STUDIES ON RISK AND OCCUPATIONAL HEALTH HAZARDS IN INDUSTRIAL CONTEXT: SOME CASE RESEARCH

A Dissertation Submitted in Fulfillment of the Requirement for the Award of the Degree of

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MECHANICAL ENGINEERING

BY

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This dissertation is dedicated to my

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CERTIFICATE OF APPROVAL

Certified that the dissertation entitled **STUDIES ON RISK AND OCCUPATIONAL HEALTH HAZARDS IN INDUSTRIAL CONTEXT: SOME CASE RESEARCH** submitted by **Chitrasen Samantra** has been carried out under my supervision in fulfillment of the requirement for the award of the degree of ***Doctor of Philosophy (Ph. D.)*** in ***Mechanical Engineering*** at **National Institute of Technology**, **Rourkela**, and this work has not been submitted to any university/institute anywhere before for any other academic degree/diploma.

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Abstract

This work articulates few case empirical studies on some aspects of risk management and occupational health hazards in the context of Indian Industries. Empirical research is research using empirical evidence. It is a way of gaining knowledge by means of direct and indirect observation or experience. The study focuses on five important domains investigating (i) the interrelationships among critical risk factors associated with software engineering project, (ii) risk management for IT outsourcing, (iii) risk management in metropolitan construction project, (iv) health hazard risk management, and (v) appropriate safety measure system selection for improving workers' safety in an underground coal mining industry. In this research, an ISM approach has been applied to understand the significant interrelationships among the twenty three identified risk factors associated with the software engineering projects. In relation to IT outsourcing project, a hierarchical risk-breakdown structure has been proposed comprising sixty eight risk influencing factors under eleven risk dimensions. A case study has been conducted in a famous IT sector located at the eastern part of India. An improved fuzzy based decision making approach has been proposed for assessing overall IT outsourcing project risks. The degree of risk of identified risk factors have been shown in crisp values rather than the fuzzy numbers. A logical risk categorization framework has been proposed to categorize the risk factors into different risk levels. A unique action requirement plan has been suggested for effectively controlling the risks towards IT outsourcing project success. In the later part, total twenty one occupational health hazards have been identified and assessed their risk extent based on the exposure assessment procedure. Consequently, a constructive control measure plan has been suggested for different health hazards in view of their risk extent level. A novel risk-based decision making framework has been proposed for selecting the appropriate safety measure system in an underground coal mining industry. In addition to this, a case study has been conducted using twenty potential risk factors associated with five risk dimensions for assessing metropolitan construction project risks. Decision-makers' risk bearing attitude has also been considered in this study. This study also explores the concept of risk matrix for categorizing the risk factors in different risk levels which would provide guidelines towards controlling risks for enhancing the overall project performance.

Risk analysis models delignated herein have been case studied in relation to Indian industries. However, the model or hierarchy of various risk dimensions, risk sources; and classification of health hazards can be applicable to appropriate industries all over the globe. Some alteration may incur depending on the geographic situation of coal mining industry in analyzing occupational health hazards and associated risks. The framework for analyzing risks and occupational health hazards based on fuzzy based decision making approach can be applied in industrial context of different countries.

Apart from the case studies mentioned above, the work also proposes a risk based decision support framework for selection of safety measure system for underground coal mines. In this case, occupational risks and alternative safety measure systems have been identified through literature survey. This part is a purely a theoretical formulation followed by analysis of assumed data which has not been case studied in reality.

The novelty of the proposed framework is to analyze various risk dimensions in software engineering projects, IT Outsourcing, construction projects; also occupational health hazards in underground coal mining industry in a fuzzy based decision making framework. Instead of exploring historical data, survey report of the company; an experienced decision making group has been appointed to provide subjective judgement in regards of likelihood of occurrence and impact of various risks; consequence of exposure, period of exposure, and probability of exposure of various health hazards. Subjective decision making data have been transformed into appropriate fuzzy number sets to quantify overall risks extent. Thus, the proposed framework provides a platform to quantify extent of risk in industrial context.

Keywords: risk management; occupational health hazards; software engineering project; IT outsourcing; metropolitan construction project; health hazard risk management; safety measure system; risk-based decision making; risk matrix

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CHAPTER 1

RESEARCH BACKGROUND

1.1 Introduction

Today's economic climate enforces every industry towards focusing on achieving maximum production capability with minimal capital investment. Apart from this, safety and reliability appear as essential issues in every industry; whether it is a production industry or a software concern. The utilization of modern equipment, systems as well as associated work environment should satisfy various technical, safety and environmental protection requirements. The project management body of knowledge (PMBOK, 2000) reports that risk is an integral part of any business; to have a business at all risk free is not to have a business at all. In order to achieve strategic goals, an organization should inevitably take some risks.

The organizations possessing high level of risk awareness are capable of actively managing potential problems (threats) and also finding potential opportunities towards gaining a competitive advantage. In order to survive successfully in the competitive business environment, organizations should inherently take some risks and should have the capabilities in managing the same. The term 'risk' means the potential for realization of undesirable consequences of an event (Iranmanesh et al., 2011). Risk can be considered as a threat that could exploit possible vulnerabilities of the system, with a certain possibility. It is often called as an undesired or unpleasant event, which is likely to incur due to specific reasons. Therefore, risk may be defined as the likelihood of occurrence of an event resulting in certain consequences. It can be understood by the combination of the likelihood and the consequence of a specified hazard being recognized (Blair et al., 2001). In industrial context, risk can be appeared as undesirable potential loss, personal injury or death, property technical damage, and failure of the undertaking projects. Therefore, in order to prevent the occurrence of an undesired event generating considerable impact on the industry, appropriate control measures should be taken. Moreover, risk can be avoided rather completely eliminated by developing plans to mitigate, control, and/or minimize. As a result, there exists an amplified need for adapting appropriate risk management strategies in different business managerial hierarchy.

Risk management is the act or practice of controlling risks. It is the central part of any organization's strategic management. Risk management can be defined as a collection of activities including risk identification, risk assessment and risk prioritization followed by coordinated and economic application of resources in order to minimize, monitor, and control the likelihood of occurrence and/or impact of unfortunate events or to maximize the realization of opportunities (ISO 31000:2009). Moreover, risk management is a systematic way of protecting the concern's resources and income against losses so that the aims of the business can easily be achieved without interruption. It is basically concerned with both positive and negative aspects of risks. In the safety field, it has been recognized that consequences are only negative; therefore, management of safety risk is concerned with the prevention and mitigation of harm. Risk is universal and exists at every levels of human and business activity. Individuals, organizations and government should concern about the risk sources and cope up with it by adopting proper risk management strategy. Risk is often confused with uncertainty. Both risk and uncertainty are associated with exposure to events resulting significant losses. While risk involves an element of uncertainty creating an adverse situation that decision maker does not have enough information to assign probabilities to possible outcomes. Risk and uncertainty are related in that aspect, where uncertainty leads to risk. Effective management of risks minimizes potential losses that lead to the overall success of the organization. Therefore, risk management has become the predominant research area for both production as well as service sectors. In this context, the present work would highlight on some aspects of risk management with a unified attempt to develop efficient decision support models for effective evaluation and assessment of risks in industrial context.

1.2 Benefits of Risk Management

Risk management proposes providing a framework for an organization that enables the activities to take place in a reliable and controlled manner. Effective management of risk enables to:

- Improve reliability and effectiveness of the product, process or service,
- Minimize the impact of potential problems or adverse effects,
- Protect people from harmful hazards and provide early warning of potential threats,
- Improve the resilience of the organizations,
- Maximize potential opportunities or production capabilities,
- Minimize capital investment,
- Protect project revenue and enhance value for money,
- Articulate and manage the uncertainty associated in the decision making process,
- Improve decision making, planning, and prioritization by comprehensive and structured understanding of associated risks, business activity, volatility and project opportunity/risk.

1.3 Factors Associated with General Risk Management Strategies

The risks incurring to an organization can result from the factors that may be external or internal to the organization. Risks may take place in different forms depending upon the nature and size of the organization. Thus, risks can be classified into two major categories: internal risks and external risks. Internal risks are the risks arising from the events taking place within the organization. However, external risks can be viewed from the events taking place outside the organization. Internal risks arise from the endogenous factors such as human factors (skill management, strikes), technological factors (advanced technology), physical factors (fire or theft, breakdown of machine), and operational factors (inventory cost, maintenance cost), which are controllable in actual practice. External risks arise from the exogenous factors such as economic factors (market risks, material price fluctuation), natural or environmental factors, (floods, earthquakes), and political factors (compliance and regulations of the government) which are difficult to control. In some situations, some specific risks can have both internal and external drivers and therefore, overlap with the two categories. Hence, they can be categorized further into types of risk such as strategic, financial, operational and legal etc.

1.4 Risk Management Framework

Risk management is an iterative and cyclic process whose prime intention is to eliminate or minimize the risks based on the ALRAP (as low as reasonably practicable) principle. The more general PDCA (Plan-Do-Check-Act) methodology is being adopted for risk management practice towards improving workplace health and safety issues in various modern industries as well as service sectors. The aforesaid methodology follows the systematic process, which includes examining all features of work performed by the workers such as the workplace, the equipment or machines, materials, work methods and work environments; aiming at identifying the factors that can cause injury or harm to the workers; and deciding on proper risk control measures (safety measures) to prevent work accidents and occupational diseases and implementing them effectively.

The framework for executing risk management pathways involve several phases, which are demonstrated in Fig. 1.1. Considering a work system under study, the first phase is the risk analysis, usually performed for the collection of data. This phase includes identification of hazards present in the workplace that are exposed to the workers, and also involves identification of risks i.e. the potential consequences of recognized hazards like potential causes of injury to the workers, either a work accident or an occupational disease. The second phase is the risk assessment phase, which involves risk evaluation, ranking of the estimated risks, and their classification whether it is acceptable or not. The outcome of this phase identifies the unacceptable health and safety hazards or risk factors.

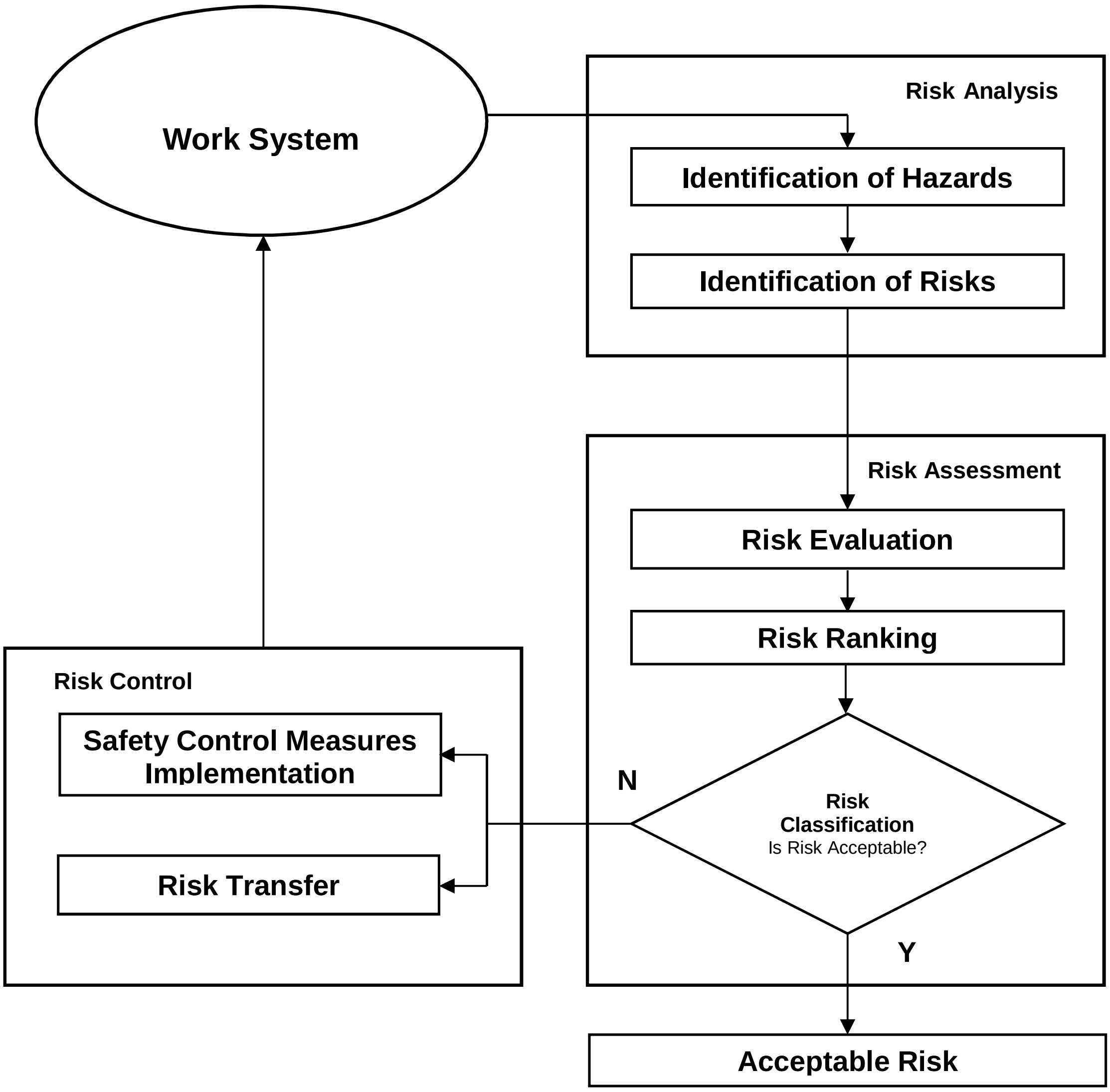

Fig. 1.1: Phases of risk management process (Source: Nunes, 2010)

The final phase of risk management is the risk control that includes designing or planning risk control measures to eliminate or reduce risks to ALRAP, followed by the effective implementation of risk control measures. The process of risk control should be carried out in hierarchical order, first prevention measures and then protection measures (Harms-Ringdahl, 2001). The risk control measures should be implemented based on the current technical knowledge and past experience. After the risk assessment phase, part of the risks can also be handled by transferring the risks to the insurance companies. Moreover, it is very important that workers should have adequate knowledge to understand from where the risks may appear to the organization, and which type of control options may be appropriate to control them. Therefore, this needs safety information and training programs for the workers to recognize the risks which they are actually exposed to.

1.5 Risk Analysis and Assessment

Risk analysis and assessment are critical components of the risk management process. Risk analysis identifies risk sources as they exist; i.e. it identifies potential risk factors or risk items for investigating their consequences to the certain domain of the organization. However, risk assessment further quantifies the magnitude of risk by evaluating potential impact and possibility of occurrence of these potential risk factors (Zhang, 2007). The objective of risk assessment is to determine the magnitude of risk and recognize the level of acceptability. According to BSI (2007), risk assessment is the process of estimating risks arising from hazards, taking into account the adequacy of any existing controls, and deciding whether or not the risk is acceptable. It is an integral part of the risk management process, which includes the process of performing the mitigation of risks up to an acceptable level. The type of risk analysis used should be appropriate for the available data and to the exposure, frequency and severity of potential loss. Risk analysis techniques are broadly divided into three basic categories qualitative, semi-quantitative, and quantitative. Some traditional risk analysis methods such as hazard and operability study (HAZOP), Event Tree Analysis (ETA), Fault Tree Analysis (FTA), Quantitative Risk Assessment (QRA), Layer of Protection Analysis (LOPA), and Probabilistic Risk Assessment (PRA) have been used to identify potential accident settings, estimate their likelihoods and consequences, and improve health and safety status of the particular industry (Marengo et al., 2013; Mohaghegh and Mosleh, 2009). The level of risk can be calculated by using statistical analysis and calculations combining impact and likelihood. The formulas and methods used to combine them must be consistent with the criteria defined as a part of risk management practice. The likelihoods and impacts can be estimated based on the available data or past experience. Apart from this, international safety standards and guidelines, and specialists as well as experts' advice may also be helpful to acquire information regarding the likelihood as well as the impact.

Analysis of risk is usually performed by two standard ways: (1) interviews with experts in the area of the interest using questionnaires; (2) use of existing models and simulations. Risk analysis may vary in detail according to the nature of risk, the purpose of the risk analysis, and the required protection level of the relevant information, data and resources. The analysis may be qualitative, semi-quantitative, and quantitative types to carry out the risk assessment task. A short description of aforementioned types of risk analysis is given as follows:

1.5.1 Qualitative Analysis

This type of analysis can be used to identify the assets to be detailed and bear a simple and rapid assessment. In this case, risk parameters such as likelihood and impact are described in words or artificial language rather than number. The aforementioned information details are collected from individuals, in-depth interviews and focus groups. Limited group of people are interviewed to identify and define individual's perceptions, opinions and feelings about the risk likelihood and impact. Linguistic assessment concept can be used to suit the circumstance to describe the degree of informativeness of risk variables. The quality of this analysis directly depends upon the skills, experience and sensitiveness of the interviewer and group moderator. Qualitative analysis is mostly preferable for the following circumstances:

(a) Where initial assessment is carried out to identify risks which will further required the detailed analysis;

(b) Where intangible aspects of risk are to be considered (i.e. reputation, culture, and image).

(c) When numerical data are inadequate or unavailable, and resources are limited.

1.5.2 Semi-Quantitative Analysis

The objective of this analysis is to assign some values to the scales used in the qualitative assessment. These values are basically indicative and not real; but it facilitates in adapting the quantitative approach. Although the numbers used for representing the actual magnitude of impact or likelihood are not accurate but it must require to be combined using a formula that recognizes the limitations and assumptions made in the descriptions of the scales. This type of analysis may lead to various inconsistencies due to the fact that the numbers chosen may not reveal similarities between the risks particularly when either one parameter (likelihood or impact) value is extreme.

Semi-quantitative risk assessment provides an intermediary level between the textual evaluation of qualitative risk assessment and the numerical evaluation of quantitative risk assessment, by evaluating risks with a score. Semi-quantitative risk assessment is most useful in providing a structured way to rank risks according to their probability, impact or both (severity), and for ranking risk reduction actions for their effectiveness. This is achieved through a predefined scoring system that allows one to map a perceived risk into a category, where there is a logical and explicit hierarchy between categories.

The case studies reported in the present dissertation deal with semi-quantitative risk analysis since all risk dimensions have been assessed by the experts in a subjective (qualitative) way expressed in linguistic terminologies. This linguistic decision making information has further been analyzed in fuzzy environment to ensure a quantitative basis of risk analysis.

1.5.3 Quantitative Analysis

This type of analysis is being performed where adequate numeric data or resources are available. The numeric values are derived from various sources and assigned to both likelihood and impact. A variety of statistical models have been developed for analyzing the risks using numeric data. However, the reliability of this analysis depends on the accuracy of the assigned values and validity of the statistical models. Risk impact can be determined by evaluating and processing various results of an event or past data. Many popular quantitative methods such as decision tree analysis, sensitivity analysis, Bayesian network analysis, Monte Carlo method have been used by the pioneers for analyzing the risk in various domains of application (PMBOK, 2000). However, quantitative approaches are not recommended for analyzing the risks pertaining subjectivity of likelihood and impact data.

In the context of construction project risk management, the concept of Expected Monetary Value (EMV) is very popular. Here, different risks can be categorized based on EMV.

In order to quantitatively prioritize a risk, the risks can be prioritized either with the highest probability of occurrence or the risks with the greatest monetary impact. This is where Expected Monetary Value (EMV) comes to the rescue in project risk management.

After conducting a qualitative risk analysis, a list of risks with a priority and urgency is assigned. By using Expected Monetary Value, each risk can be quantified to determine whether the qualitative analysis is backed by numbers. Expected Monetary Value is a recommended tool and technique for quantitative risk analysis in project risk management. To calculate the Expected Monetary Value in project risk management, the steps are:

1. Assign a probability of occurrence for the risk.
2. Assign monetary value of the impact of the risk when it occurs.

3. Multiply Step 1 and Step 2.

The value obtained after performing Step 3 is the Expected Monetary Value. This value is positive for opportunities (positive risks) and negative for threats (negative risks). Project risk management requires addressing both types of project risks.

[Source: http://www.brighthubpm.com/risk-management/48245-calculating-expected-monetary-value-emv/]

1.6 Risk Assessment Framework based on Fuzzy logic

1.6.1 Uncertainty in Risk Analysis

The term 'uncertainty' is used in different ways in different fields including philosophy, economics, engineering and science. In case of risk analysis, uncertainty applies to the imperfect prediction of future accident scenario, risk related to hazards encountered in work environment. Such a prediction provides unobserved results of risk provision that reflects the uncertainty in data and models used in the risk analysis. According to (Markowski et al., 2009), uncertainty can be differentiated by two major concepts: (a) uncertainty due to physical variability; (b) uncertainty due to lack of knowledge. The uncertainty due to physical variability is an objective type of uncertainty, which may arise due to the random behavior of some parameters such as, variability in weather conditions, in properties of various variables, experimental data variability for basic events (BEs) and safety functions (SFs). However, uncertainty due to lack of knowledge is a subjective type of uncertainty related with vagueness, imprecision or incompleteness concerning the quality of risk analysis, especially in the risk identification phase of risk assessment and consequence modeling. In addition, this type of uncertainty also arises from the experts' judgment during subjective assessment of accident scenario in terms of likelihood and its severity of the consequence. Many approaches such as classical statistics, probabilistic, sensitivity analysis and possibility approach have been used by the pioneers to deal all types of uncertainty (Nielsen and Aven, 2003). However, uncertainty due to lack of knowledge and vagueness can effectively be tackled by means of fuzzy logic.

1.6.2 Basics of Fuzzy Logic

Fuzzy logic is a general name of "fuzzy set analysis" and "possibility theory", which can deal with uncertainty, vagueness, and impression; and is an effective tool for the application where no sharp boundaries (problem definitions) are possible (Markowski and Mannan, 2009). In classical set theory, a specific object is either a member or non-member of the set. However, in real life situations, due to lack of knowledge or existence of imprecise data, it is not always obvious to say whether an object belongs to a set or not. Therefore, fuzzy sets deal with an uncertainty in an approximate way. Conceptually, fuzzy set theory permits an object belonging to multiple exclusive sets in the cognitive context. Each set incorporates a degree of truth that an object belongs to a fuzzy set.

According to (Zadeh, 1965), fuzzy set A can be defined as a collection of objects called universal set X, represents a class of objects with a range of grades of membership. Such a set has been characterized by the membership function $\mu_A(x)$, which provides a grade of membership ranging between zero (non-membership) and one (total membership) to each object. In relation to this, a fuzzy set can be known as a set of pair: $A=\{(x,\mu_A(x);x\in X)\}$, where $\mu_A : X \rightarrow [0,1]$ is the membership function defining the degree of belonging to x in the set A. Markowski and Mannan (2009) has described the differences between a classical set and a fuzzy set for "safe state" as shown in Fig. 1.2.

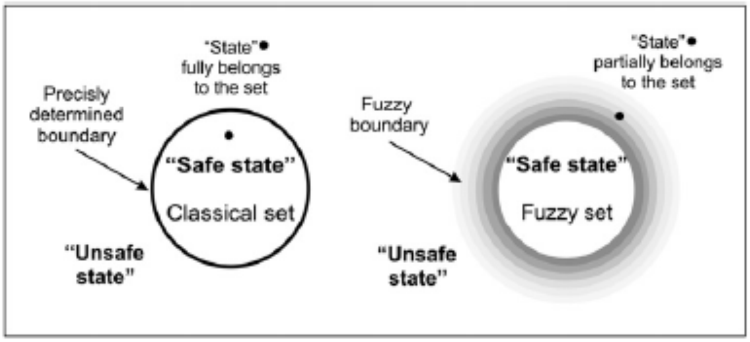

Fig. 1.2: Classical set and fuzzy set for safe and unsafe state
(Source: Markowski and Mannan, 2009)

Classical set with its crisp, exactly determined boundary sharply divides safe state from unsafe one; whereas, fuzzy set demonstrates smooth change from safe to unsafe state. It indicates that safety can be considered as a "fuzzy issue" because plant safety cannot be strictly categorized as safe or unsafe, as inherent hazards always occur. The actual level of safety and risk may belong partly to one or the other state. Such type of situation can be tackled by fuzzy logic where use of membership function representing the possibility to occur a certain incident and consequently fuzzy set theory can be applied into risk analysis to significantly reduce the knowledge uncertainty.

1.6.3 Risk Assessment: A Decision Making Viewpoint

A risk assessment platform in light of a decision making task made on a fuzzy set system can provide consistency when analyzing risks with inadequate data and vague knowledge environment.

It facilitates experts to focus on the foundation of the risk assessment, which includes the cause-and-effect relationship between potential factors as well as the exposure for each specific hazard/risk. Fuzzy logic system not only permits a direct input for the likelihood and potential impact of a risk event, but also motivates human reasoning from the facts and knowledge to the outcome in a consistent and well documented manner. Fig. 1.3 shows the risk assessment hierarchy structure based on the combined strength of fuzzy set theory and decision making. The hierarchy is basically followed a bottom up structure, which begins from each individual risks. The risk exposure has then been aggregated at the business unit and organization level to identify the top risks. In order to make it comparable among all recognized risks, the same procedure requires to be adopted when quantifying the exposure of each risk. Then, the investigated risks may be ranked based on the result of defuzzification, a numerical value that measures the level of risk exposure. The ranking based on the fuzzy risk assessment system enables the decision-makers to identify the major risks and also provides better understanding of the relative magnitude of risks. This may help management to select appropriate control measures for mitigating and minimizing the level of risks in a cost effective way.

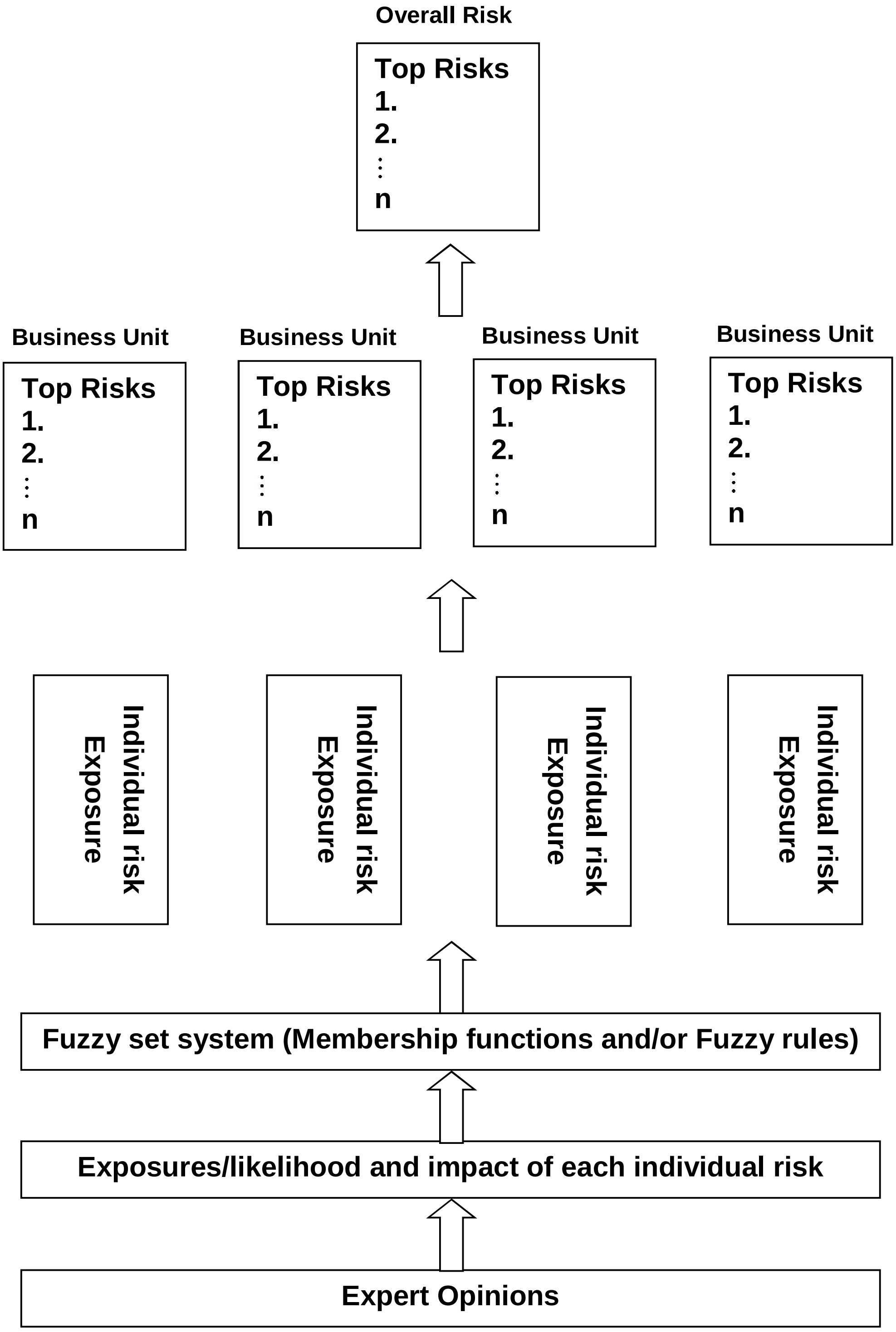

Fig. 1.3: Risk assessment hierarchy structure (Source: Shang and Hossen, 2013)

1.7 Occupational Health and Safety: Emphasis on Underground Coal Mining Industry

It is recognized that enhanced level of workers' health and safety concerns at the managerial level has a positive impact on productivity as well as economic growth of any industry. Injury prevention and safety promotion is an integral part of industrial economic activities as high level of safety and health standard at work is very important towards enhancing overall business performance. National policy on safety and health at workplace is not only play an important role to eliminate the incidence of work related injuries, diseases, fatalities by ensuring achievement of a high level of occupational health and safety performance through proactive approaches; but also enhance the well-being of the employee and society, at large. It is accepted that, mining is a most hazardous sector because of its dangerous work ambience (ILO, 2010). According to the latest report by Directorate General of Mines Safety (DGMS) India, coal mines are inherently more dangerous than metal mines; and, underground mines appear to be more dangerous than open cast mines. In addition to the high frequency of accidents, coal mining is ranked at the top in the list of hazardous workplaces; wherever, statistics are maintained the potential for a major incident involving multiple loss of life, which is always present in underground mining operations (DGMS, 2011). Underground coal mining is one of the highest risk prone activities as far as occupational safety and health issues are concerned. Although there has been substantial improvement in ensuring coal mining safety and health since past few years; still the persons involved in underground mining operations such as coal extraction, transport, and processing may expose to a wide range of hazards (or workplace activities or conditions) that may cause adverse incidents, injury, death, ill-health or disease, if not properly controlled.

Incidence of accidents being an important indicator of the status of safety, it may be relevant to examine the accident scenario. According to DGMS (2011), total 385 underground coal mines having gassy seams have been operating in India. Total 65 fatal accidents involving 67 fatalities have occurred during the year 2011. 23(35%) fatal accidents have occurred in belowground workings with fatality rate of 0.13; 29(45%) fatal accident in opencast workings with fatality rate of 0.36 and 13(20%) in surface operation with fatality rate of 0.12 during the year 2011. Survey depicts that, 508 numbers of persons have injured due to the occurrence of 486 numbers of serious accidents. The major causes of accidents are spontaneous heating of below ground, ground movement, contamination of coal dusts, gases, and explosives, and transportation of machinery. The frequency of disasters due to fires, and explosions has been terrifyingly increased in the recent past. In addition, inundations and strata failures are also common causes of occurrence of disasters at regular intervals. In case of fatal accidents, roof falls continues to be the area of major concern followed by accidents caused by dumpers and trucks in coal mines.

