scores for respondents. At the initial stage, the respondents assign scores for the variables. After performing factor analysis, each factor assigns a score for each respondent. Such scores are called ‘factor scores’.

The expression to compute the factor score of a respondent by the factor k is shown below. By substituting the standardized values of the input variables assigned by a respondent in this expression, the factor score of that respondent can be obtained:

$$F_k = w_{1k}X_1 + w_{2k}X_2 + w_{3k}X_3 + \ldots + w_{nk}X_n = \sum_{i=1}^{n} w_{ik}X_i$$

Where w_{ik} is the weight of the input variable X_i in the linear composite of the factor, k for $k = 1,2,3\ldots,n$.

Steps of Principal Component Method

This method maximizes the sum of squares of loadings of each identified factor. This is a popular technique which determines loadings of variables on different factors by using the standard normal values of the observations of the original (input) variables.

The steps of the principal components analysis are summarized as follows:

Step - 1: In the original sets of observation

$[a_{ij}]; i = 1,2,3,\ldots,m$ and $j = 1,2,3,\ldots,n$

Step - 2: Find the standardized sets of observations $[Z_{ij}]$ from $[a_{ij}]$ using the following formula:

$$Z_{ij} = \frac{a_{ij} - \overline{X}_j}{\sigma_j};\ i = 1,2,3,\ldots,m \text{ and } j = 1,2,3,\ldots,n$$

where Z_{ij} is the standardized observation of the i^{th} original observation under the variable j and σ_j is the standard deviation of the original observations of the variable j

Step - 3: Determine the weights of the different linear composites of factors $[w_{ij}]$ such that the variance of the unstandardized factor scores of the entire set of observations is maximal. These weights are nothing but directional cosines of the respective vectors.

Step - 4: Find the unstandardized factor scores using the following formula:

$$[f_{ij}]_{m\times n} = [z_{ij}]_{m\times n} \times [w_{ij}]_{n\times m}$$

Step - 5: Find the loadings of the variables on the factors L_{ij} is the correlation coefficient between the values in column *i* of matrix $[Z_{ij}]$ and that of column j of the matrix $[f_{ij}]$ for $i = 1,2,3,\ldots,n$ and $j = 1,2,3,\ldots,n$

Step - 6: Find the standardized factor scores using the following formula:

$$S_{ij} = \frac{f_{ij} - \overline{M}_j}{s_j};\ i = 1,2,3,\ldots,m \text{ and } j = 1,2,3,\ldots,n$$

where S_{ij} the standardized factor is score of the i^{th} set of observations on the factor j; $\overline{M}$, the mean of the unstandardized factor scores of the factor j and S_j is the standard deviation of the unstandardized factor scores of the factor j.

Step - 7: Find the prediction of the standardized original observations using the following formula:

$$[Z_{ij}]_{m\times n} = [S_{ij}]_{m\times n} \times [L_{ij}]_{n\times n}$$

Step - 8: Find the sum of squires of loadings of each column- j (principal component- j/factor- j) which is known as eigenvalue of that column j.

Step - 9: Drop insignificant principal components which have eigenvalues less than 1. Let the number of principal components retained be X.

Step - 10: Perform the rotation of the retained principal components for better interpretation. The rotation can be done by 'varimax rotation method'.

Step - 11: Assign each variable to the principal component (factor), with which it has the maximum absolute loading (irrespective of sign).

Step - 12: Find the sum of squares of loadings for each variable i (row i). It is denoted by h_1^2. Also, find the common variance, whose formula is given below:

$$\text{Common variance} = \sum_{i=1}^{X} h_1^2 ;$$

where X is the number of retained principal components.

Step - 13: For each retained principal component, $k(k = 1,2,3,\ldots, X)$, find the following and state inferences:

$$\text{Proportion of total variance of the principal component } k = \frac{\text{Eigenvalue of principal component k}}{\text{Total variance}}$$

Where the total variance is equal to the number of variables, n. Also,

$$\text{Proportion of common variance of the principal component } k = \frac{\text{Eigenvalues of principal component k}}{\text{Common variance}}$$

$$= \frac{\text{Eigenvalues of principal component k}}{\text{Sum of the eigenvalues of the ratained principal component}}$$

Appendix 3.3

Varimax Method of Factor Rotation

Varimax rotation is the most popular form of factor rotation was developed by Kaiser (1958). For varimax a simple solution means that each factor has a small number of large loadings and a large number of zero (or small) loadings. This simplifies the interpretation because, after a varimax rotation, each original variable tends to be associated with one (or a small number) of factors, and each factor represents only a small number of variables. In addition, the factors can often be interpreted from the opposition of few variables with positive loadings to few variables with negative loadings.