Other than loss of lives or serious physical injuries due to mining accidents; occupational health hazards in underground coal mining is seemed critical and remains as a prominent issue. Occupational health is an aspect of public health programme, which is established to ensure that the health status of everybody in any occupation is protected, maintained and promoted. It takes care of the diseases, accidents, emergencies and other hazards encountered in the workplace and how the problems can be prevented, improved and controlled. The persons working in the mines are exposed to a number of hazards to a physical, chemical or biological agent at work which adversely affect their health. Some of the common health hazards are coal dust, noise, heat, humidity and vibration etc. In recent years, there has been increasing awareness among the coal mining workers about the occupational diseases like pneumoconiosis, silicosis, manganese poisoning, musculoskeletal diseases, and hearing impairment etc. caused by exposure to health hazards at work. It is observed that most of the occupational diseases are known to cause permanent disablement and there is no effective treatment for permanent cure. However, it can be prevented by adopting proper occupational health risk measures and engineering control on health hazards at workplace. When workers are exposed to physical, chemical, and biological hazards, the employers should take the following few responsibilities and rights for improving the health and safety status at workplace (ILO, 2006):

1. Employer should inform more comprehensively to the workers regarding the hazards associated with their work, the health risks involved, and relevant preventive and protective measures.
2. Employer should assess the risks and take appropriate measures to eliminate or minimize the risks resulting from exposure to health hazards.
3. Employer should provide the use of primary protective equipment's for workers towards adequate protection against risk of accidents or injury to health including exposure to adverse conditions.
4. Employer should provide the workers who have suffered from injury or illness at the workplace with first aid, appropriate transportation facility to avail appropriate medical facilities.
5. Employer should ensure that adequate safety training and retraining programs and comprehensible instructions are provided for the workers.

1.7.1 Definitions of Key Terms

Hazard: A situation or thing that has the potential to cause an adverse health effect or harm including injury, disease, illness or death and damage. Hazards at work may include: noisy machinery, a moving forklift, chemicals, electricity, working at heights, bullying, and violence at the workplace (Source: www.safework.sa.gov.au).

Hazard Identification: The process of examining each work area and work task for the purpose of identifying all the hazards which are inherently exists in the job and defining its characteristics.

Risk: The likelihood or possibility that harm (injury, illness or death) might occur when exposed to a hazard (Source: https://osha.europa.eu). In other words, risk is an estimate of the combination of the likelihood and time exposure of an occurrence of a hazardous event or exposure(s), and the severity of injury or illness that may be caused by the particular event or exposure(s) (BSI, 2007).

Exposure: Contact with or closeness to a hazard, taking into account duration and intensity. The exposure is dependent on the emission, dispersion and type of contact with workers.

Likelihood/Frequency: Chance per unit time (usually per year): Exposure × Probability.

Risk Control: The actions taken to eliminate health and safety risks so far as is reasonably practicable, if that is not possible, minimizing the risks so far as is reasonably practicable. Eliminating a hazard can also be eliminating any risks associated with that hazard (Source: www.safework.sa.gov.au).

1.8 State of Art: Risk and Occupational Health Hazards in Industrial Context

Recently, risk management concept has grown immense interest in various fields including marketing, insurance and banking, software as well as production industry concerns. Many industrial sectors throughout the globe are adapting these concepts in order to enhance health and safety status at workplace, to improve reliability and effectiveness of the product, process or service, since these organizations have upgraded themselves to be efficient in managing identified risks. In addition to this, effective management of risks enables to protect project revenue, enhance value for money and improve resiliency of the organizations. However, todays modern industries necessitate an efficient risk management strategy through which they can maximize potential opportunities (example: production capabilities) with minimal capital investment. In order to identify the research objectives and thereby conceptualizing the direction of the present work, the following section exhibits state of art on understanding of various aspects of risks, risk assessment methods and risk management strategies used in various fields of applications.

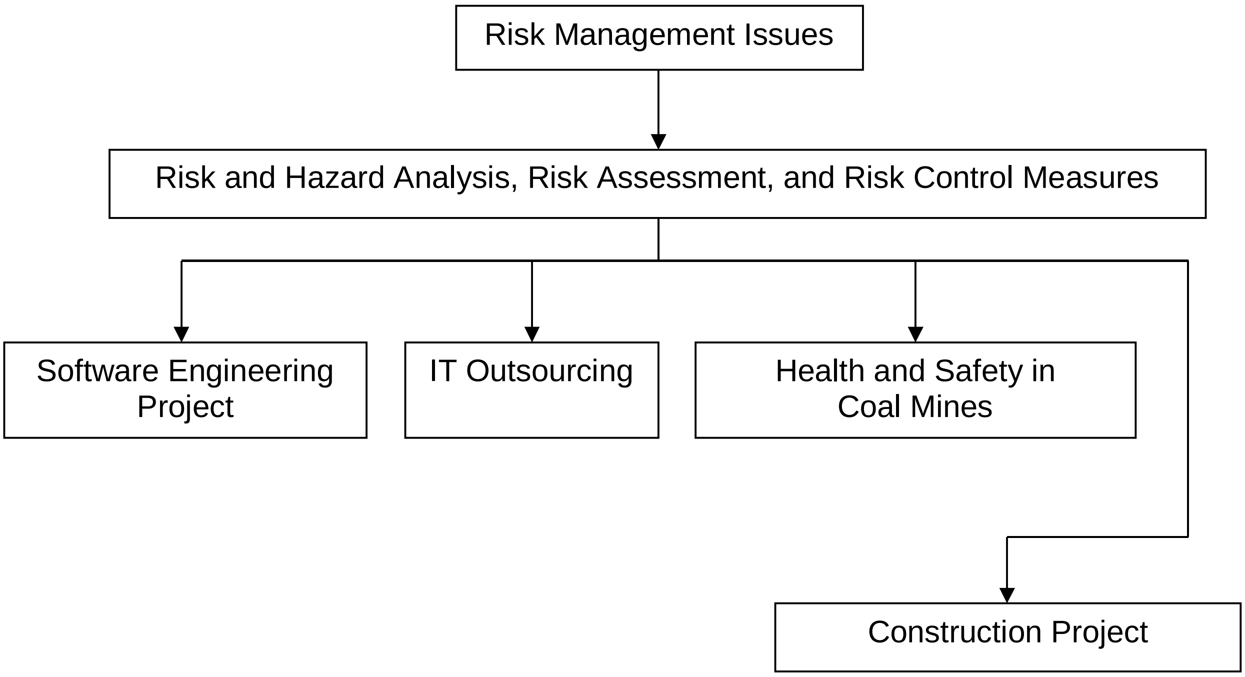

Fig. 1.4: Research on risk management issues in four emergent domains

The literature review provides a clear understanding in identifying a pertinent gap or methodological weakness present in the extent body of knowledge to solve the research problems under consideration. The literature is classified into four categories; each categories dealing with risk management related specific issues (risk identification, risk assessment, and risk control measures). The emphasis is made on software engineering project, IT outsourcing (ITO), occupational health and safety in coal mines, and construction project as illustrated in Fig. 1.4.

1.8.1 Risk Management in the Context of Software Engineering Project

Execution of software projects is not always successful; the risk associated with software development is a challenging as well as important issue in the current scenario. In recent times, most of the software industries are under tremendous pressure due to their undertaking project failures, and escalation of original budget due to delay in project implementation. Controlling risk in software engineering projects is considered to be a major contributor to project success (Bannerman 2008). Software project failures are often a result of inadequate and ineffective risk management. Extensive research has been conducted on risk management in software projects through identification, assessment and control of risks, which threaten the assets of a software enterprise (Boehm, 1991). Risk is defined as a chance of danger, damage, loss, failure or any undesired/negative consequences. Büyüközkan and Ruan (2010) proposed Choquet integral based aggregation approach for evaluating software development project risks. The authors examined the interactions among various risk factors in relation to software project associated with product engineering, development environment, and program constraints to evaluate overall project risks in a decision making environment. Hoodat and Rashidi (2009) developed a probabilistic model to analyze and to assess the risks in software engineering projects. They used a risk tree structure to relate several risk sources and categorize different risks. Cerpa et al. (2010) used a logistic regression model to predict the project outcome and analyze the effect of various factors on outcome. Li et al. (2012) proposed a two metric model - software process module with risk management and cost control module to calculate risk management efficiency and trustworthiness values of software process management. López and Salmeron (2012) presented a risk checklist which affected the performance of software projects. All risk factors were placed in a four quadrant matrix on the basis of their impact and probability ratings. Huang and Han (2008) explored the relationship between software project duration and risk exposure by using cluster analysis technique. The authors observed that risk exposures associated with user, requirement, planning and control, and team risk dimensions were affected by project duration. The work also provided appropriate guidelines to manage software risks effectively through observing relational trends among the investigated risk components. Nakatsu and Iacovou (2009) studied the effect of important risk factors on project outcome when software development projects were outsourced inshore and offshore using Delphi method. Keil et al. (2008) investigated the software practitioners' risk perception and decision making; whereas Jun et al. (2011) considered perception of vendors. It was concluded that process performance could be improved by enhancing planning and control for low risk projects. Product performance could be improved by increasing user participation for high risk projects. Bakker et al. (2010)

investigated how risk management contributed to the success of projects through meta-analysis of the empirical evidence. Jani (2011) proposed a simulation based experiment for assessment of risk factors in software project development. Sharma and Gupta (2012) used factor analysis approach for identifying key organizational climate dimensions which affected software project risk dimensions in Indian software industry. They also established empirical relations between the organizational climate dimensions and project risk dimensions using regression analysis. The authors found that most of the risk factors affecting software projects could be controlled by providing clarity in roles and responsibilities and providing an environment where employees could be encouraged to accept and own up the responsibility of their actions.

Aloini et al. (2012) proposed an Interpretive Structural Modelling (ISM) technique to analyze the enterprise resource planning (ERP) project risks. Hu et al. (2013) proposed a model using Bayesian networks with causality constraints for risk analysis of software development projects. They found that casualty between risk factors and project outcomes were significantly controlling project risks via effect influenced by controlling the cause principle. Neves et al. (2014) analyzed the integration of knowledge management techniques into the activity of risk management for software development projects of micro and small Brazilian incubated technology-based firms. They examined various knowledge management techniques including training at work, brainstorming, customer interactions, and face-to-face meetings etc. through four important conversion modes such as combination, socialization, externalization and initialization for controlling the identified risk factors. The authors found that "combination" conversion mode was more significant for software projects risk management practice. Bakker et al. (2012) investigated the potential influence of various risk management activities on software project success based on the stakeholders' perspectives. They observed that risk identification was the most influential risk management activity, followed by risk reporting, risk registration and risk allocation, risk analysis, and finally risk control. Costa et al. (2007) presented a technique for evaluating risk levels in software projects through analogies with economic concepts. They estimated various level of risk based on the probability distribution of earnings and losses incurred by an organization in relation to its software project portfolio. Han and Huang (2007) examined the relationship between software project risks and project performance in the high, medium, and low performance projects. They identified six potential risk dimensions: user, requirement, project complexity, planning and control, team, and organizational environment comprising twenty seven software risks, and analyzed the probability of occurrence and impact of software risks on project performance through MANOVA (multiple analysis of variance) analysis. The authors found that the ‘requirement’ risk dimension was the principal factor which significantly affecting the project performance.

Mathew and Chen (2013) studied the moderating effects of different relational norms on the link between behavioral risks and offshore software development success. They focused on three key modes of relational norms: norm of flexibility, norm of solidarity and norm of information exchange. The authors found that the norms of solidarity and flexibility reduced the negative effects shirking risk on offshore software development success. Lehtinen et al. (2014) analyzed potential causes of software project failure through cause and effect analysis. The causes of failures were detected by conducting root cause analysis. The authors analyzed each failure through causal relationships diagrams including various possible causes and found that lack of cooperation, weak task backlog, and lack of software testing resources were the common bridge causes of software project failure. Hu et al. (2015) proposed a cost-sensitive and ensemble-based hybrid modeling framework for software project risk prediction. They explored cost-sensitive analysis and classifier ensemble method for comprehensively predicting risk associated with software projects. The resultant model presented low misclassification cost and relatively high prediction accuracy. Kester (2013) applied formal concept analysis approach for evaluating and visualizing risk matrix in software engineering project. They considered the set of objects and attributes of risk levels assessment which facilitated to categorize the risks based on risk types. Hatei et al. (2013) analyzed the relationships among the risk factors involved in public-private partnerships (PPP) projects using Interpretive Structure Modelling (ISM). They identified twenty risk factors and, pursuant to the model’s characteristics, classifying them into three categories such as; dominating factors, transferring factors and indicating factors. Fu et al. (2012) developed a probabilistic model based on design structure matrix (DSM) to evaluate risk of change propagation from requirements to software development projects. The model was also capable to estimate the schedule and cost of a software project.

1.8.2 Risk Management in the Context of Information Technology Outsourcing

In the recent business scenario, many IT industries are facing daunting challenges in terms of healthy alliances on their ITO strategy due to existence of inherent risks. Success of any IT industry depends on success rate of their outsourcing projects, which in turn depends on several factors such as cost, time, and availability of resources. These factors often formulate the risk areas, which needs to be addressed in a proactive way. The objective of risk management is to avoid the possibility of their occurrence by identifying the risk influencing factors, preparing the contingency plans and mitigation plans in order to reduce the consequences of the risks. IT outsourcing is the use of a third party to successfully deliver IT enabled business process, application service and infrastructure solutions for a cost effective business outcome. Moreover, IT outsourcing is defined as a decision taken by an organization to contract out or sell some or all the organizations' IT assets, people and/ or activities to a third party vendor, who in turn provides and manages these activities/services as set forth in the contractual agreement and monetary fee (Dhar et al., 2004, Loh and Venkatraman, 1992; Lacity and Hirschheim, 1993). Karami and Guo (2012) proposed an integrated Multi-Criteria Decision Making (MCDM) framework for selecting IT service provider in information system outsourcing. The authors selected an appropriate IT vendor by approximately trading off the perceived risks as well as the benefits. Abdullah and Verner (2012) developed a literature based conceptual risk framework for strategic IT system development outsourcing from the clients perspective. The critical risk factors such as complexity, contract, execution, financial, legal, organizational environment and user were identified as influencing factors on the outcome of strategic IT system development outsourcing projects. Rusu and Hudosi (2011) presented a design of an information technology outsourcing (ITO) tool that included a procedure based on transaction cost theory (TCT) for examining as well as assessing the risk exposure in ITO. Susarla (2012) examined renegotiation design in contracts for outsourced information technology (IT) services using a sample of one hundred forty one IT outsourcing contracts. Pareto improving amendments was proposed to assess renegotiation outcomes, which enhanced the value from outsourcing by hazard equilibration and incorporating learning. Contractual flexibility and rent seeking were also analyzed in order to measure the effectiveness of IT outsourcing contracts. Zhang and Huang (2012) presented a fuzzy risk evaluation method for information technology service outsourcing in which the risk factors were assessed by fuzzy value and the risk grades of each risk factor were calculated by fuzzy linguistic values. The risk rate of IT service outsourcing was determined through the probability of occurrence of each risk factor. Cheng (2012) developed an information security risk assessment model of IT outsourcing managed service. The qualitative process of quantifying degree of risk was performed by Borda sequencing and Analytic Hierarchy Process (AHP). Al-Hamadany and Kanapathy (2012) examined the effect of perceived risks and benefits to increase level of Information Technology (IT) outsourcing amongst eighty three companies in Malaysia. A questionnaire survey was conducted which exhibited the financial risk factor as the most significant factor amongst all perceived risks; whereas, technical resources and time were found as the most influencing factors for perceived benefits. Thouin et al. (2009) used transaction cost economics (TCE) of IT

Outsourcing examining the effect of level of low asset specificity on firm level financial performance.

Karimi-Alaghehband et al. (2011) assessed transaction cost theory (TCT) based ITO models in terms of faithfulness and concluded that the models could hardly capture all the essential elements of TCT. Chou and Chou (2009) developed an information system outsourcing life cycle model considering various risks factors encountered during different contracting phases (pre-contract, contract, and post-contract phases). In another paper, Chou and Chou (2011) described various issues related to innovation outsourcing including uncertainty, risks, productivity and quality perspectives. Shi et al. (2011) proposed a linear mixed model (LMM) approach for outsourcing decisions considering heterogeneity among the experts in risk perception. Fan et al. (2012) proposed a methodology to identify IT outsourcing risk factors as well as their importance in the decision making process.

Han et al. (2013) investigated direct and complementarity effects of client and vendor IT capabilities on the success of IT outsourcing projects. Yuan and Xu (2013) proposed a rough set approach for risk analysis of IT outsourcing. Kim et al. (2013) proposed a model for IT outsourcing management considering governance effectiveness facilitated as key indicator for the success. Bachlechner et al. (2014) highlighted various important aspects of security and compliance challenges in complex IT outsourcing from the perspective of multi-stakeholders based on the series of interviews and online survey. The authors realized that the factors like auditing clouds, heterogeneity of services, coordination between parties, relationships between clients and vendors, and lack of data security awareness could be viewed as risks if these were not properly managed. Tjader et al. (2014) developed a balanced scorecard (BSC) based Analytic Network Process (ANP) model for determining IT outsourcing strategy. Verner et al. (2014) studied various sources of risks and their risk mitigation strategy for global software development. The study identified eighty five risks and seventy seven risk mitigation advice items from the extensive literature review and categorized them under four major captions such as outsourcing rationale, software development, human resources, and project management. The aforesaid work aimed at furnishing appropriate risk and risk mitigation advice to provide guidelines to the organizations involved with global software development. However, they did not attempt to quantify the degree of risk extent that should be considered as a limitation of their study.

1.8.3 Occupational Health Hazard Risk Management: In the Context of Coal Mines

Occupational health and safety risk is a critical issue in coal mine industries. The persons working in coal mining industry are exposed to wide range of hazards from physical, chemical or biological agents at work which adversely affect their health resulting injury, occupational disease, illness or death. Occupational disease can be understood by several determinants, including hazards at the workplace leading to musculoskeletal diseases, chronic lung diseases, hearing loss, circulatory diseases, stress related disorders, communicable diseases and others. Therefore, there is a need for identifying the health hazards at workplace, assessing the risks associated with hazards, and developing appropriate measures to eliminate or minimize the risks resulting from exposure to the health hazards. Extensive research has been conducted on occupational health risk management in coalmines including identification of health hazards at workplace, and framing of risk assessment procedures as well as risk control measures. Various techniques have been applied by the pioneers for risk analysis and assessment using traditional methods to the most advanced fuzzy approaches. Badri et al. (2013) presented a conceptual risk management model that facilitated to examine various potential hazards in relation to occupational health and safety (OHS) issues for underground goldmines in Quebec. The model also provided a systematic procedure to evaluate associated inherent hazard risks through an Analytical Hierarchy Process (AHP) based on the concept of hazard concentration. Amponsah-Tawiah et al. (2014) examined physical and psychosocial hazards in Ghanaian mining industry (gold, manganese and bauxite). The potential impact of the hazards on the quality of life and general well-being of the employees was analyzed based on the survey data of mining equipment, ambient conditions, and work demands and control, through exploration of Principal Component Analysis (PCA). Bahn (2013) reported the details of two workshops focusing on hazard identification training for underground mining operations that were conducted in Western Australia in 2011. First workshop was “Hazard Identification” where a training program was provided to successfully identify workplace hazards for all staff members associated in mining operational activities. Within the subsequent training activities, the identified hazards were placed into following four categories: obvious, trivial, emerging and hidden hazards. The second workshop “Managing workplace hazards” highlighted a comprehensive list of hazards which belonged to aforesaid four categories and developed a list of strategies to manage these hazard risks. Chen and Zorigt (2013) investigated the relationship between five important factors: act and regulation, stakeholder pressure, investment, integrated occupational health and safety management (OHSM) and organizational culture, which were effectively influencing on the implementation of OHSM among the operational mining companies in Mongolia. The authors critically examined aforesaid five factors through statistical factor loading technique and found that investment, stakeholder pressure and act and regulation were the most influencing factors on implementation of OHSM. Hassim and Edwards (2006) developed a process route healthiness index (PRHI) to quantify inherent occupational health hazards for various alternatives of chemical process routes; higher the index, the higher the hazards. They believed that occupational health risks could be reduced by better selection of the chemical process route during the early stage of process design. Hassim and Hurme (2010a) developed a method called the Health Quotient Index (HQI) in order to quantify occupational health risks from exposure to fugitive emissions for various alternatives of process routes in petrochemical plants. They selected one healthier process route which carried least HQI value amongst the other. In another work, Hassim and Hurme (2010b) developed an Inherent Occupational Health Index (IOHI) towards assessing health risks of the workers during the process research and development stage in chemical process routes. The method mostly focused on both the hazard from the chemicals present and the potential for the exposure of workers to the chemicals. Hassim et al. (2013) introduced a graphical method to evaluate occupational health hazards of chemical processes during the R&D stage. The method was developed with a four input health parameters: process mode, material volatility, operating pressure and chemical health hazard, which were found significantly affecting inherent health hazard of the chemical process. Khanzode et al. (2011) examined various recurring hazards (dust, water, ventilation, illumination, ground fall and machinery) in relation to health and safety for underground coal mining through statistical techniques. The authors characterized various hazards in terms of hazard rate and cumulative risk of occurrence. Khanzode et al. (2012) presented a comprehensive review of the concepts of occupational injuries and accident causation and prevention. They highlighted some important areas such as hazard identification, the issues on risk assessment, accident causation, and intervention strategies. Bridbord et al. (1979) suggested that occupational safety and health implications in coal mining must be considered as a major concern to increase the coal production and subsequent utilization. They identified some hazards related to mining activities resulting in many mine related accidental deaths, disabling injuries, and death from chronic lung disease. Donoghue (2004) presented an overview of occupational health hazards in mining industry considering physical, chemical, biological, ergonomic and psychosocial factors of miners. Kovalchik et al. (2008) described the quite-by-design approach, which facilitated to reduce the noise exposure for controlling the noise induced hearing loss of workers in underground coal mining using prevention through design (PTD) concept. Kurnia et al. (2014) examined the flow behavior and dust dispersion of underground tunnel with or without auxiliary ventilation system using computational fluid dynamic (CFD) by taking into account of six possible scenarios (blowing fan, exhaust fan, brattice, combination of blowing and exhaust fan, and combination of brattice and exhaust fan). The authors found that application of brattice offered better dust control scenario than amongst others. The prime objective of the study was to provide protective measures for the coal dust exposures (occupational health hazard) in underground coal mining. Li et al. (2012) presented a review article describing researches on occupational health risk assessment for managing the health hazard risks in an industry perspective. The authors underlined various risk assessment approaches (quantitative, semi quantitative and qualitative) on acute intoxication and chronic diseases, such as carcinogenesis and non-carcinogenesis caused by occupational exposure for occupational risk assessment and health management practice. Sari et al. (2009) proposed a stochastic model considering the randomness in the occurrence of the days-lost accidents towards predicting accident risks associated with an underground coal mine in Turkey. Schatzel and Stewart (2012) investigated mineral matter provenance for two Appalachian coal basins (underground coal mines) of United State based on the observed samples indicating the mineralogical, geochemical and neodymium (Nd) isotope data. The study provided an understanding towards controlling coal dust exposures, which might lead to reduce the occurrence of dust related occupational diseases (silicosis, black lung) of underground coal mine workers. Singh et al. (2011) developed a screening method for understanding hazards as well as risks to human health influenced by the environment associated with the use of synthetic chemicals. The work provided a basis of developing risk assessment procedure for the mining industry. The screening method was the combine aspects of several available procedures, which performed the process of screening chemicals based on their hazardous properties such as accommodating the range of volumes, exposure scenarios, different uses, unknown mixtures, range of disposal routes and disparities in chemical housekeeping. Zhu-Wu et al. (2011) proposed a risk assessment model for the occupational hazards in coal mine based on the hazard theory. The hazard risks on the coal faces were evaluated using fuzzy comprehensive evaluation method in order to provide hazard prevention and control strategy.

1.8.4 Selection of Safety Measure System in Underground Coal Mining Industry

The risks associated with various aspects such as financial, operational as well as maintenance that are likely to incur to the coal industry should be taken into account whilst selecting an appropriate safety measure system alternative towards improving coal mine workers safety. Managers should implement such a plan or strategy towards improving workers safety that should correspond to minimum risk to the industry. Literature depicts intensive focus rendered by pioneer researchers to the occupational safety issues for coal mine workers. Kursunoglu and Onder (2015) applied Analytic Hierarchy Process (AHP) for selecting an appropriate fan for an underground coal mine under a Multi-Criteria Decision Making (MCDM) environment. They identified four main criteria for selecting the appropriate fan such as technical, operational, environmental, and economic (operating cost); each with specific sub-criteria. The authors realized that sufficient ventilation system could provide adequate fresh air to underground mines to ensure a safe working environment. Sousa et al. (2015) highlighted on financial and economic issues regarding the implementation of additional safety measures. They proposed a cost-benefit analysis model for applying the safety alternative measures towards improvement of the worker safety in construction work environment. Tappura et al. (2015) analyzed the safety related investment costs and its benefits through a management accounting perspective. They used balanced scorecard approach for evaluating the cost and benefits of safety including non-financial benefits and value created through preventing accidents. Mahdevari et al. (2014) applied fuzzy-TOPSIS method for selecting the safest coal mine among three hazardous underground coal mines located at the Kerman coal deposit, Iran. They assessed the risks associated with workers health and safety using human intuitive assessment process and selected the best alternative, which acquired minimum risks. Rathnayaka et al. (2014) presented a risk-based decision making tool for designing the industrial work systems considering inherent safety. The authors proposed a risk-based inherent safety index (RISI) which incorporated both consequence and probability of accident occurrence reduction throughout the process design life cycle. Caputo et al. (2013) used AHP based decision making approach for selecting safety alternative device aiming at ensuring personal safety at workplace. They first identified possible mechanical hazards and associated risks applicable in industrial machinery, and then selected appropriate safety device based on the number of criteria including cost, reliability, maintainability, flexibility, and useful life. Wang et al. (2012) developed a risk-based maintenance strategy to reduce the overall risk in the operating facility used in catalytic reforming plant. They used failure mode and event analysis for analyzing the economic loss associated with maintenance of safety alternative system. Vaurio (2011) studied the applications of importance measures of components and configurations for making risk-informed decision relevant to system operations, maintenance and safety.

Caputo et al. (2011) optimized the economic loss of industrial safety measures using genetic algorithm. The authors minimized the total safety-related cost including investment, operating expenses of adopted safety measures, and expected monetary loss of accidents through the computer added methodology. Aven and Hiriart (2011) developed a generalized safety investment model for analyzing economic investments of safety measures applicable in industrial perspective. They examined the investment costs towards safety measure systems and its benefits in terms of avoiding accidental risk. The authors minimized the level of investment without compromising the level of workers safety. Arunraj and Maiti (2010) used AHP and goal programming approach for selecting a proper maintenance strategy of benzene extraction plant based on risk of equipment failure and cost of maintenance. They observed that condition based maintenance strategy was found to be more significant for high risk equipment; whereas, corrective maintenance appearing mostly preferable for low risk. Lawrence (2000) investigated the software qualification of safety instrumentation and control systems used in worker safety applications. The author observed that proper designing of safety components could reduce the cost and monetary risk involved in qualifying commercial components for safety application service. Na et al. (2011) highlighted the application of safety information system for the coal mines. They applied web server information system comprising safety production management, accident prevention, training management and emergency exercise for the coal miners through the common gateway interface, active server page, and hypertext pre-processor technology. Toraño et al. (2009) presented modeling of ventilation and methane behavior of roadway in deep underground coal mine using computational fluid dynamics (CFD). Wang et al. (2013) proposed safety technologies for the excavation of coal and gas outburst coal seams in deep shafts. They performed an analysis of stress distribution characteristics of shaft working faces in deep underground coal mines using theoretical analyses and field tests. Su et al. (2005) proposed a methane assessment and mitigation procedure for Queensland coal mine, Australia. They also discussed some features of existing and developing technologies for coal mine methane mitigation and utilization, as well as identified the best options for mine site applications. Saleh and Cummings (2011) analyzed safety issues in the mining industry and the unfinished legacy of mining accidents. The authors identified technical, organizational, and regulatory deficiencies that failed to prevent the escalation of mine hazards into an accident. Qing-gui et al. (2012) analyzed the safety measure system applicable in coal mine. They highlighted the applicability of safety system that could manage and control potential accident risks, hazards and human behavior risks. Lu and Li (2011) proposed a hazard detecting and controlling method using a theory of system safety engineering to tackle safety problems in coal mining industries of China. Paul and Maiti (2007) examined the role of behavioral factors on the occurrence of mine accidents and injuries through a case study of two Indian coal mine industry. The observation of the study showed that accident victims were more job dissatisfied, negatively affected, and highly risk taking compared to the non-accident group of workers. Maiti and Khanzode (2009) developed a risk-based decision model for fatal accidents in underground coal mines using log-linear analysis of two way contingency table. They analyzed the statistics of potential fatalities, relative risk fatalities, and safety measure effectiveness which could be considered as safety performance indicators of accidents in underground coal mines.

1.8.5 Risk Management in the Context of Construction Project

Construction industries are highly risky due to their complex and dynamic nature of work system activities. If the risks associated with construction projects are not properly identified, assessed, and controlled; it may result poor performance with increasing costs and delay in project completion. Therefore, risks related to cost escalation, project delay and safety concerns are remaining as critical issues for the construction projects. It is obvious that effective management of project risks can improve the chance of project success. Risk management includes risk identification, risk assessment, and risk mitigation/control. Risk assessment is one of the critical phases of risk management, which is inherently related to the risk modeling. In recent years, a number of publications could be found in existing literature resource emphasizing risk analysis models and risk assessment techniques in relation to construction projects.

Mandal and Maiti (2014) developed a methodology for risk analysis by integrating the concepts of fuzzy similarity value measure and possibility theory. Similarity value measure was applied for grouping together failure modes having similar amount of risk value; whereas, possibility theory was used for checking the conformance guidelines. Purnus and Bodea (2014) used a Monte Carlo Method for analyzing the risks associated with in the construction projects. The correlation between the parameters of time, cost and resource limitation were analyzed, and perceived project risks were estimated using Spider Project software. Pinto (2014) developed a fuzzy based qualitative risk assessment model for the assessment of occupational safety risks in relation to a construction industry. The degree of risk extent was estimated effectively considering the parameters of subjective evaluation of likelihood of occurrence and consequence of risk using fuzzy set theory. The author supported that fuzzy set theory was found to be well suited for handling the ill-defined and complex problems involving subjectivity. Nasirzadeh et al. (2014) presented an integrated fuzzy system dynamic approach for quantitative risk allocation in construction projects by which all the factors affecting the risk allocation process were modeled. Fuzzy set theory was integrated into the system dynamic approach because the values of different risk factors were uncertain in nature that could be effectively determined by the fuzzy numbers. Chien et al. (2014) used decision-making trial and evaluation laboratory (DEMATEL) method for identifying and assessing critical construction project risks during the process implementation of the Building Information Model (BIM) technology. The authors identified thirteen risk factors related to the technical, management, personnel, financial, and legal aspects, and analyzed the critical risk factors of projects at various levels through the casual relationship diagram. Kang et al. (2013) developed a four dimensional computer added design (CAD) based risk management visualization system for analyzing degree of risks in construction projects using quantifying methodologies for gathering risk information. Project risk information was quantified effectively by using fuzzy and analytic hierarchy process (AHP) techniques. Špačkova et al. (2013) presented three probabilistic models for the prediction of tunnel construction project risks. Firstly, simple probability model was used for the estimation of the damage due to tunnel construction failure; secondly, decision making under uncertainty model was used for the demonstration of the attitude of stakeholder towards risk; and thirdly, a stochastic model was applied for the assessment of excavation impacts on the surface structure. Tamošaitiene et al. (2013) applied TOPSIS-F method, a multi-criteria decision making approach for assessing and ranking of construction project risks. Fuzzy set concept was used for evaluating the risk information criteria subjectively. Fang et al. (2012) used a network theory to analyze the risk interactions in large engineering projects. In this work, different key risk elements were identified from the structure of interrelated risks significantly affecting to the large engineering projects. Subramanyan et al. (2012) demonstrated the use of AHP approach within a multi-criteria decision making framework for assessing construction project risks considering the quantitative values of the probability of occurrence and impact of risk. Moreover, the complexity and subjectivity of project risk assessment was handled by (Nieto-Morote and Ruz-Vila, 2011) through exploration of the combining strength of AHP and fuzzy set theory. Bakr et al. (2012) proposed a heuristic approach for risk assessment modeling of contract management within the construction project environment. The inherent project contractual risks in relation to time, effort, and wading back and forth between constructions cases were analyzed through the engineer procure construct contract management (EPCCM) modeling system. Wang and Yuan (2011) investigated critical factors affecting contractors' risk attitude in construction projects using statistical methods of ranking analysis. Three important factors namely consequences of decision making, engineering experience, and completeness of project information were found significantly influencing to the contractors' risk attitude from the initial analysis of multiple identified factors. Idrus et al. (2011) developed a project cost contingency estimation model to estimate cost contingency for the construction projects based on the strength of risk analysis and fuzzy expert system. The model was accommodated contractors experience and subjective judgment for analyzing potential risks affecting to the overall cost of the project.

Mousavi et al. (2011) demonstrated the use of non-parametric bootstrap re-sampling technique for the assessment of large engineering project risks within the decision making environment. The authors argued that traditional statistical techniques could not contribute significantly to analyze the risk data because of their inherent characteristics of uncertainty as well as subjectivity. Xu et al. (2010) proposed a fuzzy synthetic evaluation approach for assessing the overall risk level associated with public private partnership projects covering highway construction in China. They calculated group wise risk index for critical risk factors affecting to the projects based on their risk probability and severity using fuzzy membership function. Fung et al. (2010) developed a risk assessment model (RAM) for promoting occupational injury prevention priorities for workers based on the historical data from the different trades of works. The model highlighted the occurrence probability of accident as well as perceived risks, and then prioritized the risk factors in different risk levels of different work trades. Luu et al. (2009) developed a Bayesian belief network model to quantify risks of time overruns for the construction projects. The probability of project delay was analyzed through the cause-effect relationship of sixteen identified risk factors; it was found that factors like financial difficulties of owners and contractors, contractor's inadequate experience, and shortage of materials were significantly influencing to the project delay. Kuo and Lu (2013) proposed a fuzzy multiple criteria decision making approach to quantify risk for a metropolitan construction project. The authors used consistent fuzzy preference relation (CFPR) method for relative impact assessment; and fuzzy multiple attribute direct rating approach for analyzing the probability of occurrence of identified risk factors. The risk extent was evaluated and ranked with the synthesized analysis of the relative impacts and probability of occurrence of each risk factor. However, the drawback of the CFPR method appeared that it could not be used directly to quantify construction risk because of their pairwise comparison results of risk impact score. Yildiz et al. (2014) proposed a knowledge based risk mapping tool for systematically assessing the risk factors influencing cost overrun of the international construction projects. The level of vulnerability and magnitude of potential risk events were estimated on the basis of subjective evaluation of experts through the lessons learned database.

1.9 Motivation and Objectives

Risk management is a serious concern for every industry/enterprise. Effective risk management strategies and its implementation not only help in achieving various organizational goals but also create a healthy work environment and ensure workers' safety. Risk (sources of risk) identification is of utmost important in course of efficient risk management. Adequate experience and prior knowledge are indeed essential to identify sources of various risks in industrial context. Historical data or statistics on work related accidents, injuries are not always available unless the company maintains a strong data base and shares the information to others. In many cases, companies are not willing to share or reveal that sensitive information. In presence of inadequate historical data, how decision and information sciences can contribute to risk management has been articulated in this dissertation.

While developing an effective risk management strategy in industrial context, the following questions may definitely arise:

(1) What are the sources of risks, and what are factors that influence the risks? How they can be identified?
(2) What are the potential losses incurred by the hazards or risks?
(3) How can risk be estimated?
(4) Which type of analysis: quantitative, qualitative, or semi-quantitative analysis to be considered towards effective risk assessment?
(5) Is there any relationship amongst risk factors? How they affect the overall business performance?
(6) How risk can be categorized? What is the critical level of risks?
(7) What type of control measures should be chosen to mitigate the risks?
(8) What benefits an organization is likely to get, if proper risk management strategy is implemented?

In this work, risk assessment followed by prioritization of different risk sources has been conceptualized as a decision making task. Multiple experts (decision-makers) need to be involved to express their judgment in regards of possibility of occurrence (of adverse event) and also the consequence through linguistic terminology. As linguistic evaluation information bears some kind of uncertainty (ambiguity and vagueness); in order to overcome this, fuzzy numbers set theory has been explored in this work. Based on extensive literature review, the following focus areas have been identified for case studies like (i) risks involved with software engineering projects, (ii) IT outsourcing risks, (iii) risk based decision making towards improving workers' safety in mining industry (selection of appropriate safety measure system), (iv) risks associated with occupational health hazards in mining sector and, (v) risks associated with construction projects.

In all cases, risk assessment has been carried out through fuzzy based approaches rather than exploring crisp (numeric) data and probabilistic theory of risks. Based on extensive literature review and recent business reports, a structured framework consisting of potential risk sources (followed by sub-risk factors) has been constructed for assessment of risk extent (rating) in relation to different industrial sectors. Decision-makers' have been requested to express their opinion in relation to (i) possibility of occurrence and (ii) consequence against each risk factor by utilizing a presumed linguistic scale. Expert opinion has further been transformed into appropriate fuzzy numbers; by exploring fuzzy based decision making modules, the extent of overall risk has been computed, different risk sources have been categorized and proper action plans have been suggested to mitigate those risks.

The objectives of the research are as follows:

(1) To identify and analyze the interdependencies of critical risk factors and their effect in the context of software engineering project.

(2) To propose a unique hierarchical risk assessment module in relation to outsourcing risks in IT sector through a case study.

(3) To analyze risks of occupational health hazards in an Indian underground coal mining industry through a case study.

(4) To propose a risk-based decision support framework towards selecting appropriate safety measure system to enhance workers' safety in underground coal mining workplace.

(5) To propose a comprehensive risk assessment framework in the context of a metropolitan construction project for identification and effective evaluation of degree of risk using fuzzy integrated decision-making approach.

1.10 Organization of the Present Dissertation

In order to meet aforementioned objectives, the present dissertation has been organized into seven chapters including Chapter 1. A brief outline of each chapter has been highlighted as follows:

Chapter 1 (Research Background) provides a brief introduction on benefits of adopting risk management strategies in different phases of business activities followed by highlighting the general framework for risk management, risk analysis and assessment in decision making platform. In addition, this chapter includes sources of uncertainty associated in risk analysis domains, and also highlights methodologies that can be used for risk assessment practice. Moreover, prior state of art on understanding of various issues including occupational health and safety issues, risk and hazard analysis, risk assessment procedures, and risk control measures in various industrial sectors have been thoroughly documented in this chapter; based on which possible research gaps or methodological weakness have been identified and the specific objectives of the present study have been articulated as well.

Chapter 2 (Understanding of Critical Risk Factors in Software Engineering Project) focuses on application of Interpretive Structural Modelling (ISM) approach towards identifying and understanding the interrelationship among various risk factors associated in software engineering projects. A total of twenty three risk factors in relation to software projects have been identified through an extensive literature review. This study enables to identify critical risk factors by examining their functional interdependencies, which may provide in-depth knowledge to the managers in taking actions in terms of risk assessment, treatment and control towards successful execution of software engineering projects.

Chapter 3 (Risk Assessment in IT Outsourcing: A Case Study) includes a hierarchical ITO risk breakdown structure towards developing a formal model for qualitative risk assessment. The hierarchy includes eleven different sources of ITO risks and each of their risk influencing factors that have been identified from the survey of past literature. The two basic parameters such as likelihood of occurrence and its impact have been used for estimating individual risk extent of each risk influencing factor. An improved decision making method using fuzzy set theory has been attempted for converting linguistic data into numeric risk ratings. In this study, the concept of 'Incentre of centroids method' for generalized trapezoidal fuzzy numbers has been used to quantify the 'degree of risk' in terms of crisp rating. Finally, a framework for categorizing different risk factors has been proposed on the basis of distinguished ranges of risk ratings (crisp). Consequently, this chapter suggests an action requirement plan for providing guidelines to successfully manage inherent risks in the context of ITO exercise.

Chapter 4 (Analysis of Occupational Health Hazards in Underground Coal Mining Industry) presents a hierarchical structure on occupational health hazards comprising various physical, chemical, biological, ergonomic and psychosocial health hazards and associated risks in relation to an underground coal mining industry. Twenty one potential health hazards are identified, which are more sensitive at the mining workplace. Also, it highlights a systematic fuzzy based qualitative health hazard risk assessment model for estimating the risk extent of occupational health hazards through three measuring parameters: consequence of exposure, period of exposure, and probability of exposure. Identification and categorization of hazards are explored based on their fuzzy risk rating. This chapter analyses individual risk extents from various hazard agents and their effects to the overall health hazard risks. An effective control action plan is suggested to stimulate injury control as well as disease prevention by mitigating potential health hazards in underground coal mining industries.

Chapter 5 (A Risk-based Decision Support Framework for Selection of Appropriate Safety Measure System for Underground Coal Mines) highlights a risk-based decision support module for selecting an appropriate safety measure system towards enhancing workers safety in underground coal mines. The most suitable safety measure system is chosen based on the minimal level of risk with respect to multiple risk criteria such as financial risk, operational risk as well as maintenance risk that are likely to incur to the host organization in implementing the particular safety measure system. In this context, the proposed methodology utilizes interval-valued fuzzy modified TOPSIS approach for solving safety measure system selection problem; the appropriate safety system is one which should have minimum risks while making decision to implement in coal mine industry.

Chapter 6 (Risk Assessment for Metropolitan Construction Project: A Case Study) provides a fuzzy based formal qualitative risk assessment model for assessing overall risks in metropolitan construction project. A total of twenty potential risk factors are identified from five different risk dimensions: engineering design, construction management, construction safety related, natural hazards, and social and economic. The identified risk factors are more sensitive to the construction projects. This study explores 'Circumference of centroids' method for evaluating the ‘degree of risk’ in terms of crisp ratings. Expert’s different mental attitudes (pessimistic, optimistic and moderate) are considered to improve reliability of the subjective risk assessment procedure. The risk matrix concept has been explored to categorize various risk factors at different risk levels for facilitating in enlisting necessary actions requirement plan. Moreover, this chapter highlights percentage contribution of various risk dimensions towards overall project risk. The applicability of the proposed methodology has been validated through a real time case study. The proposed risk assessment module as well as risk control plan would definitely help to the project managers towards understanding of various risk factors associated with the metropolitan construction project.

Chapter 7 (Summary and Findings) presents executive summary of the current dissertation. It also discusses specific contributions of the present research work. In addition, this chapter highlights current research limitations followed by highlighting future scope of work.

CHAPTER 2

UNDERSTANDING OF CRITICAL RISK FACTORS IN SOFTWARE ENGINEERING PROJECT

2.1 Coverage

Success of software projects depends on identification of project risks and managing the same in a proactive manner. Risk management requires thorough insights into interrelationship of various risk factors for proposing strategies to minimize failure rate. The present study aims at development of a comprehensive structural model to interrelate important risk factors affecting the success of software projects. Specifically, this study reveals how Interpretive Structural Modelling (ISM) helps the risk managers in identifying and understanding the interrelationship among various risk factors. A total of twenty three risk factors (or risk sources) have been identified through an extensive literature review and expert opinions. Necessary modeling information has been gathered from expert through a structured questionnaire survey. MICMAC (*Matrice d'Impacts croises-multipication appliqué an classment*) analysis has been employed to classify the risk factors into four clusters such as autonomous, dependent, linkage and independent based on their driving and dependence power. Risk factors with strong dependence and weak driving power need urgent attention from managerial perspective. The proposed model is useful for software managers/practitioners to address risk factors associated with complicated projects.

2.2 Problem Statement

Software engineering concerns with design, creation and maintenance of software using latest tools, techniques and practices from computer science, project management, information technology and other application domains (Grimstad, 2006). Since execution of software projects are not always successful, their development is a challenging and an important issue in the current scenario. Today, most of the software industries are concerned with failure and escalation of original budget due to delay in project implementation (Williams, 2004). In 1995, Chaos report of Standish Group reveals that only 16.2% of software projects were completed on time and budget. Over 31.1% of software projects were cancelled before they got completed and 52.7% of the projects were escalated by 198% of their original estimates. In order to reduce the failure rate of software projects, managers need to pay attention to schedule management, finance management, unmet user requirements, and quality management. Each of these areas appears as risk if not managed in an adequate manner (Kester, 2013). Generally, risk is defined as a potential future loss or undesirable outcome that may arise from some present action. However, software project risk factors are defined as a source that can pose a serious threat to the successful completion of software development project (March and Shapira, 1987). Failure to understand, identify, and manage risk is often regarded as a major cause of software engineering project failure (Wallace et al., 2004a; 2004b). Therefore, a proactive systematic decision making process in light of risk management is indeed required to manage underlying risks within the software project. Thus, risk management is the process that starts with identifying, analyzing and managing threats to success and plan for necessary course of actions to reduce the chance of project failure. Researchers have often emphasized on categorization and prioritization of different sources and types of risks in order to minimize undesirable losses. Extensive literature review on project management suggests that there is paucity of simple and systematic tools to identify and classify risk factors concerning with software project issues. It is to be noted that risk factors not only affect an individual project but also influence other projects because they are interrelated. Therefore, it is important to understand the nature of risk factors and their interrelationship so that those factors which support other factors ('driving sources') and those which are more influenced by others ('dependent sources') are to be examined (Raj et al., 2008). To this end, current research explores various risk sources in the software project management and develops a structural decision model for establishing the interrelationship among different risk sources through interpretive structural modeling (ISM) methodology. Moreover, the risks are classified depending upon their driving and driven power with the help of indirect relationship by MICMAC analysis.

The main objectives of this research are as follows:

(a) To identify and analyze the interdependencies of different risk factors and their effect in successful execution of software engineering projects.
(b) To establish relationships among the identified risk factors through subjective judgment of experts in a structured manner.
(c) To propose an effective as well as systematic procedure to analyze and to classify the risk factors based on their driving and dependence power which can help managers in project risk assessment, treatment and control.
(d) To develop a structured model which can represent graphically the interdependencies among the risk factors through casual links to make it effective to communicate among the managers for the formulation of project risk management strategy.

2.3 Research Methodology

In order to develop an interrelation among various risk factors in software project development, an ISM approach has been employed. The relevant data for ISM model is collected through a cross sectional questionnaire survey.

2.3.1 Interpretive Structural Modelling (ISM)

ISM is an interpretive method which is often used in the case of complex situations arising in the system. This method facilitates researchers to understand the complex relationship between many elements associated in the system by developing a comprehensive structured systematic model. The advantage of ISM method lies in converting the unclear, poorly defined mental models into a well-defined hierarchical model for better understanding of complex issues (Warfield, 1994). Moreover, ISM is a well-established methodology for constructing and analyzing the fundamentals of interrelationships between the elements in complex systems. This method helps to impose order and direction on the complexity of relationship among the elements of a system so that influence can be analyzed between the elements (Mandal and Deshmukh, 1994; Sharma et al., 1995; Singh et al., 2003). ISM methodology has three important characteristics. Firstly, it is interpretive as judgment of the experts decides whether and how the elements are related. Secondly, it is structural as a complete structure is extracted from the set of elements on the basis of their relationship. Thirdly, it is a modeling technique as a complete structure is represented by diagraph model depicting specific relationships (Raj et al., 2008). When these aforementioned characters inherently exist, it is entitled as "Interpretive Structural Modelling". More precisely, ISM is an interpretive learning process that supports the decision-makers to structure their collective knowledge and to enhance the ability to understand the complexity of interrelationships between elements through a hierarchical systematic structured model. Many studies in the past have applied ISM approach in various fields and successfully analyzed how interrelationship among the element affects to the performance of the overall system (Qureshi et al., 2008; Yang et al., 2008; Khurana et al., 2010; Pfohl et al., 2011; Aloini et al., 2012; Debata et al., 2012).

The procedural steps involved in ISM methodology are as follows (Fig. 2.1):

(1) Identification of the elements relevant to the issue or problem.

(2) Establishing contextual relations among the identified elements. This represents the possible statement of relationship whether the relations are comparative, influence and

natural or temporary type. In the present study, an influence type contextual relationship has been chosen. This means one risk influence to another risk element.

(3) Developing a structural self-interaction matrix (SSIM) on the basis of pairwise comparison of the elements.
(4) Construction of reachability matrix from the SSIM and checking for transitivity property. Transitivity of a reachability matrix is the basic assumption of relations that if an element A is related to B, and B is related to C, then it should be considered as A is related to C (Ravi and Shankar, 2005). Transitivity of elements in a matrix leads to construct the final reachability matrix. Reachability matrix is a binary matrix in which the entries V, A, O and X of the SSIM are converted into 1 and 0.
(5) In this step, the obtained reachability matrix is partitioned into different levels.
(6) Drawing a directed graph by removing the transitivity links and also on the basis of reachability matrix.
(7) Conversion of diagraph into ISM model by replacing element nodes with statements.
(8) In last, check the conceptual inconsistency of developed ISM model.

The application of aforesaid steps in applying ISM methodology for analysing software engineering project risks have been explained in more detail in the following subsections.

2.3.2 Identification of Risk Factors

In software engineering projects, identification of different risks factors which influence to undesirable project outcome is a critical task. The field experience and insightful perception is indeed required to mitigate the areas of concern. Past studies have been devoted to identify the sources from where risk arises in software engineering projects. On the basis of comprehensive literature survey and opinion of experts, a total of twenty three important risk factors have been identified in the present work for the analysis of their inter-relationship affecting to the success of software engineering projects directly or indirectly. A questionnaire based survey has been conducted to test the validity of each of the identified risk factor affecting to the performance of software engineering projects. The identified risk factors and their sources have been presented in Table 2.1.

2.3.3 Survey Administration

The aim of the questionnaire survey is to collect the relevant data from the experts or industry personnel for establishing a relationship matrix as a first step towards developing an ISM based model. A questionnaire containing twenty three risk factors of software engineering projects has been administered to the respondents with an instruction to compare each and every pair of criteria as depicted in Appendix A. Each respondent is requested to compare the column statement to the row statement for each cell and to select an appropriate value from the symbol set (V, A, X, or O) according to his/her perception towards direct relationship between two risk factors at a time. The relational descriptions of symbols have been provided in the questionnaire in which V represents relation when the factor i influences or reaches the factor j, but not in the opposite direction; A for the relation when factor j influences or reaches the factor i but reverse is not possible; X for the relation both i and j factors are interrelated and O represents the case of relation when both i and j factors are unrelated to each other. Initially the survey has used convenient sampling to select the respondents through Tata Consultancy Services (TCS) lab mailing list containing one hundred seventy five members who have been the experts in software project management discipline having more than ten years' experience in software project practice. The detailed questionnaire has been mailed to the identified experts with a request to explore best of their experience and expertise in assessing various risk quantifying factors in relation to the software engineering exercise. Experts have been personally requested to avoid biasness in responding various issues related to the software project risk scenario. No face to face interviews have been conducted. Respondents have been provided a couple month of time duration to understand, to analyze and to recapitulate their experience in addressing interactions among the risk factors as depicted in the detailed questionnaire. Thereafter, response data have been received and those have been critically analyzed. The decision judgment of the aforesaid expert group has been considered fully reliable and ultimate which could be utilized on investigating interrelationship among various risk influencing factors in relation to software project practice. Out of one hundred seventy five, only fifty five respondents have participated in the survey with a response rate of thirty two percentages approximately. Finally, forty eight correct and complete responses have been used for further analysis. The remaining responses have been rejected due to incompleteness and irrationality.

2.3.4 Formation of Structural Self-Interaction Matrix (SSIM)

This is the most important and demanding phase of ISM methodology where the contextual relationship among the risk factors based on experts opinion is incorporated. Keeping this in mind, questionnaire has been designed in such a way that the existence of a relation between any two risk factors (i and j) and associated direction of the relation execution is questioned. Thereafter, the participants decide upon pairwise relationship between two risk factors. Based on expert's feedback on twenty three identified software project risks, the SSIM has been constructed and presented in Table 2.2. The entries in the SSIM matrix was based on the maximum responses obtained for the pair of risk factors.

2.3.5 Construction of Reachability Matrix

The SSIM has been transformed into reachability matrix by two sub-steps. First, SSIM has been converted into initial reachability matrix by substituting the entry of each cell (V, A, X and O) into binary digits (1 or 0) as per the following rules:

- If the (i, j) entry in the SSIM is V, then the (i, j) entry in the initial 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 initial reachability matrix becomes 0 and the (j, i) entry becomes 1.
- If the (i, j) entry in the SSIM is X, then both the (i, j) and (j, i) entries of the initial reachability matrix becomes 1.
- If the (i, j) entry in the SSIM is O, then both the (i, j) and (j, i) entries of the initial reachability matrix becomes 0.

Based on the following rules, the initial reachability matrix has been prepared as shown in Table 2.3. In second sub-step, initial reachability matrix has been transformed into final reachability matrix by checking the transitivity property. After integrating the transitivity concept as mentioned in fourth step of ISM methodology, the final reachability matrix has been constructed and furnished in Table 2.4. Final reachability matrix also represents the driving power and the dependence of each risk factor. Driving power of each risk is the summation of total number of risk interactions in the row (including it-self) which it affects. However, dependence of each risk is the summation of total number of risk interactions in the column (including it-self) by which it is affected. Based on these driving power and dependence, software project risks have later been classified in Section 2.4.

2.3.6 Level Partitioning

Level partitioning helps for constructing the diagraph model based on the final reachability matrix (Warfield, 1977). Final reachability matrix provides the information about the reachability and antecedent set for each risk factor. The reachability set of the element is the set of elements that contains the element itself and other elements to which it may reach, whereas the antecedent set contains the element itself and the other elements which may reach to it (Mandal and Deshmukh, 1994). More precisely, reachability set of the risk is the set of elements of a final reachability matrix which contain 1 in row of that particular risk. Conversely, antecedent set of the risk is the set of elements which contain 1 in column of that particular risk (Pfohl et al., 2011). Based on the reachability set and antecedent set, the intersection sets have been derived for all elements. Intersection sets are the common elements of both reachability set and the antecedent set. The case where the elements of reachability and intersection sets are same, that is the indicator of top-level element. For example, in the present case, five risk factors such as (i) lack of project standard, (ii) software quality risks, (iii) software cost risks, (iv) software requirement risks and (v) software scheduling risks have been identified as top-level elements as shown in Table 2.5 (Iteration 1). The significance of top-level elements is that they will not influence any other element above their own level in the hierarchy. Once the top-level element is recognized, then it is discarded from further hierarchical consideration (i.e., separated out that elements from all the different sets). Similarly, the next level of elements has been partitioned by the same process. The stepwise level partitions of all twenty three risk factors have been completed in nine iterations as shown in Tables (2.5-2.7). The summary of all partition levels has been represented in Table 2.8.

2.3.7 Development of ISM Model

After level partitioning, lower triangular form of reachability matrix has been prepared by arranging the elements according to their levels. After removing the indirect links, a diagraph has been drawn by means of nodes or vertices and lines of edges. The relationship between elements i and j has been shown by an arrow which connects from i to j. This constructed diagraph has been converted into an ISM based model by mentioning the descriptions of elements within it (Fig. 2.2). The elements of ISM model has been connected in a complete hierarchical form with no feedbacks or no cycles.

2.4 MICMAC Analysis

The abbreviation of MICMAC is the '*Matrice d'Impacts croises-multipication appliqué an classment*' means cross-impact matrix multiplication applied to classification (Sharma et al., 1995). MICMAC analysis is a part of structural analysis which aims to identify the most important variables of a system from matrix that establishes the relations among them (Villacorta et al., 2012). In this study, the identification and classification of risk is essentially required for the implementation of risk management strategy in software engineering project. MICMAC is an indirect classification method which helps to critically analyze the scope of the risks (Saxena and Sushil, 1990). The objective of MICMAC analysis is to analyze and classify the risk elements based on their driving power and dependence. Based on the concept of MICMAC, all risk factors have been classified into four clusters of risks according to their driving power and dependence value (Fig. 2.3).

Cluster I consists of autonomous risk factors which have weak driving power and weak dependence. There are eight risk factors which come under autonomous cluster viz., inadequate budget, lack of reassessment of management cycle, inadequate knowledge about tools and techniques, complexity of architecture, lack of testing, lack of good estimation in projects, and lack of monitoring. These risk factors are comparatively separated from the system although a few existence of links which may not be strong and do not have much influence on the system.

Cluster II includes the dependent risk factors which have weak driving power and strong dependence. A total number of seven risk factors have been identified in this cluster. Mostly top level risk factors of ISM model come under this category. In the present study, top level factors viz., software cost risks, software quality risks, software scheduling risks, software requirement risks, and lack of project standard have been shown in dependent cluster. Top level factors are most resulting action of risks in software projects. The factors having strong dependence property indicates that it is being strongly influenced by other risk factors and thereby increases in software project risks. Thus, managers should pay special attention to manage these risks.

Cluster III comprises linkage risk factors which have both strong driving and dependence power. The risk factors associates with linkage clusters are unstable, because if any change occurs on these risks that will have an effect on other risks. In this research, there is no risk factors exist in the linkage cluster.

In cluster IV, all independent risk factors are clustered that have strong driving power but weak dependence. Eight risk factors have been identified in this cluster viz., lack of enough skill, lack of employment of manager experience, inadequate design and documentation, lack of report for requirements, lack of analysis for change of requirements, lack of trust between partners, wrong partner/s selection, and heterogeneity of partners. The factor which has very strong driving power in the independent cluster is called as "key factor". Heterogeneity of partners has been observed as a key risk factor which has maximum driving power (twenty-two). It seems strongly influencing to other risk factors (Fig. 2.2). The theoretical basis of evaluating driving and dependence power of each risk factor have previously been described in Section 2.3.5 and shown in Table 2.4.

2.5 Results and Discussions

The results of this study provide an understanding of identified software project risks in different levels of ISM model. The developed hierarchical ISM model comprises twenty three software project risk factors in different levels from top to bottom. Understanding the impact of risk at each level is indeed important as it would help managers to construct and implement successful risk management strategy towards achieving success of the software projects. In this research software cost risks, software quality risks, software scheduling risks, software requirement risks, and lack of project standard have been found placed in top level as shown in ISM model (Fig. 2.2). These are the risks which can produce major impact on software engineering projects because all other risks which are being placed just below the top level, strongly influences to them. Thus, managers should pay special attention to control the aforementioned risks for reducing the chance of project failure. Moreover, lower level risks such as; heterogeneity of partners, lack of trust between partners, wrong partner/s selection, lack of analysis for change of requirements, inadequate design and documentation, lack of report for requirements, lack of enough skill, lack of monitoring, human errors, and others are strongly influence to the middle level factors like lack of good estimation in projects, unrealistic schedule, lack of testing, and others (Fig. 2.2). Also, aforesaid middle level risks are again seemed to influence to the top level in the ISM diagraph. Top level factors are more harmful than the others that can pose serious impact to the projects. However, lower level factors are mainly responsible for increasing the degree of risk extent as they are influencing strongly to the top level factors. In this regard, it is observed that interdependency among various risk factors plays an important role for the assessment of risk impact on the software development projects. Moreover, this can also be an important insight into the extent body of knowledge to the managers towards implementing appropriate risk management strategy for the reduction of overall risk extent.

MICMAC analysis has been carried out for the twenty three risk factors those have further been classified into four clusters (autonomous, dependent, linkage, independent) based on their driving power and dependence. The risk factors viz. software cost risks, software quality risks, software scheduling risks, software requirement risks, and lack of project standard are dependent factors. The impact of these risks depends on other remaining risks of software projects affecting seriously to the system. Similarly, the risk factors like lack of enough skill, lack of employment of managerial experience, inadequate design and documentation, lack of report for requirements, lack of analysis for change of requirements, lack of trust between partners, wrong partner/s selection and heterogeneity of partners have been found independent having strong driving power. These are the risks which play important role to influence others and finally intensifies the strength of impact on software engineering projects. As a result, this cluster analysis may help the project managers to understand and to assess the intensity of risks as well as provides fruitful insights towards managing these risks by implementing a proactive risk management strategy in future. The results of the present study support a socio-technical perspective providing an ISM approach to conceptualize the category of software project risks and to understand interrelationships between twenty three risk factors that have been identified.

Apart from discussing outcome and implications of the present research, it is important to address the limitations of this study. The source of risk is evidently enormous but not limited. In this work, a total of twenty three software risk factors that had been selected in relation to their possible effect towards software project area but there may be some other factors that may also affect the success of software projects need to be taken under consideration.

2.6 Concluding Remarks

The aforesaid work aims to provide empirical evidence highlighting interrelationships among various risk factors affecting successful execution of the software engineering projects. Based on extensive literature review and expert opinion, a total of twenty three risk factors have been identified which impose negative impact on schedule time, quality, cost, requirement or total failure of the software projects. In this research, an ISM approach has been applied to understand the significant relationships and interdependencies among twenty three identified risk factors associated with software projects. In this context, ISM provides a systematic hierarchical structured model helpful in managerial context to understand the interrelationships among different risk factors. Moreover, the direct and indirect relationships between risk factors can also be identified from the ISM based model. The process has been found systematic as well as efficient, capable of producing a structured model which graphically represents the original problem that can be communicated more effectively to the decision-makers. Another contribution of this study is the MICMAC analysis that provides a concept of identification and classification of software project risk factors in four different clusters based on their driving and dependence power. The result of this analysis provides an understanding of risk factors as a function of driving power and dependence. The above research findings provide important guidelines to the software project managers to implement a proactive risk management strategy for the success of software projects.