Steps of Varimax Method of Factor Rotation

Formally varimax searches for a rotation (i.e., a linear combination) of the original factors such that the variance of the loadings is maximized, which a mounts to maximizing

$$v = -\frac{1}{p}\sum_{j=1}^{m}(\text{variance of squares of (scaled) loadings for } j^{th} \text{ factor})$$

Where $p \times m$ is a matrix of estimated factor loadings obtained. The steps of varimax rotation method for two factors are presented below:

Step - 1: Input the factor loading matrix. Number of variables $= n$. Number of principal components (factors) $= 2$. Angle of rotation $= q$.

Step - 2: Plot the factor loadings on a two-dimensional space, F_1 - F_2 plane, where F_1 and F_2 are factor -1 and factor -2 respectively. Let θ be the angle between the nearest axis F_1 or F_2 and each vector of factor loadings.

Step - 3: Rotate the F_1 - F_2 plane by an angle such that the factor loadings are revised to have a simple structure. A simple structure means that each variable has very high factor loading (as high as 1) on one of the factors and very low0.factor loading (as low as 0) on other factors. Let the rotated plane be F_1 - F_2.

Step - 4: Set variable number, $i = 1$.

Step - 5: Let a_i and b_i be the factor loadings of the variable i on F_1 and F_2 respectively. Find the magnitude of the vector C_i of the factor loadings of the variable i, using the following formula:

$$C_i = (a_i^2 + b_i^2)^{0.5}$$

Let the angle of the vector of factor loadings with the nearest part (positive side and negative side) of F_1 axis be α.

Step - 6: Find $\cos\theta$ and treat it as the factor loading on the nearest axis (a_i if the nearest axis as explained in step-1 is F_1 axis, b_i if the nearest axis is F_2 axis). Fix the sign of the revised loading depending on the side of the factor (plus for positive side and minus for negative side).

Step - 7: Find $\cos(90 - \theta)$ and treat it as the factor loading on the other axis (b_i if the nearest axis as explained in step-1 is F_1 axis, a_i if the nearest axis is F_2 axis). Fix the sign of the revised loading depending on the side of the factor (plus for positive side and minus for negative side).

Step - 8: $i = i + 1$

Step - 9: If $i \leq n$, then go to step-5; or else go to step-10.

Step - 10: Print the revised factor loading matrix.

Step - 11: Group variables into factors and make inferences.

Appendix 3.4

Linear Discriminant Analysis (LDA)

Linear Discriminant Analysis (LDA) is a well-known method for dimensionality reduction and classification that projects high-dimensional data onto a low dimensional space where the data achieves maximum class separability. The derived features in LDA are linear combinations of the original features, where the coefficients are from the transformation matrix. The optimal projection or transformation in classical LDA is obtained by minimizing the within-class distance and maximizing the between-class distance simultaneously, thus achieving maximum class discrimination. It has been applied successfully in many applications including face recognition and microarray gene expression data analysis. The optimal transformation is readily computed by solving a generalized eigenvalue problem. The original LDA formulation, known as the Fisher Linear Discriminant Analysis (FLDA) deals with binary-class classifications. The key idea in FLDA is to look for a direction that separates the class means well (when projected onto that direction) while achieving a small variance around these means.

Steps of Three-group Discriminant Analysis

Step - 1: Input the data. Let the predictor variables representing the three factors be X_1, X_2 and X_3.

Step - 2: Classify the data into two mutually exclusive and collectively exhaustive groups, G_1, G_2 and G_3

Let n_1, n_2 and n_3 be the number of sets of observations in the Group-1, Group-2 and Group- 3 respectively.

Step - 3: Find the mean of X_1 as well as X_2 in each group.

Let $\overline{X}_{1(G_1)}$ be the mean of X_1 in Group-1; $\overline{X}_{1(G_2)}$ be the mean of X_1 in Group-2; $\overline{X}_{1(G_3)}$ be the mean of X_1 in Group-3; $\overline{X}_{2(G_1)}$ be the mean of X_2 in Group-1; $\overline{X}_{2(G_2)}$ be the mean of X_2 in Group-2; $\overline{X}_{2(G_3)}$ be the mean of X_2 in Group-3; $\overline{X}_{3(G_1)}$ be the mean of X_3 in Group-1; $\overline{X}_{3(G_2)}$ be the mean of X_3 in Group-2; $\overline{X}_{3(G_3)}$ be the mean of X_3 in Group-3.

Step - 4: In each group, find: $\sum X_1^2$, $\sum X_2^2$ $\sum X_3^2$ and $\sum X_1 X_2 X_3$.

Step - 5: Define the linear composite as: $Y = aX_1 + bX_2 + cX_3$

Step - 6: Find the values of a, b and c by solving the following normal equations:

$$a \sum (X_1 - \overline{X_1})^2 + b \sum (X_1 - \overline{X_1})(X_2 - \overline{X_2}) + c \sum (X_1 - \overline{X_1})(X_2 - \overline{X_2})(X_3 - \overline{X_3}) = \overline{X}_{1\,(G_3)} - \overline{X}_{1\,(G_2)} - \overline{X}_{1\,(G_1)}$$

$$a \sum (X_1 - \overline{X_1})(X_2 - \overline{X_2}) + b \sum (X_2 - \overline{X_2})^2 + c \sum (X_3 - \overline{X_3})^2 = \overline{X}_{2\,(G_2)} - \overline{X}_{2\,(G_2)} - \overline{X}_{3\,(G_1)}$$

In each of the above $\sum X_1^2$, $\sum X_2^2$, $\sum X_3^2$ and $\sum X_1 X_2 X_3$ are computed using the data sets of the corresponding group.

Step - 7: In each group, find the discriminant score for each combination of the variables X_1, X_2 and X_3. Then find the average of the discriminant scores of each group and also the grand mean of the discriminant scores for the entire problem.

Step - 8: Find the variability between groups (V_{BG}) using the following formula:

$$V_{BG} = n_1(\overline{S_1} - \overline{S})^2 + n_2(\overline{S_2} - \overline{S})^2 + n_3(\overline{S_3} - \overline{S})^2$$

where S_1 and S_2 are the means of the discriminant scores in the Group-1, Group-2 and Group-3, respectively; and $\overline{S}$ is the grand mean of the discriminant scores for the entire problem.

Step - 9: Find the variability within groups (V_{WG}) using the following formula:

$$V_{WG} = \sum_{j=1}^{n1}(S_{1j} - \overline{S_1})^2 + \sum_{j=1}^{n2}(S_{2j} - \overline{S_2})^2 + \sum_{j=1}^{n3}(S_{3j} - \overline{S_3})^2$$

where S_{1j}, S_{2j} and S_{3j} are the means of the discriminant scores in the Group-1, Group-2 and Group-3, respectively; $\overline{S_1}$, $\overline{S_2}$ and $\overline{S_3}$ are already defined in the step-8.

Step - 10: Find the discriminant ratio, (K) using the following formula and identify the predictor variable(s) which has/have more importance when compared to the other predictor variables.

$$K = \frac{V_{BG}}{V_{WG}}$$

This is the maximum possible ratio between 'the variability between groups' and 'the variability within groups'.

Step - 11: Validate the discriminant function using the given data sets by forming groups based on the critical discriminant score of a data set is less than the critical discriminant score, then include the member of the entity representing that data set in the 'Below' category; otherwise, include it is the 'Above' category.

-

Step - 12: Find F ratio using the following formula:

$$F = \frac{n_1 n_2 n_3 (n_1 + n_2 + n_3 - m - 1)}{m(n_1 + n_2 + n_3)(n_1 + n_2 + n_3 - 2)} D^2$$

where m is the number of predictor variables (in this case, it is equal to 2); and D^2 is known as Mahalanobi's squared distance; and degrees of freedom $= [m, (n_1 + n_2 + n_3 - m - 1)]$.

Step - 13: Find the table F value for $[m, (n_1 + n_2 + n_3 - m - 1)]$ degrees of freedom at a significance level of α.

Step - 14: If the calculated F value is more than the table F value, reject the null hypothesis, H_0; otherwise, accept the null hypothesis (H_0), where

H_0: The group means are equal in importance

H_1: The group means are not equal in importance.

(This means that one variable is more important than the other variable).

Appendix 6.1

A Sample Questionnaire for Prediction of Accident Types

We are conducting a survey to assess occupational health and safety environment in Indian organizations. The study is purely of academic nature. Your identity will not be disclosed and the data will be kept confidential. The questionnaire consists of nine parameters. We request you to spare some of your valuable time in answering the questionnaire.