Table 2.1: Software project risk factors and their references/sources

	Risk factors	Description	Descriptive references
1	Lack of good estimation in projects	Lack of good estimation in projects acts as risk in software engineering projects, which refers to the lack of experience of a personnel's towards forecasting the project duration, budget, software cost and expenditure of man and machinery. Good estimation of projects can reduce the unexpected cost of software and also helps to make a project success.	Hoodat and Rashidi, 2009; Wallace et al., 2004a
2	Unrealistic schedule	The risk and uncertainty due to unrealistic schedule can impact the software project performance. Poor planning and control often leads to influence the unrealistic schedules. As a result, excessive schedule pressure or unrealistic schedules that can increase the project risk.	Hoodat and Rashidi, 2009; Keider., 1984; Wallace et al., 2004a
3	Human errors	Risk that a propensity for certain common mistakes by people; the making of an error as a natural result of being human (Wikipedia, 2013). Human errors are another major risk factor which may occur due to large size of architecture, complexity of architecture and lack of knowledge. Moreover, failure of tools and hardware's may also invite the human error. As a result, human error can impact the project performance as well as increase the uncertainty of a projects outcome.	Hoodat and Rashidi, 2009; Keider., 1984
4	Lack of testing	Lack of testing during the system development project is one of the risk factor that cited in the literature. In each and every steps of development process, testing is needed in order to achieve better quality of a software product. Lack of testing can impact the quality, reliability and cost of a product in software engineering projects.	Hoodat and Rashidi, 2009; Wallace et al., 2004a
5	Lack of monitoring	The risk or uncertainty arises due to lack of monitoring during the management of software projects, may causes the failure of the projects. Lack of monitoring can increase the possibility of project delay, poor quality and cost of the software product. Lack of experience and schedule pressure is the main drivers to invite lack of monitoring of software projects in the view of managers concern.	Hoodat and Rashidi, 2009; Wallace et al., 2004a
6	Complexity of architecture	Architecture complexity is intend to increase as components and infrastructure built using new technology with large number of links to	Hoodat and Rashidi., 2009; Schmidt et al., 2001

		existing systems and external entities. The number of adaptation of units can also be an inherent cause to increase the project complexity. Complexity becomes in terms of cost, time estimates, and specification of requirements, hardware needs, business process and engineering activities, and also the involvement of multiple organizational units. For example, if a new system works in a multiple sites, it may be difficult to define all requirements precisely, because different sites serve different customers and also have different policy or procedures.	
7	Lack of reassessment of management cycle	Risk will increase tremendously if management cycle not functioning effectively. Reassessment of management cycle from top to bottom level is essential for the success of software projects. For example, if wrong decision is played by the top management regarding a particular operation that will affect to the bottom level management and ultimately affect to the entire project in terms of serious loss. Thus, the role of management cycle is critical that responsible for all activities at every level of organization.	Hoodat and Rashidi, 2009; Wallace et al., 2004a; Kanter, 1997
8	Lack of employment of manager experience	To overcome the organizational difficulties and resistance to change, experienced managerial persons are highly required. They can utilize relevant experience and knowledge as well as power to manage the resources. As a result an experience manager can make and implement better decision to control the uncertainty situations with in the software projects. So lack of employment of manager experience cited as a risk in the literature.	Hoodat and Rashidi, 2009; Wallace et al., 2004a
9	Lack of enough skill	The nature of software engineering projects are basically complex because of the combinations of many hardware and software, as well as a wide range of organizational, human and political issues. Therefore, there is a need of significant project management skills and also required operators with better skill to adopt the knowledge of advance techniques for software projects. Noticeably, high skilled operators and management personnel's have major contributions towards making the project success. Thus lack of enough skill is considered as a risk that can impact on the project performance.	Hoodat and Rashidi, 2009; Wallace et al., 2004a
10	Inadequate design and documentation	The elements of design and documentation include central planning or decentralisation, specific control and specialisation, and workforce	Hoodat and Rashidi, 2009; Wallace et al., 2004a;

		management. Dynamic and inadequate documentation invites risks as it is impossible to coordinate similar activities. Because, responsibilities are not adequately shared out with in the dynamic documentation system. For example, the information like who is in overall charge, how far any control extent and many more. Thus, inadequate design and documentation is another major risk of software projects often cited in the literature.	Zhang and Dilts, 2004
11	Inadequate knowledge about tools, techniques and programming language	Inadequate knowledge about tools, techniques and programming language is another risk that can make failure of the software project. To overcome this problem, well train operators or personnel's will be required in the deployment stage. Non-train employees do not know adequately how to use the tools, techniques and programming language during the system development.	Hoodat and Rashidi, 2009; Wallace et al., 2004a
12	Lack of project standard	Every project should come under some standard and a guideline which was regulated and established by National Standard Commission; for example, CARE standard act in UK. The project beyond or lack of that standard guideline can impact on cost, quality and performance of a software product. Thus lack of project standard is considered as one of the risk factor in software engineering projects.	Hoodat and Rashidi, 2009; Wallace et al., 2004a
13	Inadequate budget	Poorly formulated budget can affect to the quality of a software development project. So this is also taken as risk in software projects.	Hoodat and Rashidi, 2009; Wallace et al., 2004a
14	Inadequate of requirements	There are several kinds of requirements needed in software projects such as; functional, interface, data, security and quality etc. But many projects do not manage their requirements effectively. Managers store their requirement in paper documents rather store the requirements in a database or the repository of a requirements tool (http://www.jot.fm/issues/issue_2007_01/column2/). Thus, scattered requirements are difficult to find, sort, query and maintain itself which can impact to the performance of software projects.	Hoodat and Rashidi, 2009; Wallace et al., 2004a
15	Lack of report for requirements	Reports with lack of necessary detail of requirements regarding the usable methods and techniques will cause the requirement engineer to waste time and delay the project. A Poor documented report can produce poor software products that must be in poor quality	Hoodat and Rashidi, 2009; Wallace et al., 2004a

		outcome. So lack of report for requirements is also considered as a risk factor in software project often cited in the literature.	
16	Lack of analysis for change of requirements	Lack of analysis of frequently changed requirements in software engineering projects is considered as a risk that can impact on the cost, quality and performance of the software project outcomes.	Hoodat and Rashidi, 2009; Wallace et al., 2004a
17	Lack of trust between partners	Lack of trust is one of the main risk factor in software engineering projects. The degree of trust represents the honesty, generosity between the partners and also the overall competence to others. If there is no trust between partners then the problems, such as unwilling to pass on sensitive information, unable to agree towards the decision of finance management may come to arise. Due to this, lack of trust invites the risk, and affects to the scenario of cooperation or collaboration which may lead to damage the stability of an organization.	Alawamleh and Popplewell, 2011; Zaheer et al., 1998; Sinha et al., 2004
18	Heterogeneity of partners	Heterogeneity of partners of software engineering projects or information technology systems adds another riskiness factor that often cited in the literature. Heterogeneity refers the differences that subsist between the partners in terms of unsuited hardware, operating systems, difference in languages, and sharing the information. Such type of risks usually exists in IT infrastructure, working methods and business practices when the nature between possible partners is heterogeneous.	Alawamleh and Popplewell, 2011; Sari et al., 2007; Singh and Kant, 2008
19	Wrong partner/s selection	Insufficient information about the partners and conflict between partners are the real cause of wrong partner/s selection. Organizational conflict problems can reveal through the conflict relationships, task conflict and conflict over process. The consequences of these factors can badly impact on the software development projects. Thus, wrong partner/s selection is considered as a risk in software projects.	Alawamleh and Popplewell, 2011; Sari et al., 2007; Wilmot and Hocker, 2001
20	Software cost risks	Software cost risks is one of the most important risk factors in software projects which mostly depends on the cost of a projects. Several sub factors like, lack of good estimation of projects, unrealistic schedule, human errors, and the changes in terms of management, technology, personnel, and environment may also responsible for increasing software cost risks. The consequences of	Expert opinion

		aforementioned risks will damage the software projects and increase the cost of software.	
21	Software quality risks	Risks that can affect to the quality of software are called as software quality risks. Loss of technical equipment's, lack of stability between personnel, lack of skill towards programming knowledge and training, undesired event in costs and requirements, weakness of management and lack of project standard are the main causes which may arise in the view of risks, and affects to the quality of a software engineering projects.	Expert opinion
22	Software scheduling risks	Scheduling risk is the main cause to delay the software projects and can effect in financial damage during project life cycle. Human errors, improper planning, lack of monitoring, inadequate business pressure, shortages and changes in software projects are the main influencing factors responsible for increase the scheduling risks with in software engineering projects.	Hoodat and Rashidi, 2009; Thayer et al., 1980
23	Software requirement risks	Risk or uncertainty surrounding in the system requirement is one of the major concerns that can be affecting to project performance. Usually, changing requirements are not the only expected requirement-related problem in software development projects. Moreover, incorrect, unclear, ambiguous and unusable requirements may also enhance the requirement risks associated in software engineering projects.	Hoodat and Rashidi, 2009; Wallace et al., 2004a

Table 2.2: Structural self-interaction matrix (SSIM)

	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2
1	O	V	V	V	O	O	O	O	O	O	O	O	O	O	A	A	O	O	O	O	O	O
2	O	V	V	V	A	A	O	O	O	O	O	O	O	O	O	A	O	O	A	O	A	
3	O	V	V	V	A	A	A	O	O	O	O	O	O	O	A	A	O	O	A	O		
4	O	O	V	V	O	O	O	O	O	O	O	O	X	O	A	A	O	O	O			
5	O	O	O	V	O	A	A	O	O	O	O	O	O	O	A	A	A	A				
6	O	O	O	V	O	A	O	O	O	O	O	O	O	O	O	O	O					
7	O	O	O	V	A	A	A	O	O	O	O	O	O	O	O	O						
8	O	V	O	O	O	O	O	A	A	O	O	O	O	O	O							
9	O	V	V	O	A	O	O	O	O	O	O	O	O	A								
10	O	O	V	O	A	A	A	O	O	O	O	O	O									
11	O	V	V	O	A	A	A	O	O	O	O	O										
12	O	O	V	A	O	O	O	O	O	O	O											
13	O	O	V	O	O	O	O	O	O	O												
14	V	O	O	O	O	O	O	A	A													
15	V	O	O	O	O	A	A	A														
16	V	O	V	O	O	A	A															
17	V	O	V	O	V	A																
18	V	V	V	V	V																	
19	V	V	V	V																		
20	A	A	X																			
21	X	X																				
22	O																					
23																						

Table 2.3: Initial reachability matrix

Elements	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0
2	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0
3	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0
4	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	1	0	0
5	0	1	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
6	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
7	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
8	1	1	1	1	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
9	1	0	1	1	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	1	0
10	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	1	0	0
11	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1	1	0
12	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0
13	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	0	0
14	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1
15	0	0	0	0	0	0	0	1	0	0	0	0	0	1	1	0	0	0	0	0	0	0	1
16	0	0	0	0	0	0	0	1	0	0	0	0	0	1	1	1	0	0	0	0	1	0	1
17	0	0	1	0	1	0	1	0	0	1	1	0	0	0	1	1	1	0	1	0	1	0	1
18	0	1	1	0	1	1	1	0	0	1	1	0	0	0	1	1	1	1	1	1	1	1	1
19	0	1	1	0	0	0	1	0	1	1	1	0	0	0	0	0	0	0	1	1	1	1	1
20	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	1	0	0
21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1
22	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0
23	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	1

Table 2.4: Final reachability matrix with driving and dependence power

Elements	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	Driving power
1	1	0	0	0	0	0	0	0	0	0	0	1*	0	0	0	0	0	0	0	1	1	1	1*	6
2	0	1	0	0	0	0	0	0	0	0	0	1*	0	0	0	0	0	0	0	1	1	1	1*	6
3	0	1	1	0	0	0	0	0	0	0	0	1*	0	0	0	0	0	0	0	1	1	1	1*	7
4	0	0	0	1	0	0	0	0	0	0	1	1*	0	0	0	0	0	0	0	1	1	1*	1*	7
5	0	1	1	0	1	0	0	0	0	0	0	1*	0	0	0	0	0	0	0	1	1*	1*	1*	8
6	0	1*	1*	0	1	1	0	0	0	0	0	1*	0	0	0	0	0	0	0	1	1*	1*	1*	9
7	0	1*	1*	0	1	0	1	0	0	0	0	1*	0	0	0	0	0	0	0	1	1*	1*	1*	9
8	1	1	1	1	1	0	0	1	0	0	1*	1*	0	0	0	0	0	0	0	1*	1*	1	1*	12
9	1	1*	1	1	1	0	0	0	1	0	1*	1*	0	0	0	0	0	0	0	1*	1	1	1*	12
10	1*	1*	1*	1*	0	0	0	0	1	1	1*	1*	0	0	0	0	0	0	0	1*	1	1*	1*	13
11	0	0	0	1	0	0	0	0	0	0	1	1*	0	0	0	0	0	0	0	1*	1	1	1*	7
12	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1*	1	1*	1*	5
13	0	0	0	0	0	0	0	0	0	0	0	1*	1	0	0	0	0	0	0	1*	1	1*	1*	6
14	0	0	0	0	0	0	0	0	0	0	0	1*	0	1	0	0	0	0	0	1*	1*	1*	1	6
15	1*	1*	1*	1*	1*	0	0	1	0	0	1*	1*	0	1	1	0	0	0	0	1*	1*	1*	1	14
16	1*	1*	1*	1*	1*	0	0	1	0	0	1*	1*	0	1	1	1	0	0	0	1*	1	1*	1	15
17	1*	1*	1	1*	1	0	1	1*	1*	1	1	1*	0	1*	1	1	1	0	1	1*	1	1*	1	20
18	1*	1	1	1*	1	1	1	1*	1*	1	1	1*	0	1*	1	1	1	1	1	1	1	1	1	22
19	1*	1	1	1*	1*	0	1	0	1	1	1	1*	0	0	0	0	0	0	1	1	1	1	1	15
20	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	1	1*	1*	5
21	0	0	0	0	0	0	0	0	0	0	0	1*	0	0	0	0	0	0	0	1	1	1	1	5
22	0	0	0	0	0	0	0	0	0	0	0	1*	0	0	0	0	0	0	0	1	1	1	1*	5
23	0	0	0	0	0	0	0	0	0	0	0	1*	0	0	0	0	0	0	0	1	1	1*	1	5
Dependence	9	13	12	10	11	2	4	5	5	4	10	23	1	5	4	3	2	1	3	23	23	23	23	219/219

Note: 1* entries are indicated as transitivity.

Table 2.5: Iteration 1

Element	Reachability set	Antecedent set	Interaction set	Level
1	1,12,20,21,22,23	1,8,9,10,15,16,17,18,19	1	
2	2,12,20,21,22,23	2,3,5,6,7,8,9,10,15,16,17,18,19	2	
3	2,3,12,20,21,22,23	3,5,6,7,8,9,10,15,16,17,18,19	3	
4	4,11,12,20,21,22,23	4,8,9,10,11,15,16,17,18,19	4,11	
5	2,3,5,12,20,21,22,23	5,6,7,8,9,10,15,16,17,18,19	5	
6	2,3,5,6,12,20,21,22,23	6,18	6	
7	2,3,5,7,12,20,21,22,23	7,17,18,19	7	
8	1,2,3,4,5,8,11,12,20,21,22,23	8,15,16,17,18	8	
9	1,2,3,4,5,9,11,12,20,21,22,23	9,10,17,18,19	9	
10	1,2,3,4, 9,10,11,12,20,21,22,23	10,17,18,19	10	
11	4,11,12,20,21,22,23	4,8,9,10,11,15,16,17,18,19	4,11	
12	12,20,21,22,23	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,23	12,20,21,22,23	I
13	12,13,20,21,22,23	13	13	
14	12,14,20,21,22,23	14,15,16,17,18	14	
15	1,2,3,4,5,8,11,12,14,15,20,21,22,23	15,16,17,18	15	
16	1,2,3,4,5,8,11,12,14,15,16,20,21,22,23	16,17,18	16	
17	1,2,3,4,5,7,8,9,10,11,12,14,15,16,17,19,20,21,22,23	17,18	17	
18	1,2,3,4,5,6,7,8,9,10,11,12,14,15,16,17,18,19,20,21,22,23	18	18	
19	1,2,3,4,5,7,9,10,11,12,19,20,21,22,23	17,18,19	19	
20	12,20,21,22,23	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,23	12,20,21,22,23	I
21	12,20,21,22,23	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,23	12,20,21,22,23	I
22	12,20,21,22,23	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,23	12,20,21,22,23	I
23	12,20,21,22,23	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,23	12,20,21,22,23	I

Table 2.6: Iteration 2

Element	Reachability set	Antecedent set	Interaction set	Level
1	1	1,8,9,10,15,16,17,18,19	1	II
2	2	2,3,5,6,7,8,9,10,15,16,17,18,19	2	II
3	2,3	3,5,6,7,8,9,10,15,16,17,18,19	3	
4	4,11	4,8,9,10,11,15,16,17,18,19	4,11	II
5	2,3,5	5,6,7,8,9,10,15,16,17,18,19	5	
6	2,3,5,6	6,18	6	
7	2,3,5,7	7,17,18,19	7	
8	1,2,3,4,5,8,11	8,15,16,17,18	8	
9	1,2,3,4,5,9,11	9,10,17,18,19	9	
10	1,2,3,4, 9,10,11	10,17,18,19	10	
11	4,11	4,8,9,10,11,15,16,17,18,19	4,11	II
13	13	13	13	II
14	14	14,15,16,17,18	14	II
15	1,2,3,4,5,8,11,14,15	15,16,17,18	15	
16	1,2,3,4,5,8,11,14,15,16	16,17,18	16	
17	1,2,3,4,5,7,8,9,10,11,14,15,16,17,19	17,18	17	
18	1,2,3,4,5,6,7,8,9,10,11,14,15,16,17,18,19	18	18	
19	1,2,3,4,5,7,9,10,11,19	17,18,19	19	

Table 2.7: Iteration 9

Element	Reachability set	Antecedent set	Interaction set	Level
18	18	18	18	IX

Table 2.8: Summary of level partitioning

Element	Reachability set	Antecedent set	Interaction set	Level
1	1,12,20,21,22,23	1,8,9,10,15,16,17,18,19	1	II
2	2,12,20,21,22,23	2,3,5,6,7,8,9,10,15,16,17,18,19	2	II
3	2,3,12,20,21,22,23	3,5,6,7,8,9,10,15,16,17,18,19	3	III
4	4,11,12,20,21,22,23	4,8,9,10,11,15,16,17,18,19	4,11	II
5	2,3,5,12,20,21,22,23	5,6,7,8,9,10,15,16,17,18,19	5	IV
6	2,3,5,6,12,20,21,22,23	6,18	6	V
7	2,3,5,7,12,20,21,22,23	7,17,18,19	7	V
8	1,2,3,4,5,8,11,12,20,21,22,23	8,15,16,17,18	8	V
9	1,2,3,4,5,9,11,12,20,21,22,23	9,10,17,18,19	9	V
10	1,2,3,4, 9,10,11,12,20,21,22,23	10,17,18,19	10	VI
11	4,11,12,20,21,22,23	4,8,9,10,11,15,16,17,18,19	4,11	II
12	12,20,21,22,23	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,23	12,20,21,22,23	I
13	12,13,20,21,22,23	13	13	II
14	12,14,20,21,22,23	14,15,16,17,18	14	II
15	1,2,3,4,5,8,11,12,14,15,20,21,22,23	15,16,17,18	15	VI
16	1,2,3,4,5,8,11,12,14,15,16,20,21,22,23	16,17,18	16	VII
17	1,2,3,4,5,7,8,9,10,11,12,14,15,16,17,19,20,21,22,23	17,18	17	VIII
18	1,2,3,4,5,6,7,8,9,10,11,12,14,15,16,17,18,19,20,21,22,23	18	18	IX
19	1,2,3,4,5,7,9,10,11,12,19,20,21,22,23	17,18,19	19	VII
20	12,20,21,22,23	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,23	12,20,21,22,23	I
21	12,20,21,22,23	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,23	12,20,21,22,23	I
22	12,20,21,22,23	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,23	12,20,21,22,23	I
23	12,20,21,22,23	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,23	12,20,21,22,23	I

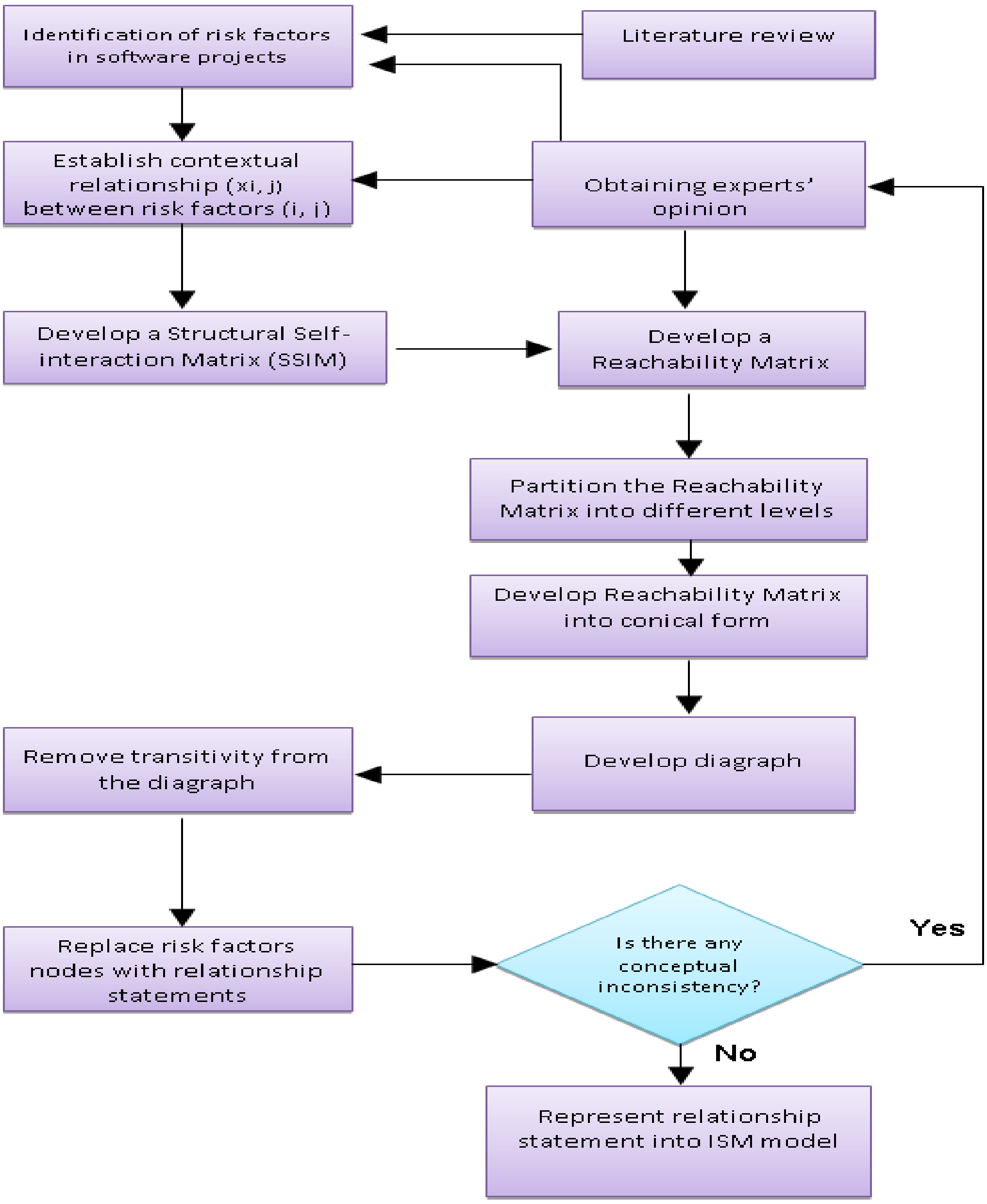

Fig. 2.1: Flow diagram for ISM methodology

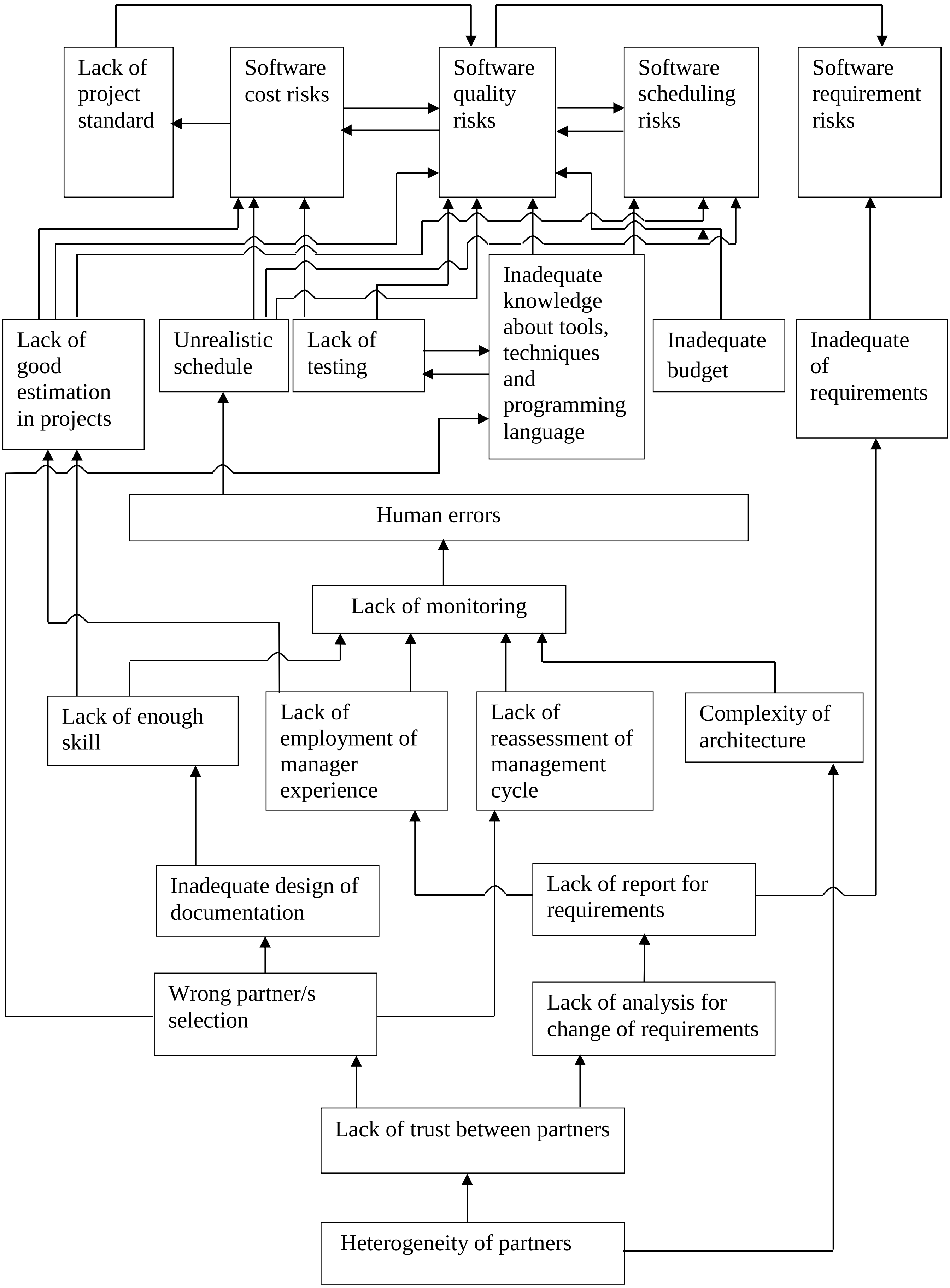

Fig. 2.2: ISM based model

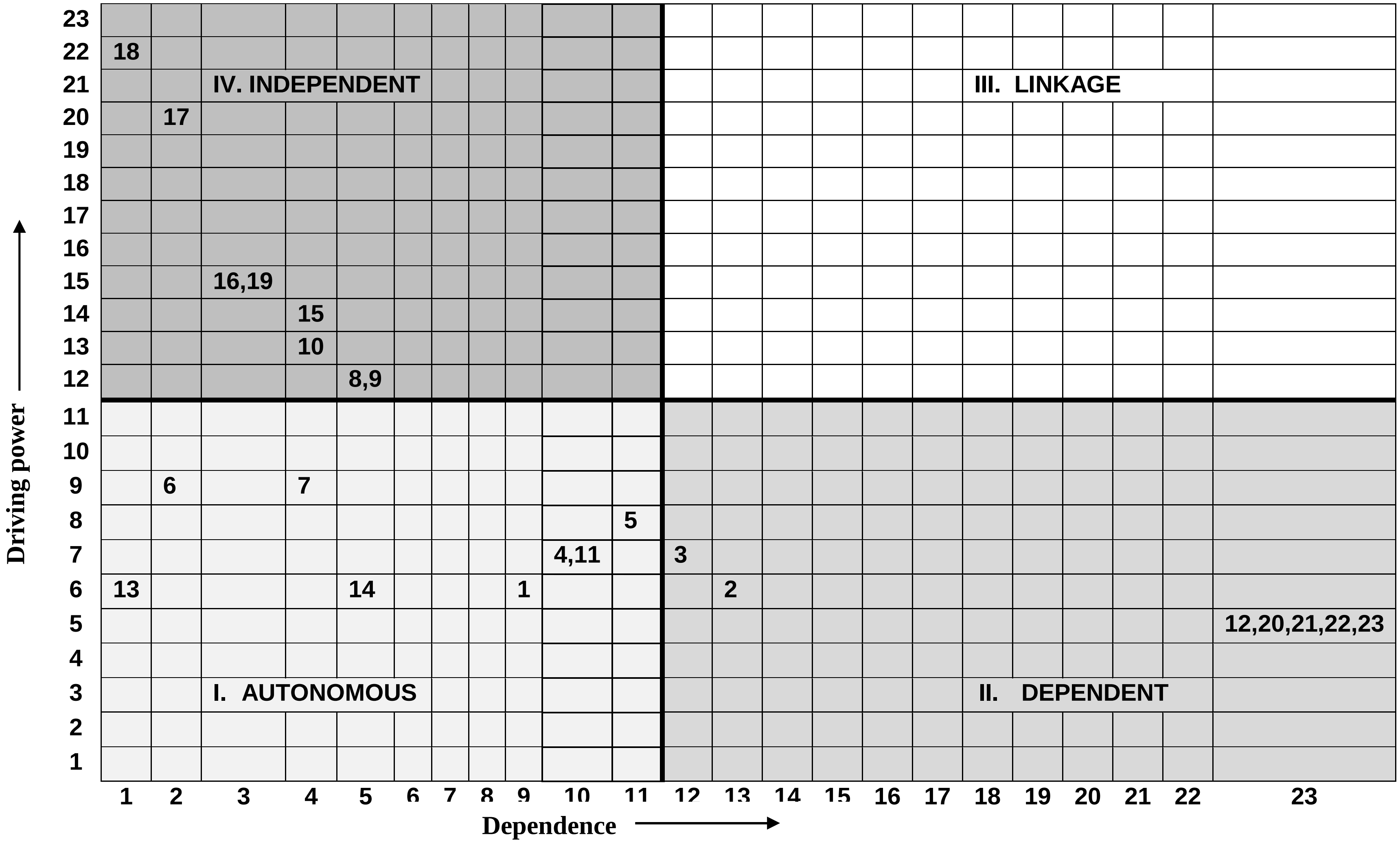

Fig. 2.3: Driving power-dependence diagram

CHAPTER 3

RISK ASSESSMENT IN IT OUTSOURCING: A CASE STUDY

3.1 Coverage

Outsourcing of Information Technology (IT) is a common practice in global business today. IT Outsourcing (ITO) refers to the contracting out of IT services (or functions) with the objective of achieving strategic advantages as well as cost benefits. Recently, many IT industries are facing daunting challenges in terms of healthy alliances on their ITO strategy due to existence of inherent risks. These risks must be recognized and properly managed towards successful establishment of effective ITO strategy. Therefore, risk assessment appears to be an important contributor to the success of an ITO venture. In this work, a hierarchical ITO risk structure representation has been explored to develop a formal model for qualitative risk assessment. The basic parameters for defining risks have been presented including the metrics for measuring likelihood and impact that aid to achieve consistent assessment. An improved decision making method using fuzzy set theory has been attempted for converting linguistic data into numeric risk ratings. In this study, the concept of 'Incentre of centroids method' for generalized trapezoidal fuzzy numbers has been used to quantify the 'degree of risk' in terms of crisp ratings. Finally, a framework for categorizing different risk factors has been proposed on the basis of distinguished ranges of risk ratings (crisp). Consequently, an action requirement plan has been suggested for providing guidelines for the managers to successfully manage the risk in the context of ITO exercise.

3.2 Problem Statement

In today's IT sector, the tremendous change in technology results in increasing competition towards achieving competitive advantage over lower costs and the ability to deliver improved IT supports. It is really difficult for the organizations to run the business using latest technologies which seem to be very expensive towards fulfilling customers' expectations from economic point of view. To cope up this unpredictable business situation, organizations must look at IT vendors to gain access to the best technology in a cost effective way. Therefore, the decision to outsource IT functions has been proved beneficial towards gaining increasing advantage in the global business today (Abdullah and Verner, 2012). IT outsourcing is the use of a third party to successfully deliver IT enabled business process, application service and infrastructure solutions for a cost effective business outcome. Moreover, IT outsourcing is defined as a decision taken by an organization to contract out or sell some or all the organizations' IT assets, people and/ or activities to a third party vendor, who in turn provides and manages these activities/services as set forth in the contractual agreement and monetary fee (Dhar et al., 2004, Loh and Venkatraman, 1992; Lacity and Hirschheim, 1993). According to the latest outlook by Gartner Inc., worldwide spending for IT outsourcing (ITO) services is on pace to reach $251.7 billion in 2012, a 2.1% increase from 2011 spending of $246.6 billion (Source: http://www.gartner.com/newsroom). The objectives of IT outsourcing are to reduce costs, accelerate time to market, and to take advantage of external expertise, assets and/or intellectual property. Despite the numerous advantages and cost benefits that offer IT outsourcing, many organizations are facing daunting challenges to manage inherent risks associated with it. The possibility of risks that are introduced when IT functions associated with outsourcing activities results in negative consequences to the business outcome. For example, NASSCOM (National Association of Software and Services Companies), a trade association of Indian Information Technology (IT) and Business Process Outsourcing (BPO) industry is too lowered its growth forecast for 2012-2013 towards IT-BPO exports to 11-14% from prior fiscals' target of 16-18%. This is because of current global volatile economic conditions and the European Sovereign Debt crisis. Similarly, this challenging economic scenario also affects in many key European countries resulting in a forecast for Western Europe ITO growth decline of 1.9% in U.S. dollars during 2012 (Source: http://www.gartner.com/newsroom).

Apart from global economic crisis, some of hidden costs and unexpected outcomes can also be viewed as risks in ITO exercise. Therefore, risk assessment appears to be the important contributor to successfully manage the possibility of ITO risks. Generally, risk is defined as a potential future loss or undesirable outcome that may arise from some present action. Risk factors are defined as a source that can pose a serious threat to the outcome. On the contrary, risk assessment is the determination of quantitative/qualitative value of risk related to a concrete situation and a well-recognized threat. Although some of the individual risk factors may be more significant than the others, the outsourcing success usually depends on effective management of all types of risks, response strategies used to assess risks and an organizations ability to overcome them. Therefore, it is indeed necessary to develop a unified risk understanding model containing perceived risks in relation to ITO exercise and factors that affect the manageability of these risks.

Exhaustive literature review reveals that limited studies have been reported so far highlighting important sources of risks and associated risk influencing factors in IT outsourcing. Moreover, it has been found out that limited attempts have been made to establish a comprehensive approach in analyzing various issues like risk assessment, mitigation, and devolvement of best practices in the perspective of IT outsourcing. Kou and Lu (2013) have pointed out that individual knowledge, experience and intuitive judgment provide better assessment of risk than probabilistic approach. Hence, the authors have highlighted the applicability of fuzzy set theory for risk assessment through capturing individuals (decision-makers') intuitive assessment. The aim of this work is to develop a unified hierarchical risk assessment model that can effectively be used to estimate the degree of risk extent using fuzzy knowledge representation theory to support qualitative risk analysis. Furthermore, all perceived risks have been classified into different categories based on their quantifying value of risk ratings and also an action requirement plan has been recommended which could provide a concrete guideline towards effective management of ITO risk.

In this part, IT outsourcing risks have been analyzed through a fuzzy based decision making approach and case studied at TCS Kolkata. The hierarchical structure for risk assessment in IT outsourcing (consisting of risk dimensions and risk influencing factors) have been constructed based on extensive literature review and expert opinion. The model is a generic one that means it can be applied in any IT sector throughout the globe. However, in this work, the implementation feasibility of the proposed risk assessment module has been case examined at an Indian IT sector.

The uniqueness of the hierarchical risk assessment model (consisting of methodological pathways of risk identification, selection of fuzzy linguistic scale, data collection, risk rating, and risk factor categorization) is to determine overall risk extent in ITO exercise followed by categorization of various risk dimensions in fuzzy environment. Apart from exploring probabilistic approach of risk analysis, deterministic approach by exploring historical data; an experienced decision making group have taken part in subjective evaluation of risks. Application of fuzzy set theory has been fruitfully utilized to overcome uncertainties of vague and ambiguous human judgement to quantify overall extent of risks.

3.3 Risk Assessment

In this chapter, risk has been described as a function of two main parameters: (a) the likelihood, which is the possibility of an undesirable occurrence, and (b) the impact, which is the degree of seriousness (Zhi, 1995). Thus, degree of risk can be calculated using a mathematical formulation as follows:

$$R = L \times I \tag{3.1}$$

Here, R is the degree of risk, L is the likelihood of risk occurring, I is the degree of impact of the risk. All may be defined within a range [0, 1] where greater values indicate higher impact. From Eq. (3.1), it has been observed that the degree of risk is close to zero if a risk factor has either less impact or less likelihood of occurrence. Moreover, if a risk factor possessing high impact and high likelihood of occurrence, its degree of risk appears to be very high i.e. close to one. Generally, likelihood of occurrence can be assessed in two ways such as subjective judgment and objective analysis. Subjective judgment process is easy and practical than the objective analysis because it does not demand historical data; rather it needs some experience as well as scrutiny (Zhi, 1995). Therefore, this study focuses on subjective judgment process for assessing both the likelihood of occurrence as well as impact of each risk influencing factor. The subjectivity of aforementioned two parameters has been tackled by means of fuzzy logic and risk has been estimated from fuzzy point of view rather than probabilistic conceptualization.

3.4 Fuzzy Set Approach

To deal with vagueness in human thought, (Zadeh, 1965) first introduced fuzzy set theory, which has the capability to represent/manipulate data and information possessing based on non-statistical uncertainties. Moreover, fuzzy set theory has been designed to mathematically represent uncertainty as well as vagueness and to provide formalized tools for dealing with imprecision inherent to decision making problems. In any decision making situation, candidate alternatives are generally evaluated based on qualitative as well as quantitative criteria. Quantitative criteria can easily be assessed by conventional tools and techniques. However, difficulty arises in dealing with subjective (qualitative) evaluation indices. As most of the risk characterizing factors are subjective in nature, its assessment relies on decision-makers' linguistic judgment. Unless the linguistic evaluation information is transformed into logical mathematic base, it seems difficult to quantify the risk. Moreover, linguistic information carries inherent impression, vagueness and to some extent uncertainty due to variation in human perception. Fuzzy logic has the capability in dealing with such incomplete information efficiently. Therefore, in the present work, an efficient risk assessment model has been postulated to perform in fuzzy environment. A linguistic variable is the variable whose values are not expressed in numbers but words or sentences in a natural or artificial language (Zadeh, 1975). The concept of a linguistic variable is very useful in dealing with situations, which are too complex or not well defined to be reasonably described in conventional quantitative expressions (Zimmermann, 1991). A fuzzy number is a fuzzy subset in the universe of discourse that is both convex and normal. Generally, various types of fuzzy numbers such as triangular, trapezoidal, bell-shaped numbers are used in decision making processes (Chen et al. 2006; Xia et al., 2006, Yang and Hung, 2007, Chen and Chen, 2009). However, trapezoidal numbers are widely used due to simple mathematical representation and easy computation. A trapezoidal fuzzy number form is the most generic class of fuzzy numbers with linear membership function (Kaufmann and Gupta, 1991). Due to generic property of this class of fuzzy numbers, it finds application in modeling linear uncertainty in scientific and applied engineering problems in comparison to triangular fuzzy numbers.

3.4.1 Concept of Generalized Trapezoidal Fuzzy Numbers

According to (Chen, 1985), a generalized trapezoidal fuzzy number can be defined as $\tilde{A} = (a_1, a_2, a_3, a_4; w_{\tilde{A}})$, and shown in Fig. 3.1.

Also, the membership function $\mu_{\tilde{A}}(x) : R \to [0,1]$ is defined as follows:

$$\mu_{\tilde{A}}(x) = \begin{cases} \dfrac{x - a_1}{a_2 - a_1} \times w_{\tilde{A}}, & x \in (a_1, a_2) \\ w_{\tilde{A}}, & x \in (a_2, a_3) \\ \dfrac{x - a_4}{a_3 - a_4} \times w_{\tilde{A}}, & x \in (a_3, a_4) \\ 0, & x \in (-\infty, a_1) \cup (a_4, \infty) \end{cases} \quad (3.2)$$

Here, $a_1 \le a_2 \le a_3 \le a_4$ and $w_{\tilde{A}} \in [0,1]$

The elements of the generalized trapezoidal fuzzy numbers $x \in R$ are real numbers, and its membership function $\mu_{\tilde{A}}(x)$ is the regularly and continuous convex function, it shows that the membership degree to the fuzzy sets. If $-1 \le a_1 \le a_2 \le a_3 \le a_4 \le 1$, then $\tilde{A}$ is called the normalized trapezoidal fuzzy number. Especially, if $w_{\tilde{A}} = 1$, then $\tilde{A}$ is called trapezoidal fuzzy number (a_1, a_2, a_3, a_4); if $a_1 < a_2 = a_3 < a_4$, then $\tilde{A}$ is reduced to a triangular fuzzy number. If $a_1 = a_2 = a_3 = a_4$, then $\tilde{A}$ is reduced to a real number.

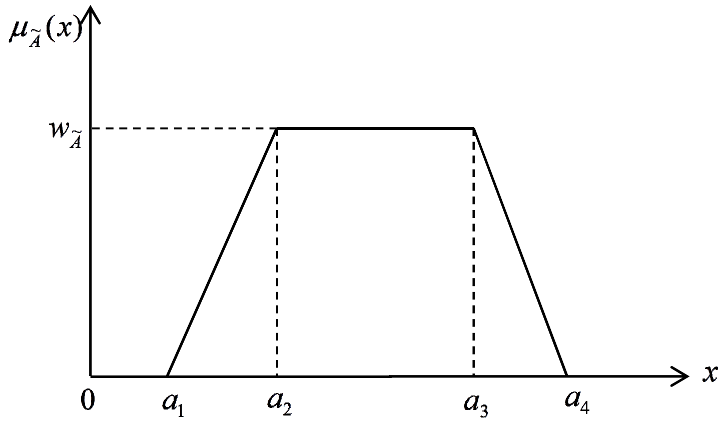

Fig. 3.1: Trapezoidal fuzzy number $\tilde{A}$

3.4.2 Fuzzy Operational Rules for Generalized Trapezoidal Fuzzy Numbers

Suppose $\tilde{a} = (a_1, a_2, a_3, a_4; w_{\tilde{a}})$ and $\tilde{b} = (b_1, b_2, b_3, b_4; w_{\tilde{b}})$ are two generalized trapezoidal fuzzy numbers then the operational rules of the generalized trapezoidal fuzzy numbers $\tilde{a}$ and $\tilde{b}$ are shown as follows (Chen and Chen, 2003; 2009):

$$\tilde{a} \oplus \tilde{b} = (a_1, a_2, a_3, a_4; w_{\tilde{a}}) \oplus (b_1, b_2, b_3, b_4; w_{\tilde{b}}) =$$
$$(a_1 + b_1, a_2 + b_2, a_3 + b_3, a_4 + b_4; \min(w_{\tilde{a}}, w_{\tilde{b}})) \tag{3.3}$$

$$\tilde{a} - \tilde{b} = (a_1, a_2, a_3, a_4; w_{\tilde{a}}) - (b_1, b_2, b_3, b_4; w_{\tilde{b}}) =$$
$$(a_1 - b_4, a_2 - b_3, a_3 - b_2, a_4 - b_1; \min(w_{\tilde{a}}, w_{\tilde{b}})) \tag{3.4}$$

$$\tilde{a} \otimes \tilde{b} = (a_1, a_2, a_3, a_4; w_{\tilde{a}}) \otimes (b_1, b_2, b_3, b_4; w_{\tilde{b}}) =$$
$$(a, b, c, d; \min(w_{\tilde{a}}, w_{\tilde{b}})) \tag{3.5}$$

Here,

$$a = \min(a_1 \times b_1, a_1 \times b_4, a_4 \times b_1, a_4 \times b_4)$$

$$b = \min(a_2 \times b_2, a_2 \times b_3, a_3 \times b_2, a_3 \times b_3)$$

$$c = \max(a_2 \times b_2, a_2 \times b_3, a_3 \times b_2, a_3 \times b_3)$$

$$d = \max(a_1 \times b_1, a_1 \times b_4, a_4 \times b_1, a_4 \times b_4)$$

If $a_1, a_2, a_3, a_4, b_1, b_2, b_3, b_4$ are real numbers, then

$$\tilde{a} \otimes \tilde{b} = \left(a_1 \times b_1, a_2 \times b_2, a_3 \times b_3, a_4 \times b_4; \min\left(w_{\tilde{a}}, w_{\tilde{b}}\right)\right)$$

$$\tilde{a} / \tilde{b} = \left(a_1, a_2, a_3, a_4; w_{\tilde{a}}\right) \Big/ \left(b_1, b_2, b_3, b_4; w_{\tilde{b}}\right)$$

$$= \left(a_1 / b_4, a_2 / b_3, a_3 / b_2, a_4 / b_1; \min\left(w_{\tilde{a}}, w_{\tilde{b}}\right)\right) \quad (3.6)$$

3.4.3 Method of 'Incentre of centroids'

Ranking of fuzzy numbers plays an important role in approximate reasoning, optimization, forecasting, decision making, scheduling and risk based analysis practices. The ranking method for fuzzy numbers was first proposed by (Jain, 1976) for decision making in fuzzy environment by representing the ill-defined quantities as a fuzzy sets. Wang and Kerre (2001a, 2001b) have classified all the ranking methods into three categories and proposed seven reasonable properties to evaluate the ranking method. Then, ranking of fuzzy numbers by preference ratio (Modarres and Nezhad, 2001), left and right dominance (Chen and Lu, 2001), area between the centroid point and original point (Chu and Tsao, 2002), sign distance (Abbasbandy and Asady, 2006) and distance minimization (Asady and Zendehnam, 2007) have been proposed. Thorani et al. (2012a) have illustrated a ranking method for ordering fuzzy numbers using orthocenter of centroid method. Thorani et al. (2012b) provided a formulation towards computing equivalent crisp score against a particular fuzzy number. This concept is utilized to rank a set of fuzzy numbers with the help of computed crisp score. This concept of crisp evaluation has been explored in this research towards development of an efficient risk assessment module. The mathematical basis of this concept has been reproduced below.

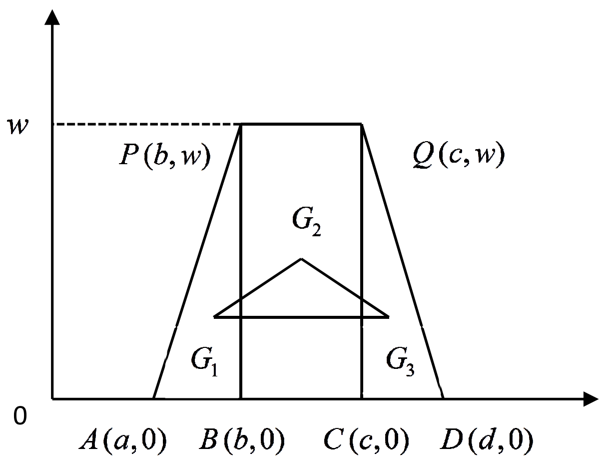

Fig. 3.2: Trapezoidal fuzzy number

The centroid of a trapezoid is considered as the balancing point of the trapezoid (Fig. 3.2). Divide the trapezoid into three plane figures. These three plane figures are a triangle (APB), a rectangle (BPQC), and a triangle (CQD), respectively. Let the centroids of the three plane figures be G_1, G_2, and G_3 respectively. The Incenter of these Centroids G_1, G_2 and G_3 is taken as the point of reference to define the crisp value of generalized trapezoidal fuzzy numbers. The reason for selecting this point as a point of reference is that each centroid point are balancing points of each individual plane figure, and the Incentre of these centroid points is a much more balancing point for a generalized trapezoidal fuzzy number. Therefore, this point would be a better reference point than the centroid point of the trapezoid.

Consider a generalized trapezoidal fuzzy number $\tilde{A} = (a,b,c,d;w)$. The centroids of the three plane figures are

$G_1 = \left(\frac{a+2b}{3}, \frac{w}{3}\right)$, $G_2 = \left(\frac{b+c}{2}, \frac{w}{2}\right)$ and $G_3 = \left(\frac{2c+d}{3}, \frac{w}{3}\right)$ respectively.

Equation of the line $\overline{G_1G_3}$ is $y = \frac{w}{3}$ and G_2 does not lie on the line $\overline{G_1G_3}$.

Therefore, G_1 G_2 and G_3 are non-collinear and they form a triangle.

We define the Incentre $I_{\tilde{A}}(\bar{x}_0, \bar{y}_0)$ of the triangle with vertices G_1, G_2 and G_3 of the generalized trapezoidal fuzzy number $\tilde{A} = (a,b,c,d;w)$ as

$$I_{\tilde{A}}(\bar{x}_0, \bar{y}_0) = \left(\frac{\alpha\left(\frac{a+2b}{3}\right) + \beta\left(\frac{b+c}{2}\right) + \gamma\left(\frac{2c+d}{3}\right)}{\alpha+\beta+\gamma}, \frac{\alpha\left(\frac{w}{3}\right) + \beta\left(\frac{w}{2}\right) + \gamma\left(\frac{w}{3}\right)}{\alpha+\beta+\gamma} \right) \tag{3.7}$$

Here

$$\alpha = \frac{\sqrt{(c-3b+2d)^2 + w^2}}{6}$$

$$\beta = \frac{\sqrt{(2c+d-a-2b)^2}}{3}$$

$$\gamma = \frac{\sqrt{(3c-2a-b)^2 + w^2}}{6}$$

As a special case, for triangular fuzzy number $\tilde{A} = (a,b,c,d;w)$, i.e. $c = b$ the incentre of Centroids is given by

$$I_{\tilde{A}}(\bar{x}_0, \bar{y}_0) = \left(\frac{x\left(\frac{a+2b}{3}\right) + yb + z\left(\frac{2b+d}{3}\right)}{x+y+z}, \frac{x\left(\frac{w}{3}\right) + y\left(\frac{w}{2}\right) + z\left(\frac{w}{3}\right)}{x+y+z} \right) \tag{3.8}$$

Here,

$$x = \frac{\sqrt{(2d-2b)^2 + w^2}}{6}$$

$$y = \frac{\sqrt{(d-a)^2}}{3}$$

$$z = \frac{\sqrt{(2b-2a)^2 + w^2}}{6}$$

The ranking function of the generalized trapezoidal fuzzy number $\tilde{A} = (a, b, c, d; w)$, which maps the set of all fuzzy numbers to a set of real numbers is defined as,

$$R(\tilde{A}) = x_0 \times y_0 = \left(\frac{\alpha\left(\frac{a+2b}{3}\right) + \beta\left(\frac{b+c}{2}\right) + \gamma\left(\frac{2c+d}{3}\right)}{\alpha+\beta+\gamma} \times \frac{\alpha\left(\frac{w}{3}\right) + \beta\left(\frac{w}{2}\right) + \gamma\left(\frac{w}{3}\right)}{\alpha+\beta+\gamma} \right) \tag{3.9}$$

This is the area between the incenter of the centroids $I_{\tilde{A}}(\bar{x}_0, \bar{y}_0)$ as defined in Eq. (3.7) and the original point.

3.5 Proposed Methodology

The concept of hierarchical structure towards ITO risk assessment with two distinct levels has been used in this part of work. First level is to evaluate fuzzy risk extent of several risk influencing factors and the second level is to evaluate the degree of risk extent of individual risk sources affecting to the outsourcing venture. A more general representation of multi-criteria decision making (MCDM) scenario has been introduced in the context of the present problem. The scenario comprises a committee of k decision makers $(DM_1, DM_2, ..., DM_k)$ who are responsible for assessing the appropriateness of m ITO risks $(R_1, R_1, ..., m)$, under each of n risk influencing factors $(F_1, F_2, ..., F_n)$. Risk of each influencing factors can be quantified based on two evaluating factors such as likelihood of occurrence and its impact. The following procedural steps have been proposed for calculating fuzzy risk ratings as well as managing the risks:

Step 1: Identification of ITO risks and their influencing factors which have been used to develop a hierarchical risk assessment model.

Step 2: Selection of fuzzy linguistic classification scale for expressing both likelihood of occurrence and impact of risks, and, also choosing suitable membership functions for each variable.

Step 3: Linguistic data (in relation to likelihood of occurrence and impact of risk) for each risk factor have been collected from the experts. Thereafter, linguistic data have been translated into appropriate fuzzy numbers.

Step 4: Combined preferences (aggregated decision-making opinion) have been computed using fuzzy aggregation operators. Fuzzy risk ratings of each influencing factor have been calculated by multiplying fuzzy likelihood of occurrence and fuzzy risk impact.

Step 5: Crisp risk rating corresponding to each risk influencing factor has been calculated using 'Incentre of centroids method' (Thorani et al., 2012b) applicable for generalized trapezoidal fuzzy numbers in fuzzy logic theory.

Step 6: Categorization of risks has been carried out based on individual crisp risk ratings.

Step 7: An action requirement plan has been formulated with reference to different risk categories.

The above procedure seems to be generic one. However, the aforementioned risk ratings may change with respect to risk-bearing attitudes of different experts, decision making environment and may vary due to different corporate policies.

3.6 Case Application

In order to validate the proposed risk assessment procedure, a case study has been conducted for one of the leading IT Industry in eastern part of India. For more than twenty years, the said company has outsourced many of its IT functions for the development of IT products as well as services. A focus group survey has been conducted from IT executives and managers who were actively associated in outsourcing information technology projects. The group selected to participate in the survey, constitutes seven IT personnel's (or experts) with more than ten years' experience in IT outsourcing. Due to anonymity reasons, expert identities have not been exposed and therefore, they have been referred to as DM1, DM2, DM3, DM4, DM5, DM6, and

DM7. The experts have been requested to express their personal opinion in a detailed questionnaire following a linguistic scale as shown in Appendix B. Also, they have been suggested to go for the choice to mention any other objectives (if applicable) and risk assessment factors that have not been specified in the said questionnaire. All the participants for this survey (experts) have been involved in outsourcing projects, and their experience helped enormously in pursuit of this case study.

3.6.1 Risk Identification

According to the definition of risk as discussed in Sections 3.2, undesirable outcomes may arise due to existence of various risk factors. In this work, a total of eleven different sources of ITO risks and their corresponding influencing factors have been identified from the survey of past literature. It has been decided to focus specifically on those risks that are fairly common, important and sensitive to the IT outsourcing practices. Table 3.1 presents a hierarchical risk assessment model that outlines numerous outsourcing risks and their influencing factors. Each influencing factor has been structured to be preceded by the corresponding risk.

3.6.2 Selection of Fuzzy Linguistic Scale

Although many researchers have used different types of linguistic scales to carry out subjective assessments in a variety of fuzzy-based decision making problems. But, the type of the membership function corresponding to a fuzzy number representing a particular linguistic variable has to be selected in accordance with user needs. A commonly used, trapezoidal membership function has been found satisfactory for this application (Xia et al., 2006). Table 3.2 presents the set of linguistic variables and corresponding fuzzy number representations that has been used for assessing different risk sources under consideration. During this risk assessment process, a five-member fuzzy linguistic scale has been adopted from the work by (Xia et al., 2006). As discussed earlier, risk is a function of two parameters such as: likelihood of occurrence, and impact of risk. Thus, linguistic variables such as Very Rare (VR), Rare (R), Often (O), Frequent (F), and Very Frequent (VF) have been used to rate the likelihood of occurrence (of risk). Similarly; Very Low (VL), Low (L), Moderate (M), Serious (S), and Critical (C) have been utilized to rate the impact of risk.

3.6.3 Data Collection

Two set of linguistic data has been collected from the expert group on assessment of likelihood of occurrence and impact of risk for each of the risk influencing factors. Experts or decision-makers (DMs) have been provided their judgment in linguistic terms. Both the data sets have been separately collected from the group of decision makers. Table 3.3 presents the likelihood of occurrence of various risk influencing factors assigned by the DMs. Also, risk impact of corresponding influencing risk factors has been presented in Table 3.4. Then, this linguistic information has been transformed into appropriate trapezoidal fuzzy numbers referring to the linguistic scale (Table 3.2).

3.6.4 Risk Ratings

During risk assessment process, experts' individual decisions have been translated into combined (aggregated) preference using fuzzy aggregation rules; based on that associated decision matrices have been prepared. The exploration of the concept of fuzzy arithmetic operations has been found necessary at this stage to form an aggregation rule.

Aggregation is the process by which the fuzzy sets are combined form a single collective preference fuzzy set. Let k is the number of decision makers $\left(DM_t, t=1,...,k\right)$, who are responsible for assessing m ITO risks $\left(R_i, i=1,...,m\right)$, with corresponding n influencing factors $\left(F_{i,j}, j=1,...,n\right)$. The aggregated fuzzy preferences $\left(\tilde{F}_{ij}\right)$ of each influencing factor in both the form (L and I) under each risk can be calculated as (Chen, 2000):

$$\tilde{F}_{ij} = \frac{1}{k}\left[\tilde{F}_{ij1} \oplus \tilde{F}_{ij2} \oplus ... \oplus \tilde{F}_{ijk}\right] \tag{3.10}$$

The following relation has been used for calculating the fuzzy risk rating of each influencing factor, such as:

Degree of Risk/ Risk rating= $\left(\tilde{F}_{ij}\right)_L \otimes \left(\tilde{F}_{ij}\right)_I$ (3.11)

Also, the crisp risk rating $R\left(\tilde{A}\right)$ of each influencing factor has been calculated by using Eq. (3.9) (by Incentre of centroids method). Then, the crisp rating of each ITO risk has been calculated by adding the corresponding influencing factors ratings. The results of aggregated preferences, fuzzy risk ratings and crisp risk ratings have been furnished in Table 3.5.

The graphical representation of risk ratings (crisp scores) in relation to various risk influencing factors have been illustrated in Fig. 3.3. It has been observed that the factors like ineffective bidding mechanisms ($F_{10,7}$), less manpower ($F_{11,4}$), inadequate terms and ambiguous contract with supplier ($F_{10,1}$), suppliers' service quality ($F_{10,2}$), lack of experience and expertise of the enterprise with the activity ($F_{4,2}$), lack of technical knowledge and education ($F_{3,4}$), complexity of new and emerging technology and interface ($F_{3,2}$) and interdependence of activities ($F_{2,4}$) impose amplified adverse impact to the performance of IT outsourcing practice. The factors other than aforementioned also have reasonable (or) less negative impact on performance but highly influence to the certain areas of risks. Therefore, the risk rating of each identified risk source can be computed by the summation of their corresponding risk ratings of influencing factors. Moreover, the overall risk extent can be determined by adding all influencing factors' risk ratings. The above results have been shown in Table 3.5 and it can also be observed that strategic risk has the highest crisp rating (1.3210) which can impose highest impact on overall IT outsourcing performance. Moreover, its percentage of contribution is about 16% to the overall IT outsourcing risk. The percentage of contribution of all individual perceived risks can be clearly understood by Fig. 3.4. The risk with high contribution value is the major source that necessitates managing their influencing factors.

3.6.5 Risk Factor Categorization

The identified ITO risk influencing factors can be categorized in different risk categories based on the risk rating (crisp) ranges. The maximum range has been decided on the highest risk rating assigned to a risk in linguistic scale (Table 3.6). The likelihood factor (L) has been multiplied by impact factor (I) and the consequence of those two trapezoidal fuzzy numbers in terms of crisp score becomes the risk rating. Table 3.6 presents risk rating (crisp) values for linguistic risk parametric scale with reference to Table 3.2. All five crisp values have been calculated using 'Incentre of Centroids Method' with 0.2900 being the highest risk rating assigned to a particular risk source. Risks have then been defined into five different risk categories (0-5) corresponding to different risk rating (crisp ranges) within a range of (0-0.2900) as shown in Table 3.7. Finally, an actions requirement plan has been prescribed on the basis of aforesaid crisp ratings by the Risk Management Team Lead, Risk Owner, Risk Committee, and Decision Team, etc. to successfully identify and manage the risks appeared in different risk categories. The identification of various risk influencing factors under each risk categories and their action requirement plans has been illustrated in Table 3.8.

3.7 Managerial Implications

The study presents an empirical research on important issues of risk and subsequent risk management plan in a long-term entire outsourcing practices, in the context of a famous Indian IT sector. The effectiveness of strategic risk management can be perceived by the critical review of risk management process which includes identifying, assessing and managing risks. A hierarchical framework has been proposed here to facilitate the process of risk identification in IT outsourcing practices. Eleven potential risks such as strategic risk, business risk, technical risk, financial risk, legal risk, operational risk, environmental risk, information risk, managerial risk, relationship risk, and time management risk have been identified from the review of past IT outsourcing literature (Earl, 1996; Di Romualdo and Gurbaxani, 1998; Tho, 2005). Each specific risk has been characterized by their influencing factors. A case study has been conducted considering a total of sixty eight risk influencing factors that have been identified for the assessment of overall risk extent in the said IT outsourcing. In this work, a unique methodology has been proposed to quantify the degree of risk and suggested a risk mitigation plan at early stage of the outsourcing projects.

The fuzzy concepts have been applied for collecting subjective data on likelihood of occurrence and information regarding impact for the identified risk factors related to the outsourcing projects. This could increase the willingness of participating experts to provide their perception of information for the qualitative risk assessment process. From the risk assessment results, it has been concluded that the risk factors with high level of risk should be carefully monitored, controlled and managed to ensure project success. Therefore, this study has introduced an action requirement plan for identified risk factors in different specific category that can be successfully monitored, controlled and managed by Risk Management Team Lead, Risk Owner, Risk Committee, and Decision Team.

In this research, the proposed methodology has been considered as a generic one; that means the hierarchical structure of risk assessment consisting of risk dimensions and risk influencing factors can be analyzed in relation to ITO exercise of any IT Industry of any country throughout the globe. However, the fuzzy based risk model proposed herein has been case examined in an Indian IT sector. Every company has its own risk knowledge with respect to specific risk sources as well as risk influencing factors, and may have different risk attitudes.

In order to validate this proposed process, fifteen IT executives from the same company with more than ten years' experience in IT outsourcing practice has been interviewed to confirm the validity of proposed process in respect to (a) applicability of the proposed risk assessment process for IT outsourcing exercise, (b) benefits of operating the proposed risk assessment steps, (c) completeness of identified risk factors for IT outsourcing, and (d) importance to the strategic planning of IT outsourcing. Ninety percent of the interviewees have been confirmed positive to the above questions after clear examination of theory and operational steps as highlighted before.

3.8 Concluding Remarks

Effective risk management in IT outsourcing necessitates a reliable risk assessment as well as risk treatment planning followed by subsequent implementation. The proposed risk assessment approach appears as more practical and reliable than traditional statistical methods since it utilizes the experts' risk perceptions in a subjective manner rather than objective way.