Sl. No.	Parameters for safety performance	Investment per annum in percentage
1	Expenses in health care	
2	Expenses in up-gradation of process related tools, instruments, machines, materials leading to safe and healthy environment	
3	Expenses in safety training	
4	Expenses on safety equipment and tools	
		Number per annum
5	Accident that do not cause any disability and do not involve any lost work days	
6	Accident that do not cause any disability but involve lost work days	
7	Accident that cause temporary disability	
8	Accident that cause permanent partial disability	
9	Accident that cause permanent full disability or fatality	

List of Publications

List of Publications in International Journals

1. Datta. S., Beriha, G.S., Patnaik, B. and Mahapatra, S.S. (2009). Use of COPRAS-G method for supervisor selection: A multi-criteria decision making (MCDM) approach. International Journal of Vocational and Technical Education 1(1), 007-013.
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Paper Accepted for Publication in International Journals

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1. Patnaik, B., Beriha, G.S., Singh, N. and Mahapatra, S.S., Organizational learning in educational settings (Technical): An Indian perspective. Higher Education, Springer Publication.
2. Beriha, G.S., Patnaik, B., Mahapatra, S.S., Sahu, R. and Deshpande, S., Assessing influence of social marketing on occupational health and safety: Quality function deployment and interpretive structural modelling approach. International Journal of Nonprofit and Voluntary Sector Marketing, Interscience, Wiley Publication.
3. Beriha, G.S., Patnaik, B. and Mahapatra, S.S., A neural network approach for assessment of occupational health practices. Safety Science, Elsevier Publication.

List of Publications in National Journals

1. Dhal, P. R., Beriha, G. S., Datta, S., Patnaik, B., Mahapatra, S.S., Mondal, G., Chakraborty, P.S. and Majumdar, G. (2010). Application of grey relational analysis and RIDIT method for selection of service quality indices in performance evaluation and appraisal of employees in a R and D sector. Industrial Engineering Journal II(9), 28-32.

List of Publications in International Conferences

1. Beriha, G.S., Patnaik, B., Datta, S. and Mahapatra, S.S. (2009). Benchmarking of technical education setting: a multi-attribute decision making approach. International Conference on Advanced Manufacturing and Automation (INCAMA 2009) Organized by Department of Mechanical Engineering and Department of Instrumentation and Control engineering, March 26-28th, Kalasalingam University, Anand Nagar, Tamilnadu, India.
2. Beriha, G.S., Patnaik, B. and Mahapatra, S.S. (2009). Service quality evaluation on occupational health in fishing sector using grey relational analysis to likert scale surveys. First IIMA International Conference on Advanced Data Analysis, Business Analysis and Intelligence, June 6-7th, IIM Ahmedabad.
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1. Beriha, G.S., Patnaik, B. and Mahapatra, S.S. (2009). Framework for improving occupational health services in industry to retain competitive edge. National Seminar on Enhancing Managerial Effectiveness in a globalized Economy, Institute of Science and Management, February 6-7th, Pundag, Ranchi.
2. Beriha, G.S., Patnaik, B. and Mahapatra, S.S. (2009). Service quality evaluation on occupational health in fishing sector using RIDIT analysis to likert scale surveys. National Seminar on Impact of Globalization on Livelihood of Fisheries Workers, Mahatma Gandhi Labour Institute, March 18-19th, Drive-In Road, Memnagar, Ahmedabad.
3. Beriha, G.S., Patnaik, B. and Mahapatra, S.S. (2010). Assessment of material damage in industries using a neural network approach: An Indian perspective. National Seminar on Global Leadership Thro' Continuous Innovation, IIPM-School of Management, October 23rd, Kansbahal, Rourkela, Odisha.
4. Beriha, G.S., Patnaik, B. and Mahapatra, S.S. (2010). Assessment of injuries in industries using a neural network approach: An Indian perspective. National Conference on Convergence of Management Practices (NCCOMP-2010) Organized by School of Management, National Institute of Technology, December 17-18th, Warangal.

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1. Beriha, G.S., Patnaik, B. and Mahapatra, S. S., (2009). A framework for occupational health and safety management using grey relational analysis: An Indian perspective. Marketing in Emerging Market, Excel Books, First Edition: New Delhi, pp. 214-223, ISBN: 978-81-7446-758-4.
2. Beriha, G.S., Patnaik, B. and Mahapatra, S.S., (2010). A data envelopment analysis approach for benchmarking of safety performance. Management Technology and Application, Research Publishing, Singapore, pp. 6-11, ISBN-13:978-981-08-6884-0, DOI: 10.3850/978-981-08-6884-0_C002.