In this work, fuzzy set theory has been embedded in risk assessment process to quantify risk ratings where both the risk impacts and likelihood of occurrence have been evaluated by experts' subjective judgment. The perceived ITO risks and their influencing factors can easily be modeled by the developed hierarchical structure. The proposed methodology not only assesses overall risk in IT outsourcing; its concept and procedure can also be implemented to evaluate risks in different industrial settings. The applicability of the proposed methodology has been tested through a real case study in an established Indian IT company. The unique research contribution of the current work relates to identification of important risk dimensions (effects) and their influencing factors (causes) in relation to IT outsourcing. Further, systematic and logical categorization of various risk dimensions followed by action plan for risk mitigation is quite useful for the practicing managers. Exploration of a risk assessment module would definitely help IT managers in understanding various risks associated with IT outsourcing and their impact on overall success of IT venture. Getting a clear knowledge on ITO risk dimensions, managers can tactfully deal with risks and finalize risk mitigation plans at corporate level. These may be helpful for ITO success. Reduction of ITO risk may enhance flexibility as well as competitiveness of IT industries against recent recession (downfall of IT sectors).

Table 3.1: Hierarchical structure for risk assessment in IT Outsourcing

Risk Dimensions	Risk influencing factors	Source
Strategic risk, R_1	• Loss of organizational competency, $F_{1,1}$	Earl, 1996; Lacity et al., 1995
	• Proximity of core competency, $F_{1,2}$	Hamel and Prahalad, 1990
	• Interdependence of activities, $F_{1,3}$	Aubert et al., 1997; Langonis and Robertson, 1992
	• Technological indivisibility, $F_{1,4}$	Earl, 1996
	• Endemic Uncertainty, $F_{1,5}$	Earl, 1996
	• Out-dated Technology skill, $F_{1,6}$	Earl, 1996
	• Lack of information flow to support ITO (IT outsourcing) strategy, $F_{1,7}$	Dhar and Balakrishnan, 2006
	• Lack of strategy focused on attaining reduction in cost, $F_{1,8}$	Lacity et al., 1995
	• Fuzzy focus, $F_{1,9}$	Earl, 1996
	• Poorly managed Mergers and Acquisitions (M&A) and partnerships, $F_{1,10}$	Expert opinion
	• Loosing ownership of the client, $F_{1,11}$	Expert opinion
Business risk, R_2	• Business Uncertainty, $F_{2,1}$	Earl, 1996
	• Small number of suppliers, $F_{2,2}$	Nam et al., 1996
	• Asset specificity, $F_{2,3}$	Williamson, 1985
	• Interdependence of activities, $F_{2,4}$	Aubert et al., 1997; Langonis and Robertson, 1992
Technical Risk, R_3	• Lack of use of new technology, $F_{3,1}$	Tho, 2005
	• Complexity of new and emerging technology and interface, $F_{3,2}$	Tho, 2005
	• Loss of key technical person, $F_{3,3}$	Tho, 2005
	• Lack of technical knowledge and education, $F_{3,4}$	Earl, 1996
	• Lack of research on IT service, $F_{3,5}$	Earl, 1996
	• Task complexity, $F_{3,6}$	Dhar and Balakrishnan, 2006
	• Loss of innovative capacity, $F_{3,7}$	Earl, 1996
	• Technological discontinuity, $F_{3,8}$	Lacity et al., 1995
Financial risk, R_4	• Hidden costs, $F_{4,1}$	Earl, 1996
	• Lack of experience and expertise of the enterprise with the activity, $F_{4,2}$	Earl, 1996; Lacity et al., 1995
	• Lack of planning and inaccurate budgeting, $F_{4,3}$	Tho, 2005
	• Endemic uncertainty, $F_{4,4}$	Earl, 1996

	• Ineffective infrastructure investment, $F_{4,5}$	Tho, 2005
	• Increased cost of services, $F_{4,6}$	Tho, 2005
Legal risk, R_5	• Different rules and regulations in global trading, $F_{5,1}$	Tho, 2005
	• Dangers of eternal triangle, $F_{4,2}$	Earl, 1996
	• Lack of experience of the client with outsourcing, $F_{5,3}$	Earl, 1996; Lacity et al., 1995
	• Uncertainty about the legal environment, $F_{5,4}$	Dhar and Balakrishnan, 2006
	• Privacy, piracy and security, $F_{5,5}$	Dhar and Balakrishnan, 2006
Operational risk, R_6	• Lack of experience and expertise of client with contract management, $F_{6,1}$	Earl, 1996; Lacity et al., 1995
	• Measurement problem, $F_{6,2}$	Alchian & Demsetz, 1972; Barzel, 1982
	• Lack of talent and innovation, $F_{6,3}$	Tho, 2005
	• Possibility of weak management, $F_{6,4}$	Earl, 1996
	• Lack of organizational learning, $F_{6,5}$	Earl, 1996
	• Lack of experience and expertise of the supplier with the activities, $F_{6,6}$	Earl, 1996
Environmental risk, R_7	• Measurement problems, $F_{7,1}$	Alchian & Demsetz, 1972; Barzel, 1982
	• Social responsibility, $F_{7,2}$	Expert opinion
	• Lack of experience and expertise of the organization and/or of the supplier with outsourcing contracts, $F_{7,3}$	Earl, 1996; Lacity et al., 1995
	• Poor cultural fit, $F_{7,4}$	Dhar and Balakrishnan, 2006
	• Danger of eternal triangle, $F_{7,5}$	Earl, 1996
Information risk, R_8	• Interdependence of activities, $F_{8,1}$	Aubert et al., 1997; Langonis and Robertson, 1992
	• Lack of experience and expertise of the supplier with the activities, $F_{8,2}$	Earl, 1996, Tho, 2005
	• Supplier size, $F_{8,3}$	Earl, 1996, Tho, 2005
	• Supplier financial stability, $F_{8,4}$	Earl, 1996, Dhar and Balakrishnan, 2006
	• Task complexity, $F_{8,5}$	Dhar and Balakrishnan, 2006
Managerial risk, R_9	• Lack of conflict management, $F_{9,1}$	Earl, 1996
	• Lack of upper management involvement, $F_{9,2}$	Earl, 1996
	• Lack of contingency plan, $F_{9,3}$	Earl, 1996
	• Lack of understanding individual authorities and responsibilities, $F_{9,4}$	Expert opinion
	• Unclear decision making process, $F_{9,5}$	Expert opinion

	• Lack of expertise and experience in IT field, $F_{9,6}$	Earl, 1996
Relationship risk, R_{10}	• Inadequate terms and ambiguous contract with supplier, $F_{10,1}$	Dibbern and Goles, 2004
	• Suppliers' service quality, $F_{10,2}$	Dhar and Balakrishnan, 2006
	• Lack of buyer and supplier relationship, $F_{10,3}$	Tho, 2005
	• Suppliers' transparency in information sharing on its capabilities, $F_{10,4}$	Tho, 2005
	• Supplier hold-up, expropriation and loss of bargaining power, $F_{10,5}$	Tho, 2005
	• Misaligned incentives between supplier and buyer, $F_{10,6}$	Tho, 2005
	• Ineffective bidding mechanisms, $F_{10,7}$	Tho, 2005
Time management risk, R_{11}	• No proper follow up, $F_{11,1}$	Dhar and Balakrishnan, 2006
	• Not paying attention to details in the starting stages, $F_{11,2}$	Lacity et al., 2009
	• Deadlines not met, $F_{11,3}$	Expert opinion
	• Less manpower, $F_{11,4}$	Expert opinion
	• Sorting delay, $F_{11,5}$	Expert opinion

Table 3.2: Linguistic classification of grades of risk factors (Source: Xia et al., 2006)

Likelihood of occurrence	Impact of risk	Trapezoidal Fuzzy numbers (TrFNs)
Very Rare (VR)	Very Low (VL)	(0, 0.1, 0.2, 0.3; 1)
Rare (R)	Low (L)	(0.1, 0.2, 0.3, 0.4; 1)
Often (O)	Moderate (M)	(0.3, 0.4, 0.5, 0.6; 1)
Frequent (F)	Serious (S)	(0.5, 0.6, 0.7, 0.8; 1)
Very Frequent (VF)	Critical (C)	(0.7, 0.8, 0.9, 1; 1)

Table 3.3: Likelihood of occurrence (L) of various risk factors assigned by the DMs in linguistic terms

$F_{i,j}$	DM1	DM2	DM3	DM4	DM5	DM6	DM7
$F_{1,1}$	R	R	O	O	F	R	F
$F_{1,2}$	R	F	O	O	O	R	F
$F_{1,3}$	F	F	R	O	O	F	R
$F_{1,4}$	F	O	O	R	O	F	R
$F_{1,5}$	O	O	O	F	O	R	O
$F_{1,6}$	O	R	O	R	O	O	R
$F_{1,7}$	O	O	O	O	O	O	R
$F_{1,8}$	R	O	R	R	O	R	R
$F_{1,9}$	O	O	R	R	O	O	O
$F_{1,10}$	O	O	R	R	R	R	R
$F_{1,11}$	O	O	O	O	O	R	R
$F_{2,1}$	O	O	O	O	O	O	R
$F_{2,2}$	O	O	O	O	O	F	R
$F_{2,3}$	O	O	O	R	O	O	R
$F_{2,4}$	O	O	F	F	O	O	R
$F_{3,1}$	VR	O	O	O	O	VR	VR
$F_{3,2}$	O	F	O	VF	O	O	R
$F_{3,3}$	O	F	O	F	O	O	R
$F_{3,4}$	F	O	O	F	O	F	O
$F_{3,5}$	O	O	O	F	O	O	R
$F_{3,6}$	F	R	R	R	R	F	R
$F_{3,7}$	O	O	O	R	O	R	R
$F_{3,8}$	O	R	O	R	O	O	R
$F_{4,1}$	O	O	O	R	F	O	R
$F_{4,2}$	O	O	O	O	O	F	O
$F_{4,3}$	O	O	R	R	O	O	O
$F_{4,4}$	O	R	R	R	O	O	O
$F_{4,5}$	VR	O	O	F	O	R	VR
$F_{4,6}$	O	O	O	O	O	O	R
$F_{5,1}$	O	F	O	O	R	R	R
$F_{5,2}$	O	VR	VR	R	VR	O	VR

$F_{5,3}$	O	O	R	O	O	O	R
$F_{5,4}$	O	O	R	O	R	O	R
$F_{5,5}$	O	O	O	O	O	O	R
$F_{6,1}$	O	O	R	R	R	O	R
$F_{6,2}$	O	O	O	O	O	O	O
$F_{6,3}$	O	O	O	O	O	O	R
$F_{6,4}$	R	O	R	O	R	R	R
$F_{6,5}$	O	F	O	F	O	O	R
$F_{6,6}$	O	O	O	O	O	R	R
$F_{7,1}$	O	O	O	O	O	F	R
$F_{7,2}$	O	O	O	O	O	O	R
$F_{7,3}$	R	O	O	O	O	R	R
$F_{7,4}$	O	R	R	R	O	O	O
$F_{7,5}$	O	O	R	R	R	R	R
$F_{8,1}$	O	O	O	O	O	O	R
$F_{8,2}$	O	O	R	R	R	R	R
$F_{8,3}$	F	O	O	O	O	O	R
$F_{8,4}$	O	O	O	O	O	O	R
$F_{8,5}$	O	O	O	O	O	O	R
$F_{9,1}$	F	R	O	O	O	F	R
$F_{9,2}$	O	R	R	R	R	O	R
$F_{9,3}$	O	O	O	O	O	O	O
$F_{9,4}$	O	R	R	R	R	O	R
$F_{9,5}$	O	R	R	R	R	O	R
$F_{9,6}$	O	O	R	O	O	O	R
$F_{10,1}$	O	F	O	F	O	F	R
$F_{10,2}$	O	F	O	F	O	F	R
$F_{10,3}$	O	O	O	O	O	O	R
$F_{10,4}$	O	O	O	O	O	O	R
$F_{10,5}$	O	O	O	O	O	O	R
$F_{10,6}$	O	O	O	O	O	R	R
$F_{10,7}$	F	VF	VF	VF	O	F	O
$F_{11,1}$	O	R	R	R	R	R	O
$F_{11,2}$	O	O	O	F	O	O	R

$F_{11,3}$	O	O	O	O	O	O	R
$F_{11,4}$	F	F	O	VF	O	O	R
$F_{11,5}$	O	O	O	O	O	R	R

Table 3.4: Impact of risk (I) of various risk factors assigned by the DMs in linguistic terms

$F_{i,j}$	DM1	DM2	DM3	DM4	DM5	DM6	DM7
$F_{1,1}$	S	C	S	C	C	S	S
$F_{1,2}$	S	C	S	C	C	S	S
$F_{1,3}$	C	C	S	C	C	S	S
$F_{1,4}$	C	C	S	S	C	S	S
$F_{1,5}$	S	C	C	C	C	S	S
$F_{1,6}$	C	C	C	C	C	M	S
$F_{1,7}$	S	C	C	C	C	S	M
$F_{1,8}$	S	C	C	C	C	S	S
$F_{1,9}$	C	S	S	C	C	S	S
$F_{1,10}$	C	C	S	C	C	S	M
$F_{1,11}$	C	C	C	C	C	S	S
$F_{2,1}$	C	C	C	C	S	C	M
$F_{2,2}$	C	C	C	S	C	C	S
$F_{2,3}$	C	C	C	C	C	S	S
$F_{2,4}$	C	C	C	C	C	S	S
$F_{3,1}$	S	C	C	C	C	S	S
$F_{3,2}$	S	C	C	C	C	S	S
$F_{3,3}$	S	C	C	C	C	S	S
$F_{3,4}$	S	C	S	C	C	S	S
$F_{3,5}$	C	S	C	C	C	C	S
$F_{3,6}$	C	S	S	S	C	C	S
$F_{3,7}$	S	C	C	C	C	S	S
$F_{3,8}$	C	C	C	C	C	C	S
$F_{4,1}$	C	C	C	C	C	S	M
$F_{4,2}$	C	C	C	C	C	C	C

$F_{4,3}$	C	C	S	C	C	S	S
$F_{4,4}$	C	S	S	C	C	S	S
$F_{4,5}$	S	C	C	C	C	S	S
$F_{4,6}$	C	C	C	C	C	S	S
$F_{5,1}$	C	S	C	C	C	S	S
$F_{5,2}$	C	S	S	S	C	S	S
$F_{5,3}$	C	C	S	C	C	S	S
$F_{5,4}$	C	C	S	C	S	S	S
$F_{5,5}$	C	C	C	C	C	S	S
$F_{6,1}$	C	C	C	C	C	C	S
$F_{6,2}$	C	S	C	C	C	S	S
$F_{6,3}$	C	S	C	S	C	C	S
$F_{6,4}$	C	S	S	S	S	S	S
$F_{6,5}$	C	S	C	S	C	C	S
$F_{6,6}$	C	M	C	M	C	S	S
$F_{7,1}$	C	C	C	C	C	C	S
$F_{7,2}$	S	C	C	C	C	C	S
$F_{7,3}$	S	M	M	M	C	S	S
$F_{7,4}$	C	C	C	C	C	C	S
$F_{7,5}$	S	S	S	S	S	S	S
$F_{8,1}$	C	C	C	C	C	C	S
$F_{8,2}$	C	C	S	C	S	C	S
$F_{8,3}$	S	S	C	M	C	C	S
$F_{8,4}$	S	C	C	C	C	C	S
$F_{8,5}$	C	C	C	C	C	S	S
$F_{9,1}$	C	C	S	C	C	S	S
$F_{9,2}$	S	C	C	C	C	S	S
$F_{9,3}$	S	S	C	S	C	C	S
$F_{9,4}$	C	S	C	S	C	C	S
$F_{9,5}$	C	S	C	S	C	C	S
$F_{9,6}$	C	C	C	C	C	S	S
$F_{10,1}$	C	C	C	C	C	C	S
$F_{10,2}$	C	C	C	C	C	C	S
$F_{10,3}$	C	C	C	C	C	C	M

$F_{10,4}$	C	S	C	S	C	C	S
$F_{10,5}$	S	S	S	S	C	C	S
$F_{10,6}$	S	S	S	S	C	S	S
$F_{10,7}$	S	S	S	S	S	S	S
$F_{11,1}$	C	S	M	M	C	C	S
$F_{11,2}$	S	C	C	C	C	C	S
$F_{11,3}$	C	C	C	S	C	C	S
$F_{11,4}$	C	C	C	C	C	S	S
$F_{11,5}$	C	C	C	S	C	C	S

Table 3.5: Aggregated preferences by seven candidates in terms of fuzzy numbers and their crisp ratings

R_i	$F_{i,j}$	Likelihood of Occurrence (L)	Impact of Risk (I)	Degree of Risk/ risk rating (fuzzy)	Risk rating (crisp)	Risk rating (crisp)
R_1	$F_{1,1}$	(0.27, 0.37, 0.47, 0.57; 1)	(0.59, 0.69, 0.79, 0.89; 1)	(0.16, 0.25, 0.37, 0.51; 1)	0.1229	1.3210 (Approx. 16%)
	$F_{1,2}$	(0.30, 0.40, 0.50, 0.60; 1)	(0.59, 0.69, 0.79, 0.89; 1)	(0.18, 0.27, 0.39, 0.53; 1)	0.1312	
	$F_{1,3}$	(0.33, 0.43, 0.53, 0.63; 1)	(0.61, 0.71, 0.81, 0.91; 1)	(0.20, 0.31, 0.43, 0.57; 1)	0.1452	
	$F_{1,4}$	(0.30, 0.40, 0.50, 0.60; 1)	(0.59, 0.69, 0.79, 0.89; 1)	(0.18, 0.27, 0.39, 0.53; 1)	0.1312	
	$F_{1,5}$	(0.30, 0.40, 0.50, 0.60; 1)	(0.61, 0.71, 0.81, 0.91; 1)	(0.18, 0.27, 0.39, 0.53; 1)	0.1364	
	$F_{1,6}$	(0.21, 0.31, 0.41, 0.51; 1)	(0.61, 0.71, 0.81, 0.91; 1)	(0.13, 0.22, 0.34, 0.47; 1)	0.1104	
	$F_{1,7}$	(0.27, 0.37, 0.47, 0.57; 1)	(0.59, 0.69, 0.79, 0.89; 1)	(0.16, 0.25, 0.37, 0.51; 1)	0.1229	
	$F_{1,8}$	(0.16, 0.26, 0.36, 0.46; 1)	(0.61, 0.71, 0.81, 0.91; 1)	(0.10, 0.18, 0.29, 0.42; 1)	0.0931	
	$F_{1,9}$	(0.24, 0.34, 0.44, 0.54; 1)	(0.59, 0.69, 0.79, 0.89; 1)	(0.14, 0.24, 0.35, 0.48; 1)	0.1145	
	$F_{1,10}$	(0.16, 0.26, 0.36, 0.46; 1)	(0.59, 0.69, 0.79, 0.89; 1)	(0.09, 0.18, 0.28, 0.40; 1)	0.0896	
	$F_{1,11}$	(0.24, 0.34, 0.44, 0.54; 1)	(0.64, 0.74, 0.84, 0.94; 1)	(0.16, 0.25, 0.37, 0.51; 1)	0.1236	
R_2	$F_{2,1}$	(0.27, 0.37, 0.47, 0.57; 1)	(0.61, 0.71, 0.81, 0.91; 1)	(0.17, 0.27, 0.38, 0.52; 1)	0.1277	0.5438 (Approx. 6%)
	$F_{2,2}$	(0.30, 0.40, 0.50, 0.60; 1)	(0.64, 0.74, 0.84, 0.94; 1)	(0.19, 0.30, 0.42, 0.57; 1)	0.1417	
	$F_{2,3}$	(0.24, 0.34, 0.44, 0.54; 1)	(0.64, 0.74, 0.84, 0.94; 1)	(0.16, 0.25, 0.37, 0.51; 1)	0.1236	
	$F_{2,4}$	(0.33, 0.43, 0.53, 0.63; 1)	(0.64, 0.74, 0.84, 0.94; 1)	(0.21, 0.32, 0.45, 0.59; 1)	0.1507	

R_3	$F_{3,1}$	(0.17, 0.27, 0.37, 0.47; 1)	(0.61, 0.71, 0.81, 0.91; 1)	(0.11, 0.19, 0.30, 0.43; 1)	0.0974	1.0301 (Approx. 12%)
	$F_{3,2}$	(0.36, 0.46, 0.56, 0.66; 1)	(0.61, 0.71, 0.81, 0.91; 1)	(0.22, 0.33, 0.45, 0.60; 1)	0.1539	
	$F_{3,3}$	(0.33, 0.43, 0.53, 0.63; 1)	(0.61, 0.71, 0.81, 0.91; 1)	(0.20, 0.31, 0.43, 0.57; 1)	0.1452	
	$F_{3,4}$	(0.39, 0.49, 0.59, 0.69; 1)	(0.59, 0.69, 0.79, 0.89; 1)	(0.23, 0.33, 0.46, 0.61; 1)	0.1565	
	$F_{3,5}$	(0.30, 0.40, 0.50, 0.60; 1)	(0.64, 0.74, 0.84, 0.94; 1)	(0.19, 0.30, 0.42, 0.57; 1)	0.1417	
	$F_{3,6}$	(0.21, 0.31, 0.41, 0.51; 1)	(0.59, 0.69, 0.79, 0.89; 1)	(0.13, 0.22, 0.33, 0.46; 1)	0.1062	
	$F_{3,7}$	(0.21, 0.31, 0.41, 0.51; 1)	(0.61, 0.71, 0.81, 0.91; 1)	(0.13, 0.22, 0.33, 0.46; 1)	0.1104	
	$F_{3,8}$	(0.21, 0.31, 0.41, 0.51; 1)	(0.67, 0.77, 0.87, 0.97; 1)	(0.14, 0.24, 0.36, 0.50; 1)	0.1188	
R_4	$F_{4,1}$	(0.27, 0.37, 0.47, 0.57; 1)	(0.61, 0.71, 0.81, 0.91; 1)	(0.17, 0.27, 0.38, 0.52; 1)	0.1277	0.7578 (Approx. 9%)
	$F_{4,2}$	(0.33, 0.43, 0.53, 0.63; 1)	(0.70, 0.80, 0.90, 1.00; 1)	(0.23, 0.34, 0.48, 0.63; 1)	0.1619	
	$F_{4,3}$	(0.24, 0.34, 0.44, 0.54; 1)	(0.61, 0.71, 0.81, 0.91; 1)	(0.15, 0.24, 0.36, 0.50; 1)	0.1190	
	$F_{4,4}$	(0.21, 0.31, 0.41, 0.51; 1)	(0.59, 0.69, 0.79, 0.89; 1)	(0.13, 0.22, 0.33, 0.46; 1)	0.1062	
	$F_{4,5}$	(0.21, 0.31, 0.41, 0.51; 1)	(0.61, 0.71, 0.81, 0.91; 1)	(0.13, 0.22, 0.33, 0.46; 1)	0.1104	
	$F_{4,6}$	(0.27, 0.37, 0.47, 0.57; 1)	(0.64, 0.74, 0.84, 0.94; 1)	(0.17, 0.28, 0.40, 0.54; 1)	0.1326	
R_5	$F_{5,1}$	(0.24, 0.34, 0.44, 0.54; 1)	(0.61, 0.71, 0.81, 0.91; 1)	(0.15, 0.24, 0.36, 0.50; 1)	0.1190	0.5471 (Approx. 7%)
	$F_{5,2}$	(0.10, 0.20, 0.30, 0.40; 1)	(0.56, 0.66, 0.76, 0.86; 1)	(0.06, 0.13, 0.23, 0.34; 1)	0.0702	
	$F_{5,3}$	(0.24, 0.34, 0.44, 0.54; 1)	(0.61, 0.71, 0.81, 0.91; 1)	(0.15, 0.24, 0.36, 0.50; 1)	0.1190	
	$F_{5,4}$	(0.21, 0.31, 0.41, 0.51; 1)	(0.59, 0.69, 0.79, 0.89; 1)	(0.13, 0.22, 0.33, 0.46; 1)	0.1062	
	$F_{5,5}$	(0.27, 0.37, 0.47, 0.57; 1)	(0.64, 0.74, 0.84, 0.94; 1)	(0.17, 0.28, 0.40, 0.54; 1)	0.1326	
R_6	$F_{6,1}$	(0.19, 0.29, 0.39, 0.49; 1)	(0.67, 0.77, 0.87, 0.97; 1)	(0.12, 0.22, 0.34, 0.47; 1)	0.1095	0.7068 (Approx. 8%)
	$F_{6,2}$	(0.30, 0.40, 0.50, 0.60; 1)	(0.61, 0.71, 0.81, 0.91; 1)	(0.18, 0.29, 0.41, 0.55; 1)	0.1364	
	$F_{6,3}$	(0.27, 0.37, 0.47, 0.57; 1)	(0.61, 0.71, 0.81, 0.91; 1)	(0.17, 0.28, 0.40, 0.54; 1)	0.1277	
	$F_{6,4}$	(0.16, 0.26, 0.36, 0.46; 1)	(0.53, 0.63, 0.73, 0.83; 1)	(0.08, 0.16, 0.26, 0.38; 1)	0.0825	
	$F_{6,5}$	(0.33, 0.43, 0.53, 0.63; 1)	(0.61, 0.71, 0.81, 0.91; 1)	(0.20, 0.31, 0.43, 0.57; 1)	0.1452	
	$F_{6,6}$	(0.24, 0.34, 0.44, 0.54; 1)	(0.53, 0.63, 0.73, 0.83; 1)	(0.13, 0.22, 0.33, 0.46; 1)	0.1054	
R_7	$F_{7,1}$	(0.30, 0.40, 0.50, 0.60; 1)	(0.67, 0.77, 0.87, 0.97; 1)	(0.20, 0.31, 0.43, 0.57; 1)	0.1469	0.5626 (Approx. 7%)
	$F_{7,2}$	(0.27, 0.37, 0.47, 0.57; 1)	(0.64, 0.74, 0.84, 0.94; 1)	(0.17, 0.28, 0.40, 0.54; 1)	0.1326	
	$F_{7,3}$	(0.21, 0.31, 0.41, 0.51; 1)	(0.44, 0.54, 0.64, 0.74; 1)	(0.09, 0.17, 0.27, 0.38; 1)	0.0853	
	$F_{7,4}$	(0.21, 0.31, 0.41, 0.51; 1)	(0.67, 0.77, 0.87, 0.97; 1)	(0.14, 0.24, 0.36, 0.50; 1)	0.1188	
	$F_{7,5}$	(0.16, 0.26, 0.36, 0.46; 1)	(0.50, 0.60, 0.70, 0.80; 1)	(0.08, 0.16, 0.26, 0.38; 1)	0.0790	
R_8	$F_{8,1}$	(0.27, 0.37, 0.47, 0.57; 1)	(0.67, 0.77, 0.87, 0.97; 1)	(0.18, 0.27, 0.39, 0.53; 1)	0.1375	0.6219 (Approx. 7%)
	$F_{8,2}$	(0.16, 0.26, 0.36, 0.46; 1)	(0.61, 0.71, 0.81, 0.91; 1)	(0.10, 0.18, 0.29, 0.42; 1)	0.0931	
	$F_{8,3}$	(0.30, 0.40, 0.50, 0.60; 1)	(0.56, 0.66, 0.76, 0.86; 1)	(0.17, 0.28, 0.40, 0.54; 1)	0.1260	
	$F_{8,4}$	(0.27, 0.37, 0.47, 0.57; 1)	(0.64, 0.74, 0.84, 0.94; 1)	(0.17, 0.28, 0.40, 0.54; 1)	0.1326	

	$F_{8,5}$	(0.27, 0.37, 0.47, 0.57; 1)	(0.64, 0.74, 0.84, 0.94; 1)	(0.17, 0.28, 0.40, 0.54; 1)	0.1326	
R_9	$F_{9,1}$	(0.30, 0.40, 0.50, 0.60; 1)	(0.61, 0.71, 0.81, 0.91; 1)	(0.18, 0.27, 0.39, 0.53; 1)	0.1364	0.6707 (Approx. 8%)
	$F_{9,2}$	(0.16, 0.26, 0.36, 0.46; 1)	(0.61, 0.71, 0.81, 0.91; 1)	(0.10, 0.18, 0.29, 0.42; 1)	0.0931	
	$F_{9,3}$	(0.30, 0.40, 0.50, 0.60; 1)	(0.59, 0.69, 0.79, 0.89; 1)	(0.18, 0.27, 0.39, 0.53; 1)	0.1312	
	$F_{9,4}$	(0.16, 0.26, 0.36, 0.46; 1)	(0.61, 0.71, 0.81, 0.91; 1)	(0.10, 0.18, 0.29, 0.42; 1)	0.0931	
	$F_{9,5}$	(0.16, 0.26, 0.36, 0.46; 1)	(0.61, 0.71, 0.81, 0.91; 1)	(0.10, 0.18, 0.29, 0.42; 1)	0.0931	
	$F_{9,6}$	(0.24, 0.34, 0.44, 0.54; 1)	(0.64, 0.74, 0.84, 0.94; 1)	(0.16, 0.25, 0.37, 0.51; 1)	0.1236	
R_{10}	$F_{10,1}$	(0.36, 0.46, 0.56, 0.66; 1)	(0.67, 0.77, 0.87, 0.97; 1)	(0.24, 0.35, 0.49, 0.64; 1)	0.1657	0.9906 (Approx. 12%)
	$F_{10,2}$	(0.36, 0.46, 0.56, 0.66; 1)	(0.67, 0.77, 0.87, 0.97; 1)	(0.24, 0.35, 0.49, 0.64; 1)	0.1657	
	$F_{10,3}$	(0.27, 0.37, 0.47, 0.57; 1)	(0.64, 0.74, 0.84, 0.94; 1)	(0.17, 0.28, 0.40, 0.54; 1)	0.1326	
	$F_{10,4}$	(0.27, 0.37, 0.47, 0.57; 1)	(0.61, 0.71, 0.81, 0.91; 1)	(0.17, 0.28, 0.40, 0.54; 1)	0.1277	
	$F_{10,5}$	(0.27, 0.37, 0.47, 0.57; 1)	(0.56, 0.66, 0.76, 0.86; 1)	(0.15, 0.24, 0.36, 0.50; 1)	0.1180	
	$F_{10,6}$	(0.24, 0.34, 0.44, 0.54; 1)	(0.53, 0.63, 0.73, 0.83; 1)	(0.13, 0.22, 0.32, 0.45; 1)	0.1054	
	$F_{10,7}$	(0.53, 0.63, 0.73, 0.83; 1)	(0.50, 0.60, 0.70, 0.80; 1)	(0.26, 0.38, 0.51, 0.66; 1)	0.1754	
R_{11}	$F_{11,1}$	(0.16, 0.26, 0.36, 0.46; 1)	(0.53, 0.63, 0.73, 0.83; 1)	(0.08, 0.16, 0.26, 0.38; 1)	0.0825	0.6494 (Approx. 8%)
	$F_{11,2}$	(0.30, 0.40, 0.50, 0.60; 1)	(0.64, 0.74, 0.84, 0.94; 1)	(0.19, 0.30, 0.42, 0.57; 1)	0.1417	
	$F_{11,3}$	(0.27, 0.37, 0.47, 0.57; 1)	(0.64, 0.74, 0.84, 0.94; 1)	(0.17, 0.28, 0.40, 0.54; 1)	0.1326	
	$F_{11,4}$	(0.39, 0.49, 0.59, 0.69; 1)	(0.64, 0.74, 0.84, 0.94; 1)	(0.25, 0.36, 0.49, 0.65; 1)	0.1689	
	$F_{11,5}$	(0.24, 0.34, 0.44, 0.54; 1)	(0.64, 0.74, 0.84, 0.94; 1)	(0.16, 0.25, 0.37, 0.51; 1)	0.1236	
Overall risk values					**8.4018**	

Table 3.6: Risk rating (crisp) values for linguistic risk parametric scale

Likelihood of occurrence (L)	Impact of risk (IR)	Fuzzy risk rating (L×I)	Risk rating (crisp)
Very rare (VR)	Very low (VL)	(0, 0.01, 0.04, 0.09; 1)	0.0108
Rare (R)	Low (L)	(0.01, 0.04, 0.09, 0.16; 1)	0.0256
Often (O)	Moderate (M)	(0.09, 0.16, 0.25, 0.36; 1)	0.0797
Frequent (F)	Serious (S)	(0.25, 0.36, 0.49, 0.64; 1)	0.1678
Very Frequent (VF)	Critical (C)	(0.49, 0.64, 0.81, 1; 1)	0.2900

Table 3.7: Risk categories

Risk rating (crisp) ranges	Risk category
(0 – 0.0599)	0
(0.0600 – 0.0999)	1
(0.1000 - 0.1499)	2
(0.1500 - 0.1999)	3
(0.2000 - 0.2499)	4
(0.2500 - 0.2900)	5

Table 3.8: Identification of risk factors belonging in various risk categories and requirement of action to manage the risk

Risk Category/ Risk rating (Crisp)	Risk influencing factors	Action(s) required
Category 5 Rating 0.2500 – 0.2900	Not Identified	• Very immediate notification of Risk by Risk Owner to the RM Team Lead (proper documentation created). • Immediate investigation required by RM Team Lead. • Risk committee convened immediately to review risk. • Decision Team placed on high alert. • Risk committee creates a recommendation to be presented immediately to Decision Team. • Decision Team reviews, approves, and or revises Action Plan. • Risk Owner implements Action Plan. • RM Team Lead tracks Action Plan results. • Risk Committee reviews monthly Action Plan implementation results. • Decision Team reviews monthly Risk Reports.
Category 4 Rating 0.2000 – 0.2499	Not Identified	• Immediate notification of Risk by Risk Owner to the RM Team Lead (proper documentation created). • Immediate investigation required by RM Team Lead. • Risk committee convened urgently to review risk. • Decision Team placed on alert.

		• Risk committee creates a recommendation to be presented to Decision Team at their next scheduled meeting. • Decision Team reviews, approves, and or revises Action Plan. • Risk Owner implements Action Plan. • RM Team Lead tracks Action Plan results. • Risk Committee reviews monthly Action Plan implementation results. • Decision Team reviews monthly Risk Reports.
Category 3 Rating 0.1500 – 0.1999	$F_{2,4}$, $F_{3,2}$, $F_{3,4}$, $F_{4,2}$, $F_{10,1}$, $F_{10,2}$, $F_{10,7}$, $F_{11,4}$.	• Immediate notification of Risk by Risk Owner to the RM Team Lead (proper documentation created). • Immediate investigation required by RM Team Lead. • Risk committee convened in a timely manner to review risk. • Risk committee creates a recommendation to be presented to Decision Team at their next scheduled meeting. • Decision Team reviews, approves, and or revises Action Plan. • Risk Owner implements Action Plan. • RM Team Lead tracks Action Plan results. • Risk Committee reviews monthly Action Plan implementation results. • Decision Team reviews monthly Risk Reports.
Category 2 Rating 0.1000 – 0.1499	$F_{1,1}$, $F_{1,2}$, $F_{1,3}$, $F_{1,4}$, $F_{1,5}$, $F_{1,7}$, $F_{1,6}$, $F_{1,7}$, $F_{1,9}$, $F_{1,11}$, $F_{2,1}$, $F_{2,2}$, $F_{2,3}$, $F_{3,3}$, $F_{3,5}$, $F_{3,6}$, $F_{3,7}$, $F_{3,8}$, $F_{4,1}$, $F_{4,3}$, $F_{4,4}$, $F_{4,5}$, $F_{4,6}$, $F_{5,1}$, $F_{5,3}$, $F_{5,4}$, $F_{5,5}$, $F_{6,1}$, $F_{6,2}$, $F_{6,3}$, $F_{6,5}$, $F_{6,6}$, $F_{7,1}$, $F_{7,2}$, $F_{7,4}$, $F_{8,1}$, $F_{8,3}$, $F_{8,4}$, $F_{8,5}$, $F_{9,1}$, $F_{9,3}$, $F_{9,6}$, $F_{10,3}$, $F_{10,4}$, $F_{10,5}$, $F_{10,6}$, $F_{11,2}$, $F_{11,3}$, $F_{11,5}$.	• Prompt notification of Risk by Risk Owner to the RM Team Lead (proper documentation created). • Timely investigation by RM Team Lead. • Reviewed and evaluated at monthly Risk Committee meeting. • Action Plan determined, if required. • Risk Owner implements Action Plan. • RM Team Lead tracks Action Plan results. • Risk Committee reviews monthly Action Plan implementation results. • Decision Team reviews monthly Risk Reports.

Category 1 Rating 0.0600 – 0.0999	$F_{1,8}$, $F_{1,10}$, $F_{3,1}$, $F_{5,2}$, $F_{6,4}$, $F_{7,3}$, $F_{7,5}$, $F_{8,2}$, $F_{9,2}$, $F_{9,4}$, $F_{9,5}$, $F_{11,1}$.	• Timely investigation by RM Team Lead. • Reviewed and evaluated at monthly Risk Committee meeting. • Action Plan defined. • Risk tracked for further possible action if Risk Rating escalates.
Category 0 Rating 0 – 0.0599	Not Identified	• No action required. • Risk placed on Watch List and reviewed by Risk Committee. • Risk tracked for further possible action if Risk Rating escalates.

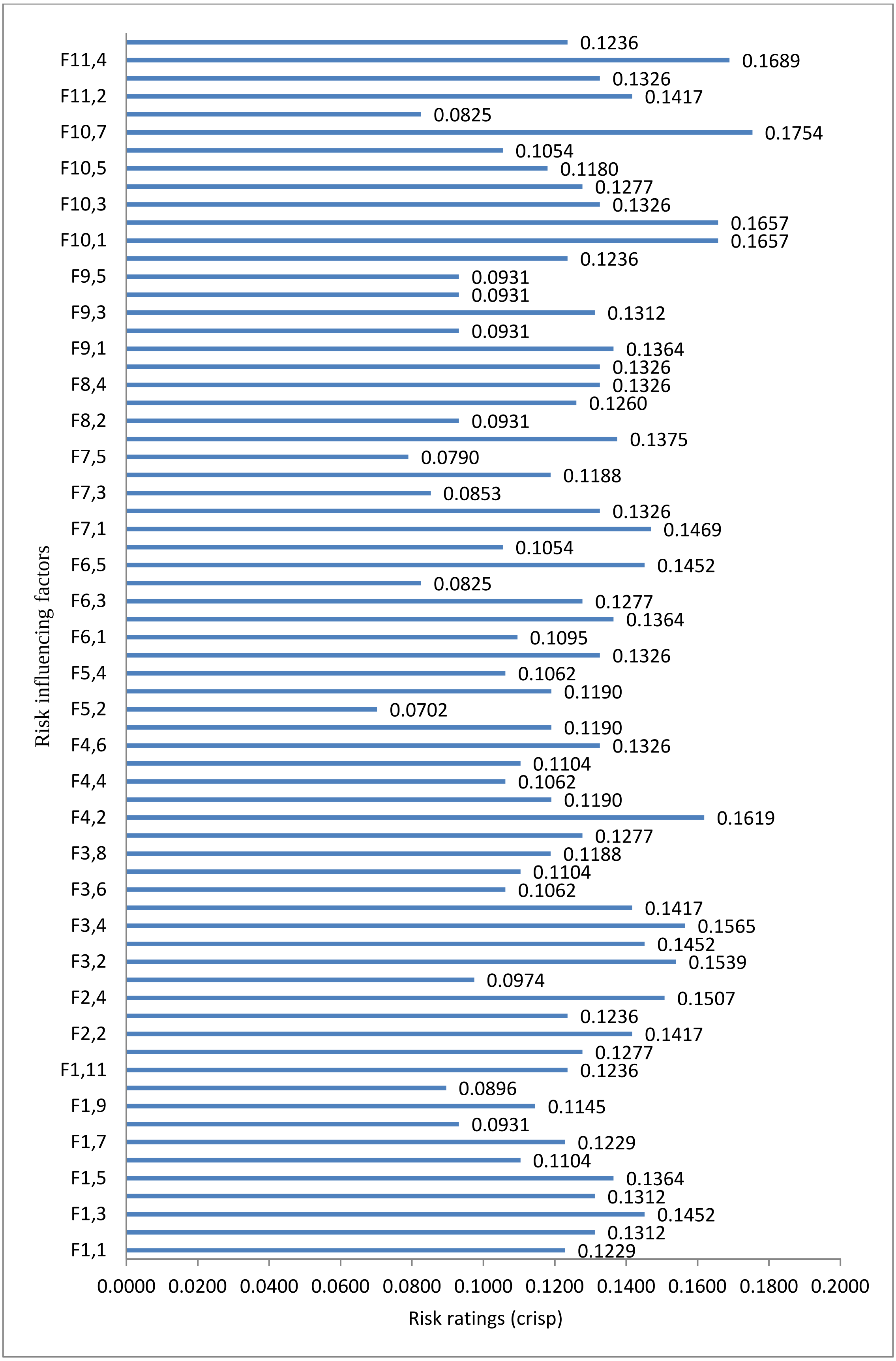

Fig. 3.3: Risk ratings (crisp) corresponding to various risk influencing factors in relation to IT outsourcing

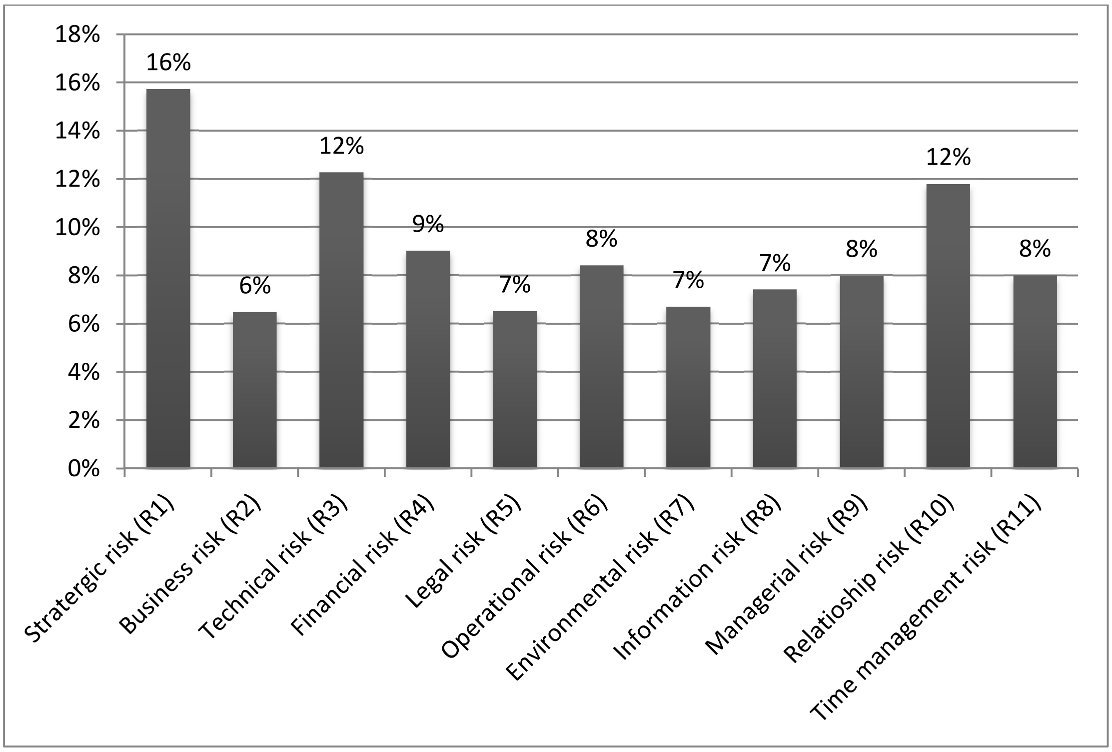

Fig. 3.4: Percentage of contribution (approx.) of individual risks to the overall ITO risk

CHAPTER 4

ANALYSIS OF OCCUPATIONAL HEALTH HAZARDS IN UNDERGROUND COAL MINING INDUSTRY

4.1 Coverage

Underground coal mining is one of the utmost risk prone activities as far as occupational safety and health issues are concerned. Other than loss of lives or serious physical injuries due to mining accidents; occupational health hazards in underground coal mining is seemed critical and remains as a prominent issue. Therefore, this work is sought to identify various physical, chemical, biological, ergonomic and psychosocial health hazards, and to analyze the risks associated with potential injuries or diseases arising out of the hazards. This study proposes a unique health hazards risk assessment methodology for estimating extent of hazard risk using three important measuring parameters: consequence of exposure, period of exposure, and probability of exposure. A case study has been conducted using the data from an underground coalmine industry located in the western part of Odisha, governing by Mahanadi coalfields limited (MCL). The hazard exposures have been assessed subjectively based on the expert judgment. The concept of 'center of area' method for generalized triangular fuzzy numbers has been used to quantify the 'degree of hazard risk' in terms of crisp values. Finally, a logical framework for categorizing health hazards into different risk levels has been constructed on the basis of distinguished ranges of evaluated risk ratings (crisp). Subsequently, an action required plan has been suggested, which could provide guideline to the managers for successfully managing health hazard risks in the context of underground coal mining exercise.

4.2 Problem Statement

Mining has always been considered as the most hazardous sectors because of its dangerous work ambience (ILO, 2010). According to the latest report by DGMS (2011), coal mining is inherently more dangerous than metal mining. However, underground coal mining appears to be more dangerous than open cast mining. In addition to the high frequency of accidents, coal mining is ranked at the top in the list of hazardous workplaces; wherever, statistics are maintained the potential for a major incident involving multiple loss of life which is always present in underground operations (DGMS, 2011). The persons working in the underground coal mines may expose to a wide range of hazards (or harmful/adverse effects due to ill-workplace conditions) that may cause serious incidents, injury, death, ill-health or disease. Occupational safety is an integral part of occupational health and safety (OHS) which promotes safety and welfare of people engaged in the work environment. Its main goal is to prevent illness, accidents, injuries, and fatalities occurring at the workplaces. Unlike occupational safety, occupational health is also a very imperative issue in underground coal mining since exposure imparts health hazards at various levels of operational work which are likely to cause physical injuries/diseases, fatalities and loss of national assets. In long run, the effects of those physical injuries/diseases may amplify and can finally cause loss of life (death). Occupational health may be defined as a condition that results from exposure in a workplace to a physical, chemical or biological agent to the extent that the health of the worker is impaired (www.labour.gov.on.ca). Workers' health can be understood by several determinants, including hazards at the workplace leading to musculoskeletal diseases, chronic lung diseases, hearing loss, circulatory diseases, stress related disorders and communicable diseases and others. Data regarding the number of coal mine workers suffering from aforesaid occupational diseases are very difficult to obtain; since most of the countries preferring to remain silent about their high mortality. For example, Pneumoconiosis (black lung) is a common chronic lung disease of coal miners which leads to reduced life expectancy. In some mining countries such as US, about 4,000 new cases (4 percent of workers) and in China, about 10,000 new cases (0.2 percent of workers) have been identified as a symptom of black lung every year (www.abelard.org). According to ILO (2010), the global survey reports that every day around 6,300 workers die as a result of occupational accidents or diseases, which reflects more than 2.3 million deaths per year (www.ilo.int). However, it is felt that the happening of the majority of various work-related diseases/injuries can be reduced (or prevented) by adopting proper occupational health hazard control measures at the workplace.

As compared to the developing countries, Indian coal mining industries are unorganized, and the proper health and safety awareness are still lagging. Coal miners are not properly trained to acquire health and safety awareness in the work environment. Aspect of adopting modern technology and increase of social awareness in the workers community are still a challenge.

In this context, research interest has been evolved to identify various occupational health hazards followed by associated risk analysis which need to be addressed for establishing proper hazard monitoring as well as prevention strategy in order to reduce work-related injuries/diseases especially in underground coal mines. In many discussions, the words "hazard" and "risk" are very often used as in interchangeably but there exists slight difference in their meanings subject to particular conditions. In relation to occupational health and safety (OHS), a hazard may be defined as an object or situation which has a built-in ability to cause an adverse effect; whilst risk, on the other hand, is the chance or likelihood that such affects may incur. Moreover, risk may be defined as a combination of likelihood of an occurrence of a hazardous event or exposure(s) and the severity of injuries or ill health that can be caused by that particular event or exposure(s) (BSI, 2007).

In particular underground coal mines, some predominant health hazards at the work place like dust, noise, heat, humidity, and vibrations adversely affect workers' health. Therefore, the chances (or likelihoods) that such adverse health effects are likely to incur imposed by various workplace hazards can be estimated by the process of efficient health-hazard risk assessment module. In a generic viewpoint, risk assessment is the process to identify hazards existing in the work environment as well as evaluating the risk(s) posed by those hazards and to rank them in accordance with the order of importance for the purpose of controlling properly (BSI, 2007).

This study, therefore, aims to identify as well as examine physical, chemical, biological, ergonomic and psychosocial occupational health hazards in relation to underground coal mines. The study also provides a unique risk assessment procedure in order to assess the extent of risks (posed by various hazards) using three measuring parameters such as consequence of exposure, period of exposure, and probability of exposure.

Exhaustive literature review reveals that limited studies have been reported so far on understanding of occupational health hazards as well as hazard risk assessment particularly at underground coal mining work. Moreover, few attempts have been made to establish a comprehensive approach in analyzing various issues like health-hazard risk assessment, hazard prioritization, and hazard prevention and control measures for improvement of health and safety status at workplace in underground coal mines. Few of the pioneer researchers have used various risk assessment methods (qualitative, quantitative, and semi-quantitative) based on the hazard theory, number of days-lost at work, accident analysis, and bow-tie diagram (Zhu-Wu et al., 2011; Sari et al., 2009; Jacinto and Silva, 2010; Persechino et al., 2013). However, Kou and Lu (2013) have suggested that individual knowledge; experience and intuitive judgment might provide better assessment of risk rather than quantitative (numeric) analysis. Motivated by this, the present work has addressed the application feasibility of fuzzy set theory for risk assessment, thereby tackling the difficulty that arises in individuals' intuitive assessment process. The objective of this work is to develop a comprehensive occupational health-hazard risk understanding model in relation to underground coal mines; and also to propose a unified health-hazard risk assessment framework towards assessing the extent of occupational health risks through exploration of fuzzy knowledge approximation theory supportive to a qualitative (descriptive) risk analysis. Furthermore, all perceived hazards have been classified into different categories based on their quantifying value of risk ratings and then a holistic hazard monitoring plan has been recommended which could provide a clear-cut guideline towards effective management of occupational health risks. The main purpose of risk assessment is to enable mine managers to comply with the requirements of occupational health and safety (OHS) improvement at underground coal mining.

4.3 Occupational Health Hazard Risk Assessment

Health risk assessment requires an inclusive understanding of the potential adverse health effects associated with excessive exposure to a specific health hazard. In general, the elements to consider for establishing a risk assessment matrix are the likelihood of the occurrence of a hazardous event (exposure) and the severity of illness that can be caused by such event (i.e. consequence of exposure). However, in order to calculate a more scientific occupational health risk rating, a generic equation needs to be explored. In this work, degree of risk extent has been assumed depends on the following three basic elements: consequence of exposure (C), period of exposure (E), and probability of exposure (P). Hence, mathematically, risk can be derived as (Schoeman, 2001):

Risk (R) = Consequence (C) × Likelihood (L)

and, Likelihood (L) = Probability of exposure (P) × Period of exposure (E)

Thus,

$$\text{Risk, } R = C \times P \times E \qquad (4.1)$$

All three exposure measures may be expressed in the range [0, 1] where larger value shows higher the impact. This can be observed from Eq. (4.1) that the extent of risk is close to zero if an exposure has either less consequence or less likelihood. Also, if an exposure poses high consequence and high likelihood of occurrence, its extent of risk is likely to be appear as very high i.e. close to one. Health hazard risk assessment depends on the magnitude, frequency and duration of the exposure for each potential hazard that can be estimated in both qualitatively and quantitatively. Qualitative risk assessment is easy and practical than the quantitative analysis because it does not demand numeric data of past history; rather it needs experts experience as well as scrutiny for subjective judgment (Pinto, 2014; Kou and Lu, 2013; Zhe, 1995). Qualitative methods are usually preferred when the available information's (or data) are inadequate for statistical analysis. Therefore, this study focuses on the qualitative risk assessment process that facilitates to evaluate all three aforesaid exposures of each potential hazard in a subjective way for assessing the extent of health risk. The subjective estimation of these exposures usually involves imprecise or vague information (data) and also there remains some guesswork in the assessment. This is the reason why the exploration of fuzzy logic concept is seemed to be fruitful to improve the effectiveness of risk assessment method in subjective viewpoint.

For qualitative risk assessment in fuzzy environment, all three components (Eq. 4.1) i.e. C, P and E are to be expressed in terms of fuzzy numbers; and multiplication of above three is likely to provide another fuzzy number representing the estimated risk extent. At present there is no correct solution as well as no specific operational rule to produce membership function for the multiplication of more than two fuzzy numbers. Therefore, defuzzifying the fuzzy numbers may be considered as an appropriate way to resolve the above limitation. Since many methods have been proposed in the literature resource to deal with ranking/ defuzzifying fuzzy numbers; still selection of a proper defuzzification method is important for obtaining satisfactory result in all situations. The term 'defuzzification' is reserved for the problem of interpreting the membership degrees of the fuzzy sets into a specific crisp value. Some recent ranking methods can be understood in (Abbasbandy and Asady, 2006; Asady and Zendehnam, 2007; Asady, 2010; Yong et al., 2006; Wang and Luo, 2009; Asady, 2011, Thorani et al., 2012b). However, in spite of number of merits, some of these methods are computationally complex and none of them provides satisfactory results to rank the fuzzy numbers in all situations. In this work, the method of center of area (COA) has been utilized to determine the crisp value of fuzzy numbers due to its simplicity of implementation.

4.4 Fuzzy Preliminaries

Fuzzy set theory is primarily concerned with the quantification of imprecise and vague information (data) in every decision making problems (Zadeh, 1965). Imprecision and vagueness are inherent to the decision maker's mental model of the qualitative assessment problem under study. Thus, Fuzzy set incorporates a representation of imprecision and subjectivity into the model formulation as well as solution process (Leekwijck and Kerre, 1999; Yu and Goh, 2014; Yu et al., 2012). A fuzzy set A is defined as: $A=\left\{\left(x,\mu_A(x)\right)\middle| x\in U\right\}$, where U is the universe of discourse, x is an element in U, A is a fuzzy set in U, $\mu_A(x)$ is the membership function of A at x, in the interval of $[0,1]$ (Kaufmann and Gupta, 1991). The larger $\mu_A(x)$ represents the stronger grade of membership for element x in fuzzy set A. Moreover, a fuzzy number can be defined as a fuzzy subset in the universe of discourse U that is both convex and normal. In decision making modeling, various types of fuzzy numbers such as triangular, trapezoidal, Gaussian numbers are used for interpreting the linguistic data to quantitative data (Chen and Chen, 2009; Xia et al. 2006; Yang and Hung, 2007). However, triangular fuzzy numbers are extensively used due to its simplicity in mathematical representation as well as easy computation. A triangular fuzzy number A can be denoted by (a,b,c), if its membership function $\mu_A(x)$ is given by (Chen and Chen, 2009):

$$\mu_A(x)=\begin{cases}(x-a)/(b-a), & a\le x\le b\\ (c-x)/(c-b), & b\le x\le c\\ 0, & otherwise.\end{cases} \tag{4.2}$$

A linguistic variable is a variable whose values are expressed in words or sentences in natural or artificial languages (Zadeh, 1975). The concept of linguistic variables is very helpful in dealing with situations, which are too complex or ill-defined to be described in traditional quantitative terms (Zimmermann, 1991). For example, “consequence of exposure” is a linguistic variable whose values include K (Catastrophic), C (Critical), S (Serious) and M (Marginal). These linguistic values can further be represented by triangular fuzzy numbers followed by standard linguistic scale.

4.4.1 *Center of Area (COA) Method*

The COA method is a basic general defuzzification operator that maps a fuzzy set into a single crisp value. The concept of COA defuzzification can be understood in Tong (1978) as early as 1978. The COA method selects the output crispy value of the fuzzy controller, which divides the area under the membership function in two equal parts. This method has been fruitfully applied to defuzzify the different types of fuzzy membership functions (triangular, trapezoidal and interval valued trapezoidal etc.) of fuzzy numbers (Halgamuge, 1998; Leekwijck and Kerre, 1999; Runkler and Glesner, 1993). In this work, triangular fuzzy membership function has been chosen for the proposed health hazard risk assessment model. The following formulae are developed to defuzzify triangular fuzzy numbers based on the above COA concept in order to complete the proposed risk assessment module. The defuzzification formulae (Eqs. (4.3-4.5)) for fuzzy number A can be derived from the following three conditions (Chu and Varma, 2012):

(a) If $\overline{ab} > \overline{bc}$ as shown in Fig. 4.1:

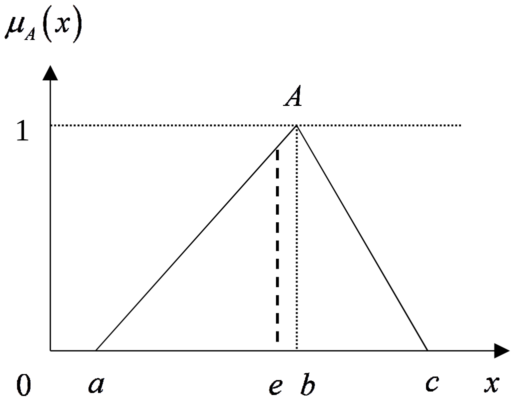

Fig. 4.1: Triangular fuzzy number A and its defuzzification value e

Thus, according to Fig. 4.1, e is derived from "$I_L(A) = I_R(A)$" as

$$\Rightarrow \frac{1}{2}(e-a)\left(\frac{e-a}{b-a}\right) = \frac{1}{2}\left(1+\frac{e-a}{b-a}\right)(b-e) + \frac{1}{2}(c-b)$$

$$\Rightarrow 2e^2 - 4ae + a^2 + ab + ac - bc = 0$$

$$\Rightarrow e = a \pm \frac{1}{2}\left[2a^2 - 2ab - 2ac + 2bc\right]^{1/2}.$$

Obviously, $e = a + \frac{1}{2}\left[2a^2 - 2ab - 2ac + 2bc\right]^{1/2}$ (4.3)

(b) If $\overline{ab} < \overline{bc}$ as shown in Fig. 4.2:

Thus, according to Fig. 4.2, e is derived from "$I_L(A) = I_R(A)$" as

$$\Rightarrow \frac{1}{2}(b-a) + \frac{1}{2}\left(1+\frac{e-c}{b-c}\right)(e-b) = \frac{1}{2}\left(\frac{e-c}{b-c}\right)(c-e)$$

$$\Rightarrow 2e^2 - 4ce + c^2 - ab + ac + bc = 0$$

$$\Rightarrow e = c \pm \frac{1}{2}\left[2c^2 + 2ab - 2ac - 2bc\right]^{1/2}.$$

Obviously, $e = c - \frac{1}{2}\left[2c^2 + 2ab - 2ac - 2bc\right]^{1/2}$. (4.4)

(c) If $\overline{ab} = \overline{bc}$ as shown in Fig. 4.3:

According to Fig. 4.3, the defuzzification value e equals b.

Thus, e is derived from "$I_L(A) = I_R(A)$" as

$$\Rightarrow \frac{1}{2}(e-a) = \frac{1}{2}(c-e) \Rightarrow e = \frac{1}{2}(a+c) \quad (4.5)$$

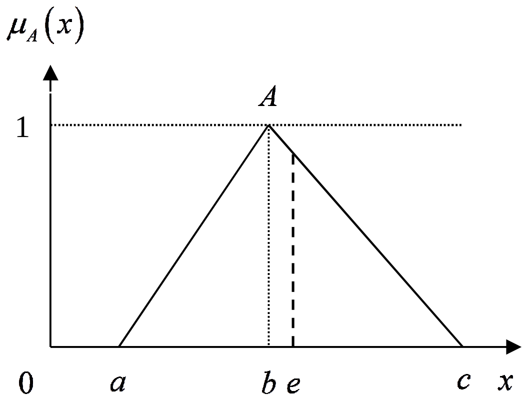

Fig. 4.2: Triangular fuzzy number A and its defuzzification value e

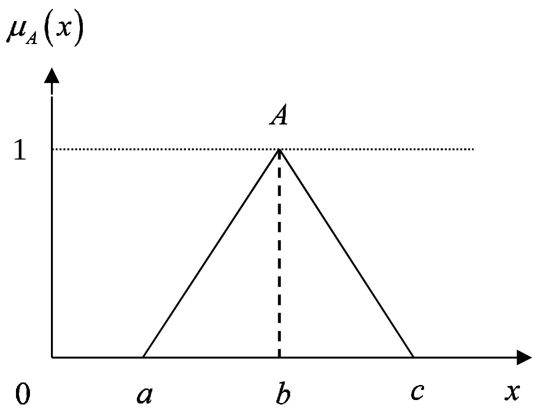

Fig. 4.3: Triangular fuzzy number A and its defuzzification value e

4.5 Proposed Methodology

A hierarchical health hazard understanding model has been developed here to evaluate the degree of risk of each individual health hazards associated with the particular hazard influencing agents that directly or indirectly affect workers' health in underground coal mining exercise (Table 4.1). A more formal multi-criteria decision making (MCDM) scenario has been introduced for successful evaluation of individual health hazard risks corresponding to the respective hazard agents. The scenario comprises a committee of k decision makers $(DM_1, DM_2, ..., DM_k)$ who are participating for assessing the appropriateness of n health hazard risks $(R(H)_i, i=1,...,n)$, with corresponding j^{th} exposure $(j \approx C, E, and\, P)$ to specific health hazards $(H(x)_i, i=1,...,n)$ under a specific group of hazard influencing agent (x). As discussed earlier, risk of each health hazards can be quantified based on their exposure assessment. Here, three evaluating factors such as: consequence of exposure (C), period of exposure (E), and probability of exposure (P) have been used for calculating the extent of risk of each individual health hazards. The following procedural steps have been used for evaluating the health hazard risk ratings as well as addressing the plan for controlling risks:

Step 1: Identification of occupational health hazards corresponding to particular hazard influencing agents to develop a hierarchical health hazard risk assessment module.

Step 2: Selection of fuzzy linguistic scales for all three exposures such as: consequence of exposure (C), period of exposure (E), and probability of exposure (P); and also selection of appropriate membership function for each exposure.

Step 3: Collection of linguistic data (in relation to consequence of exposure (C), period of exposure (E), and probability of exposure (P)) of each identified hazard from the experience of the industry personals (experts). Then, these linguistic data are to be converted into corresponding fuzzy numbers.

Step 4: Aggregation of fuzzy numbers using fuzzy aggregation operator.

Step 5: In this step, all aggregated fuzzy numbers in relation to aforesaid three evaluating exposures of each individual hazard have been transformed into crisp numbers using a novel fuzzy defuzzifying method called 'Center of Area (COA)', which is applicable for triangular fuzzy numbers in fuzzy set theory. A risk rating (degree of risk) of each health hazard is calculated by multiplying the crisp values of each evaluating exposures; the results obtained thereof can be called as 'crisp risk rating'.

Step 6: Categorization of health hazards based on the risk level ratings.

Step 7: A novel action requirement plan has been suggested finally for controlling the health hazard risks with reference to different risk level ratings.

4.6 Case Application

In order to validate the proposed health hazard risk assessment framework, a case study has been conducted for an Indian underground coal mine industry located in western part of Odisha, governing by Mahanadi coalfields limited (MCL), a subsidiary of Coal India Limited (CIL). Recently, the company has become more concerned in solving occupational health and safety issues although it adheres to the existing guidelines of traditional 'safety policy and standards'. To facilitate mining managers in re-examining status of various health and safety practices and establishing refined health risk mitigation policies, a focus group survey has been conducted from safety professionals of the said mining sector who were actively associated in underground coal excavation projects. The group entails five safety personnel's (or experts) with more than fifteen years' experience in aforesaid projects who were participated in this survey. The experts' identity have not been wide-opened here because of its anonymity reasons; therefore they have been denoted to as DM_1, DM_2, DM_3, DM_4, and DM_5. The experts have been requested to rate their personal opinion against each of individual health hazard in terms of their exposure extent referring to a linguistic scale as depicted in detailed questionnaire. Also, they are invited to go for the choice to mention, if any other items in relation to the health hazards that have not been stated in the said questionnaire. The detailed questionnaire for health hazard risk assessment is shown in Appendix C. All selected experts for this survey are usually involved in underground coal excavation projects, and their experience helped immensely in pursuit of this case study.

4.6.1 Identification of Occupational Health Hazards

According to the definition of occupational health and subsequent health hazard, as depicted in Section 4.2, workers health may impair due to existence of various health hazards resulting from excessive exposure in a workplace to a physical, chemical, and biological agent. In this work, five important health hazard influencing agents and their corresponding hazards have been identified from the review of past literature. Here, occupational health hazards have been identified by cause of health impaired, and by place of work. For example, noise induced hearing loss is found to be an important health hazard among the mine workers; pneumoconiosis caused by inhalation of coal dust is another major occupational disease. Moreover, adverse environmental conditions such as high temperature and humidity, abnormal ambience pressure, poor lighting, excessive noise and vibration, accumulation of diesel particulate, and poisonous gases are responsible towards making coal mining as a dangerous sector. In addition, many other important factors such as, ergonomic, biological as well as psychological factors may also adversely affect to the workers' health at workplace in the underground mining operations. Table 4.1 shows a hierarchical occupational health hazard understanding model that represents major health hazards as identified by their causes and effects at various workplace conditions. The identified hazards in Table 4.1 have further been used for establishing a unified health hazard risk assessment framework in order to stimulate prevention and control measures towards reducing the extent of occupational health risks in underground coal mining practice.

4.6.2 Selection of Fuzzy Linguistic Scale

A linguistic scale can be understood by a set of words of same grammatical category, which can be ordered by their semantic strength or degree of informativeness (Horn, 1972; Levinson, 1983). Moreover, fuzzy linguistic scale is an assessment instrument designed to quantify cognitive and linguistic recovery following exposure to health hazard risks at the workplace to a corresponding representation of fuzzy numbers set. Although in many literature, there are several types of linguistic scale has been used to carry out subjective assessment in a variety of fuzzy based decision making problems. But, the type of appropriate membership function of a fuzzy set representing a particular linguistic variable should be selected with the satisfaction of following three criteria: (a) available domain knowledge; (b) simplicity of the membership function; and (c) possible parametric optimization of the fuzzy sets (calibration of the membership function) (Yuen, 2014). In this work, a more general triangular membership function has been found suitable for this application. The advantage of triangular fuzzy numbers in the form of (a,b,c) over others is the most generic class of fuzzy numbers with linear membership function (Dubois and Prade, 1978). Therefore, it finds wide application in modeling linear uncertainty in scientific and decision making problems rather than trapezoidal fuzzy numbers. Moreover, triangular fuzzy numbers are widely used because of its conceptual and computational simplicity. As discussed earlier in Eq. (4.1), health risk assessment can be carried out by the assessment of exposure to a specific health hazard that includes three assessment indices such as, consequence of exposure, probability of exposure, and period of exposure. Therefore, an understanding of linguistic assessment scale for consequence of exposure, period of exposure, and probability of exposure have been presented in Tables (4.2-4.4) respectively. Also, Table 4.5 presents a seven point linguistic variable set and corresponding fuzzy number representation of all three exposure measures that has been used for assessing the risk extent associated with the specific health hazards. Thus, linguistic variables such as Catastrophic (K), Critical (C), Very Serious (VS), Serious (S), Marginal (M), Minor (m), and Negligible (N) are used to rate the consequence of exposure to a specific health hazard. Similarly, Prolonged (P), Frequent (F), Often (O), Seldom (S), Occasional (OC), Rare (R) and Exceptionally Rare (ER) are selected for period of exposure; and Very High (VH), High (H), Medium (M), Low (L), Very Low (VL), Absolutely Low (AL) and Not Applicable (NA) are used for probability of exposure. Fig. 4.4 shows the conceptual schema of triangular fuzzy numbers presented in Table 4.5.

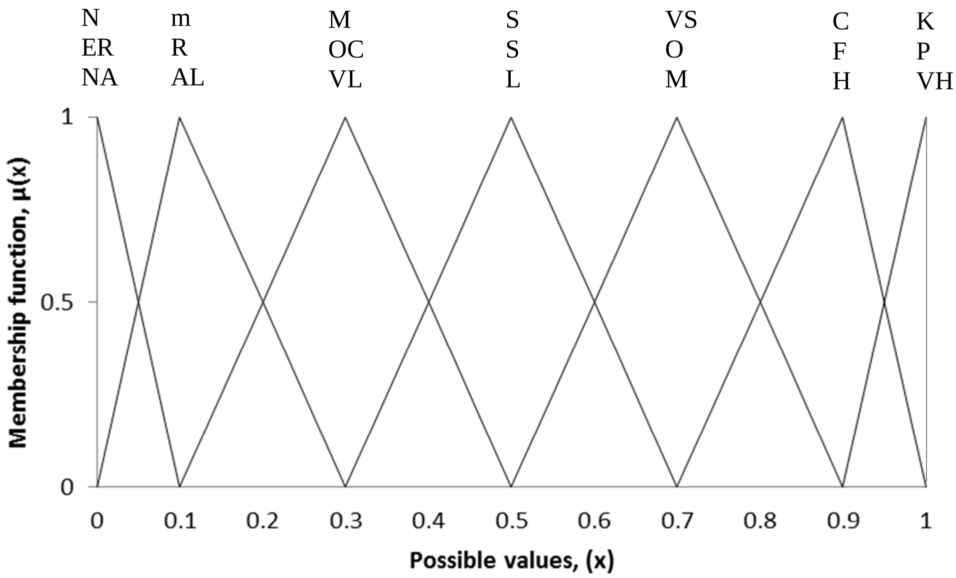

Fig. 4.4: Triangular membership function for three evaluating parameters (C, E, and P)

4.6.3 Data Collection

Three sets of subjective data has been collected from five experts on assessment of consequence of exposure, period of exposure, and probability of exposure, respectively for each of the specific health hazard as mentioned in the detailed questionnaire. All experts or decision makers (DMs) have assigned their judgment in terms of linguistic value with respect to the specific health hazards. During the judgment process, the experts have been requested to keep confidential about their judgment and not to share their personal opinion even among themselves also (to avoid biasness). These data sets are separately collected from the expert's group and tabulated in a well-structured manner. Table 4.6 presents the linguistic data set for each identified health hazards in order to express consequence of exposure assigned by DMs. Also, linguistic information's of both period of exposure as well as probability of exposure of corresponding individual health hazards have been presented in Tables (4.7-4.8), respectively. Subsequently, the above linguistic information's have been translated into corresponding triangular fuzzy numbers by referring to Table 4.5.

4.6.4 Health Hazard Risk Ratings

Risk rating is the process of estimating the event and the severity of adverse health effects that are likely to incur due to excessive occupational exposure to workplace hazards. It is the end product of risk assessment process that can be used for developing and prioritizing the control strategies as well as communicating the risks. During risk assessment process, the obtained information from multiple decision makers towards each exposure to specific health hazard can be combined to form an aggregated preference using fuzzy aggregation rules. The concept of fuzzy arithmetic operations of triangular fuzzy numbers (Gani, 2012) seems to be necessary to form an aggregation rule.

Aggregation is the process of combining the fuzzy sets to form a single collective preference fuzzy set. Assume, k is the number of decision makers $\left(DM_t, t=1,...,k\right)$, who are assigned to assess n occupational health hazard risks $\left(R(H)_i, i=1,...,n\right)$, with corresponding j^{th} exposure $\left(j \approx C, E, and\ P\right)$ to specific health hazards $\left(H(x)_i, i=1,...,n\right)$ under a specific group of hazard influencing agent (x). The basic formula for calculating the aggregated fuzzy preferences $\left(\tilde{H}(x)_i\right)_j$ of j^{th} exposure to hazards can be used as follows (Chen, 2000):

$$\left(\tilde{H}(x)_i\right)_j = \frac{1}{k}\left[H(x)_{ij1} \oplus H(x)_{ij2} \oplus ... \oplus H(x)_{ijk}\right] \quad (4.6)$$

For example, aggregated preference of consequence of exposure (C);

$$\left(\tilde{H}(x)_i\right)_{j\approx C} = \frac{1}{k}\left[H(x)_{ij1} \oplus H(x)_{ij2} \oplus ... \oplus H(x)_{ijk}\right]$$

Similarly, the aggregated preference of other two exposure measures (E and P) can also be calculated using the above Eq. (4.6). Thereafter, crisp numbers of aggregated fuzzy numbers in relation to all three evaluating exposures to specific hazards have been calculated by Eqs. (4.3-

4.5). Also, the degree of risk or risk rating of each individual health hazards can be calculated by their exposure measures using the following relation:

Risk rating, $R(H)_i = \left(C|_{crisp} \otimes E|_{crisp} \otimes P|_{crisp} \right)_i$ (4.7)

The results of aggregated fuzzy preferences, crisp values and risk ratings have been presented in Table 4.9.

The significance of exposure assessment is to obtain the data on exposures of workers to the identified health hazards in terms of consequence of exposure (severity of illness), exposure time (how many times people are exposed and for how long), and probability of exposure (possibility to exceed occupational exposure limit or level of exposure). In some instances, workers may expose to a particular health hazard in occasional, and its concentration is in low level; but exposure consequence may result in critical (more than very serious) and vice-versa. Therefore, a graphical representation of exposure measures in relation to physical hazards has been plotted to understand the level of exposure consequence against the period of exposure as well as the probability of exposure as shown in Fig. 4.5.

Moreover, risk rating of the identified health hazards (health risks) in relation to various hazard agents (physical, chemical, bio-logical, ergonomic, and psychological) can be understood by Figs. (4.6-4.10), respectively. It has been observed by Fig. 4.6, that physical hazards like noise (HP_1), vibration (HP_2), heat and humidity (HP_3), and abnormal pressure (HP_6) are likely to impose adverse effects to the workers' health due to their high value of risk rating. Also, hazards like illumination (HP_4), and shock, burns and electrocution (HP_5) have reasonable or less negative impact to the workers' health but dangerous to the certain workplace conditions.

Similarly it is clearly understood by Figs. (4.7-4.10), that hazards like coal dust (HC_2), crystalline silica (HC_1), and diesel particulate exposure (HC_4) from chemical agent; bacteria exposure (HB_2) from biological agent; awkward working posture (HE_2), and poor workstation design (HE_3) form ergonomic agent; and frustration (HS_1), prolonged stress (HS_2), and drug and alcohol abuse (HS_4) from psychosocial agent imposes severe negative impact to the workers heath. Also, hazards under specific hazard agents which are not mentioned above have reasonable health effects but may highly influence to the certain area of health risks. Therefore, the risk rating of each agent group can be computed by adding of their risk rating values of associated hazards under each agent. In addition, the overall hazard risk extent can be determined by adding all identified hazards risk ratings. The assumption in the aforesaid computational work is that all hazard agents are of equally important (equal priority). The value (risk extent) that is computed corresponding to each hazard agent indicates weighted average. The obtained results are furnished in Table 4.9. It is observed that physical hazard agent has the highest risk rating (1.8088), which can impose highest adverse effect on workers' health among the five hazard agents. Its percentage of contribution is about 29.84% to the overall health hazard risks. The agent groups like chemical hazards risk is contributing second highest percentage; and bio-logical hazards risk has lowest contribution to the overall risk value. The percentage of contributions of each identified hazard agent risks on overall hazard risks can be understood by Fig. 4.11. Therefore, the hazard agent with the highest value of risk rating is the major source that needs to be eliminate/minimize first than the others. Similarly, within the hazard agent (group), health hazards with high risk rating needs to be controlled first by minimizing their exposure to health hazards.

4.6.5 Risk Control Measures

After successful assessment of health hazards risk, actions need to be taken to eliminate risks so far as reasonably practicable in the first instance. Where elimination is not possible, then implementation of control measures is essential to minimize risks to the maximum possible extent. Control measures are the features of a facility that prevent, minimize or mitigate risks to health, safety and property from potential exposure to hazards or incidents at workplace (www.worksafe.vic.gov.au). Control measures can be taken in many forms including physical equipment, process control systems, management processes, operating and maintenance procedures, and formulating the emergency plan by key personnel's and their suggested actions (WS, 2011). The main purpose of implementing control measure is to help the manager to understand how the risks to health and safety associated with potential major hazards are properly managed.

Before the selection of any control options, all health hazards that have been assessed should be categorized in different risk level category based on the various risk rating ranges. Generally, risk rating ranges would be decided from the linguistic parametric scale (Table 4.5). The maximum range is to be selected on the highest risk rating of the exposure to hazards. As previously discussed, risk rating of hazard can be calculated by the multiplication of crisp values of three basic evaluating elements such as; consequence of exposure, period of exposure, and probability of exposure. Thus, risk rating values (crisp) for linguistic risk assessment scale has been presented in Table 4.10. Here, crisp values have also been calculated using COA method and it has been observed that, 0.9146 appears as the maximum risk rating that can be assigned to specific health hazards. Then, five different risk level categories (risk level ratings) have been selected based on the five different risk rating ranges from the overall range of (0 – 0.9146) as shown in Table 4.11.

Now, all assessed health hazards can be placed in different risk level category based on their risk rating, and then control actions could be taken immediately by the risk management team, risk committee, and/or health and safety professionals in order to minimize or eliminate risks so far as reasonably practicable. In this work, a novel action requirement plan has been provided to successfully identify and control risks appeared in different risk level categories. Therefore, identification of various health hazards under each risk level categories and their suggested control actions has been presented in Table 4.12.

The effectiveness of suggested action requirement plan can be checked through regular reviews as well as consultation with workers. Fig. 4.12 shows the hierarchy of controls proposed by SWA (2011), in which the ways of controlling risks from highest level of both protection and reliability to the lowest are ranked.

The level of control measures with in the risk control hierarchy are discussed as follows:

Level 1: Control measures – Eliminate the hazard

The most effective control measure includes eliminating the hazards as well as associated risks. This can be performed by several control options such as, by removing the hazards or selecting alternate products or equipment to eliminate the risk. In some instances, if hazard elimination is not possible then risks can be minimized by lower control measures.

Level 2: Control measures

The following control options are used to minimize risks where it is not reasonably practicable to eliminate hazards, such as:

(i) Substitute the hazard – this involves replacing a substance, method or material to reduce the risk or the hazards.

(ii) Isolate the hazard – this includes physically separating the source of harm or hazard from the workplace or people by providing distance or barriers.

For example;

a) Lock out procedure on faulty equipment;

b) Chemical store room or laboratory kept locked expect to an authorized person.

(iii) Use engineering controls – this involves modifying existing machinery or mechanical process, or purchasing different machinery or plant to provide a physical solution.

For example;

a) use trolleys, hoists or cranes to move heavy loads;
b) place guard rails around moving parts of machinery;
c) set work rates on a production lines to reduce fatigue.

Level 3: Control measures

These are the control measures basically used at the end as they do not control the hazard at the source but depends on human behavior and supervision. Therefore, these control options are tend to be the least effective in minimizing risks. Two approaches to reduce risks in this way are:

(i) Use administrative controls – this includes the work methods or procedures that are designed to minimize the conditions of risks.

For example;

a) developing safe operating procedures on how to operate machinery safely;
b) limit exposure time to a hazardous task;
c) job rotation to restrict hours worked on difficult jobs;
d) providing appropriate training, instruction or information.

(ii) Use personal protective equipment (PPE) – this offers lowest level of protection that includes ear muffs, face masks, hard hats, gloves, aprons and protective eyewear. PPE minimizes exposure to the harmful effects of a hazard but only if workers wear properly.

The aforementioned hierarchy of controls is a generic one. It can be used in the situations where hazard information's are clearly defined. In this study, the proposed action requirement plan (Table 4.12) describes the information relevant to the identified hazards including their nature as well as the level of risks. However, in some special conditions, a specific control measure may need to be developed if the available information is not relevant to the hazards as well as the risks (SWA, 2011). In order to validate the proposed methodology, twelve health and safety managers having more than fifteen years' experience were interviewed regarding to (a) applicability of proposed methods for health hazard risk assessment in coal mining sector, (b) advantages of operating the proposed risk assessment procedures, (c) completeness of identified health hazards for occupational health in underground coal mining, (d) implementation effectiveness of the suggestive control action plans for controlling risks effectively in real life.

Nighty five percent interviewers answered positive to the above questions after the clear examination of proposed risk assessment theory as well as operational steps.

4.7 Managerial Implications and Conclusion

This study highlights on important issues of occupational health risks followed by exposure to health hazards and subsequent implementation of an effective long-term hazard risk management planning, in the context of an Indian underground coal mining sector.

The effectiveness of risk management plan involves monitoring of identified hazards, assessed risks, and risk control measures; and reviewing those control measures to ensure whether they are working effectively.

In this work, a unique hierarchical occupational health hazard understanding model has been proposed to identify the hazards in accordance with their exposure to harmful effects as well as their hazardous workplace conditions. A total twenty one important health hazards under the source of different hazard agents such as; physical, chemical, biological, ergonomic, and psychosocial have been identified from the critical review of health and safety literature in coal mining practice. The hazards that appeared as sensitive to produce harmful effects have been considered in this study.

Moreover, a novel health hazard risk assessment methodology has been proposed to quantify the extent of risk from the assessment of exposures to health hazard. The risk has been characterized by their exposures to harmful effects of specific hazard. In this work, the following three parameters viz. (i) consequence of exposure, (ii) period of exposure, and (iii) probability of exposure have been used to calculate the degree of risk to a particular health hazard. The proposed fuzzy based qualitative risk assessment methodology has been appeared as more practical as well as reliable than traditional quantitative methods since it uses experts' judgment in a subjective way rather than objective.

This work explores the concept of crisp representation of fuzzy number which seems to be effective in categorizing the hazards in different risk level ratings. The obtained result of risk assessment exhibits that the hazards with high degree of risk rating should first be controlled (or managed) in order to enhance workers health and safety status. Therefore, this study has introduced a logical and systematic categorization of identified health hazards followed by effective control plan for managing hazard risks. The concept of hierarchy of risk controls has been highlighted here to provide fundamental idea to the managers for effective selection and implementation of prescribed risk control measures.

In this work, the proposed methodology used for health hazard risk assessment is generic. However, the risk management model presented here as well as developed fuzzy based decision support system towards risk assessment is truly industry specific.

In recent times, many mining industries have adopted cleaner production standards and environmental management systems. An environmental management system and cleaner production standards includes organizational procedures, environmental responsibilities and process to help a mining company to comply with environmental regulations, identify technical and economy benefits and ensure that corporate environmental policies are adopted and followed. A number of multi-national mining corporations have implemented comprehensive EMS at sites, the key in such cases being the formation of working partnerships with administrative bodies and international organizations. Implementation of cleaner production standards and EMS greatly reduce occupational health hazards and thereby reduces associated hazard risks.

Table 4.1: Occupational health hazards in underground coal mining

Agent(s) and Hazard(s)	Consequences/Diseases	Happens due to condition(s)/circumstances
Physical		
Noise (HP_1)	Noise induced hearing loss, tinnitus	Rock drilling, blasting, cutting, materials handling, crushing, conveying and ore processing
Vibration (HP_2)	Spinal disorders Hand-arm vibration syndrome	Mobile equipment operational, such as load–haul–dump units, trucks, scrapers and diggers; vibrating tools such as air leg rock drills; rough roads and vehicles
Heat and humidity (HP_3)	Heat stroke; heat cramp; heat exhaustion; irritability	Deep underground work
Illumination (HP_4)	Loss of visual acuity,	Poor light conditions at underground work
Shock, burns and electrocution (HP_5)	Injuries	Improper layout of electricity supply
Abnormal pressure (low and high barometric pressure) (HP_6)	Bends (joint pain); chokes (chest pain); air embolism; neuralgia; toothache; paranasal sinusitis	Work in deep underground or high altitude mines
Chemical		
Crystalline silica (HC_1)	Silicosis; lung cancer	Underground mining work
Coal dust (HC_2)	Pneumoconiosis or black lung; chronic obstructive pulmonary disease	Underground mining work

Methane gas explosion (HC_3)	Fatal injury; fires	Underground Coal cutting; Inadequate ventilation and monitoring
Diesel particulate exposure (HC_4)	Lung cancer; human carcinogen	Diesel powered mobile equipment, used primarily for drilling and haulage
Biological		
Parasitic and fungal infection (HB_1)	Ankylostomiasis; sporotrichosis; tineapedis and/or capitis; leptospirosis	Pit work where parasites and fungi grow easily owing to high humidity and poor sanitation
Bacteria exposure (HB_2)	Dengue; malaria	Remote location
Ergonomic		
Manual handling (HE_1)	Trauma disorders; shoulder disorders; ankle injuries	Overhead work; handling continuous miner cable; Limited working space
Awkward working posture (HE_2)	Musculoskeletal disease and injury in hands, arms, shoulders, and back etc.	Work in narrow seams and in contorted positions, work with hands above the heads
Poor workstation design (HE_3)	Musculoskeletal disorders	Improper workplace design; Limited working space
Ergonomic stressors (HE_4)	Musculoskeletal disorders such as back pain, fatigue or muscle cramps and stiffness.	Limited working space
Psychosocial		
Frustration (HS_1)	Mental disorders	Improper job schedule like long working hours, shift patterns, and

		heavy workload
Prolonged Stress (HS_2)	Physical and mental disorders	Remote location; working away from family and friends
Expatriate placements (HS_3)	Physical and mental disorders	Restructuring of the organization; a change or redeployment of workers
Drug and Alcohol abuse (HS_4)	Mental disorders; liver injury	Remote location; fatigue
Indication of decreased morale (HS_5)	Mental disorders	Unfavorable work culture like harassment, discrimination, bullying or violence

Table 4.2: Definition of linguistic terms w.r.t. consequence of exposure

CONSEQUENCE OF EXPOSURE	LINGUSTIC VALUE
Two or more mortalities from an occupational disease	Catastrophic (K)
One mortality from an occupational disease	Critical (C)
Life threatening illness. Multiple occupational disease cases	Very Serious (VS)
Serious, irreversible illness. Compensable occupational disease	Serious (S)
Reversible illness. Occupational disease	Marginal (M)
Minor illness	Minor (m)
Very minor illness	Negligible (N)

Table 4.3: Definition of linguistic terms w.r.t. period of exposure

PERIOD OF EXPOSURE	LINGUSTIC VALUE
Continuous exposure for a 8 hour shift or more	Prolonged (P)
Continuous for between 4 – 6 hours – frequent, daily	Frequent (F)
Continuous for between 2 – 4 hours – often, weekly	Often (O)
Short periods of time, a few times per day – unusual, monthly	Seldom (S)
Very unusually, a few times per week – a few times per year	Occasional (OC)
Rare, a few times per month – yearly	Rare (R)
Exceptionally exposed, a few times per year	Exceptionally Rare (ER)

Table 4.4: Definition of linguistic terms w.r.t. probability of exposure

PROBABILITY OF EXPOSURE					Linguistic value
Airborne pollutants	Noise	Thermal - Heat	Illumination	Other	
Exposure > OEL-C or exceeding the TWA-OEL more than threefold or mixture of exposure with an index > 3	≥ 105 dB(A)	WB > 35.0 °C DB > 45.0 °C	0 lux	Exposure at **Very High** levels	**VH**
Exposure ≥ OEL-TWA ≤ three fold OEL-TWA or mixture of exposure with an index between 1 and 3	≥ 85 <105 dB(A)	WB > 32.5 ≤ 35.0 °C DB > 37.0 ≤ 45.0 °C WBGT ≥ 30	>50% below the standard	Exposure at **High** levels	**H**
Exposure ≥ 50% of the OEL and < OEL or mixture of exposure with an index between 0.5 and 1	≥ 82 < 85 dB(A)	WB > 29.0 ≤ 32.5 °C DB > 32.5 ≤ 37.0 °C WBGT ≥ 27 < 30	Between 21 – 50% below the standard	Exposure at **Medium** levels	**M**
Exposure ≥ 25% of the OEL and < 50% of the OEL or mixture of exposure with an index between 0.25 and 0.5	< 82 dB(A)	WB > 27.5 ≤ 29.0 °C DB > 32.5 ≤ 37.0 °C	< the standard to 20% below the standard	Exposure at **Low** levels	**L**
Exposure ≥ 10% of the OEL and < 25% of the OEL or mixture of exposure with an index between 0.1 and 0.25		WB ≤ 27.5 °C DB ≤ 32.5 °C WBGT < 27	≥ standard	Limited exposure	**VL**
Exposure < 10% of the OEL				No contact with/ exposure to	**AL**
Exposure virtually impossible				Not applicable	**NA**

Table 4.5: A 7-Point linguistic scale with corresponding fuzzy numbers for all three exposure measures

Consequence of exposure (C)	Period of exposure (E)	Probability of exposure (P)	Triangular fuzzy numbers
Catastrophic (K)	Prolonged (P)	Very High (VH)	(0.9, 1, 1)
Critical (C)	Frequent (F)	High (H)	(0.7, 0.9, 1)
Very Serious (VS)	Often (O)	Medium (M)	(0.5, 0.7, 0.9)
Serious (S)	Seldom (S)	Low (L)	(0.3, 0.5, 0.7)
Marginal (M)	Occasional (OC)	Very Low (VL)	(0.1, 0.3, 0.5)
Minor (m)	Rare (R)	Absolutely Low (AL)	(0, 0.1, 0.3)
Negligible (N)	Exceptionally Rare (ER)	Not Applicable (NA)	(0, 0, 0.1)

Table 4.6: Consequence of exposure of various health hazards assigned by the DMs in linguistic terms

Agent	Hazards	DM_1	DM_2	DM_3	DM_4	DM_5
Physical	HP_1	S	VS	S	S	VS
	HP_2	S	M	VS	VS	S
	HP_3	VS	S	C	VS	C
	HP_4	S	M	S	S	VS
	HP_5	C	C	VS	K	VS
	HP_6	M	S	M	VS	S
Chemical	HC_1	VS	S	C	S	VS
	HC_2	C	K	VS	C	C
	HC_3	C	K	K	C	K
	HC_4	VS	S	S	VS	C
Biological	HB_1	m	m	M	M	m
	HB_2	VS	M	M	VS	M
Ergonomic	HE_1	S	S	M	S	VS
	HE_2	S	M	S	VS	S
	HE_3	S	C	VS	C	S
	HE_4	M	S	M	S	S
Psychosocial	HS_1	S	S	M	VS	VS
	HS_2	M	VS	S	M	S
	HS_3	m	m	M	M	m
	HS_4	S	VS	VS	C	VS
	HS_5	N	m	m	m	N

Table 4.7: Period of exposure of various health hazards assigned by the DMs in linguistic terms

Hazards	DM_1	DM_2	DM_3	DM_4	DM_5
HP_1	P	P	F	P	F
HP_2	S	S	O	F	O
HP_3	O	F	O	F	F
HP_4	S	O	S	O	S
HP_5	R	R	OC	ER	R
HP_6	P	F	P	P	F
HC_1	O	P	F	P	F
HC_2	P	P	F	P	P
HC_3	OC	R	ER	ER	R
HC_4	O	F	P	O	P
HB_1	O	S	F	O	S
HB_2	O	F	S	S	O
HE_1	O	S	O	F	S
HE_2	F	P	P	F	F
HE_3	F	O	O	P	F
HE_4	S	F	S	O	O
HS_1	O	O	O	S	F
HS_2	F	O	F	F	F
HS_3	OC	ER	R	R	OC
HS_4	F	O	O	F	F
HS_5	S	OC	S	O	OC

Table 4.8: Probability of exposure of various health hazards assigned by the DMs in linguistic terms

Hazards	DM_1	DM_2	DM_3	DM_4	DM_5
HP_1	H	H	H	VH	VH
HP_2	M	H	M	H	H
HP_3	M	H	M	H	H
HP_4	M	L	H	M	M
HP_5	M	M	M	L	M
HP_6	H	H	M	M	M
HC_1	H	M	H	M	H
HC_2	H	H	M	VH	VH
HC_3	M	M	M	H	H
HC_4	L	H	M	M	H
HB_1	H	M	L	H	M
HB_2	M	L	M	M	L
HE_1	M	H	H	H	M
HE_2	H	M	H	H	H
HE_3	L	VL	M	L	M
HE_4	H	VH	VH	M	H
HS_1	M	M	H	H	H
HS_2	H	M	H	M	H
HS_3	H	M	H	M	M
HS_4	M	H	M	H	H
HS_5	M	H	M	M	M

Table 4.9: Aggregated preferences of five DMs for exposure measures in fuzzy numbers and corresponding health hazards risk rating in terms of crisp numbers

Agent(s)	Hazards	Fuzzy numbers			Crisp Values			Risk Rating	Percentage of contribution
		Consequence of exposure (C)	Period of exposure (E)	Probability of exposure (P)	C	E	P	R=C×E×P	
Physical	HP_1	(0.38, 0.58, 0.78)	(0.82, 0.96, 1.00)	(0.78, 0.94, 1.00)	0.5800	0.9322	0.9127	0.4935	1.8088 (29.84%)
	HP_2	(0.34, 0.54, 0.74)	(0.46, 0.66, 0.84)	(0.62, 0.82, 0.96)	0.5400	0.6549	0.8044	0.2845	
	HP_3	(0.54, 0.56, 0.90)	(0.62, 0.82, 0.96)	(0.62, 0.82, 0.96)	0.6526	0.8044	0.8044	0.4223	
	HP_4	(0.30, 0.50, 0.70)	(0.38, 0.58, 0.78)	(0.50, 0.70, 0.88)	0.5000	0.5800	0.6949	0.2015	
	HP_5	(0.66, 0.84, 0.96)	(0.02, 0.12, 0.30)	(0.46, 0.66, 0.86)	0.8243	0.1413	0.6600	0.0769	
	HP_6	(0.26, 0.46, 0.66)	(0.82, 0.96, 1.00)	(0.58, 0.78, 0.94)	0.4600	0.9322	0.7697	0.3301	
Chemical	HC_1	(0.46, 0.66, 0.84)	(0.74, 0.90, 0.98)	(0.62, 0.82, 0.96)	0.6549	0.8786	0.8044	0.4628	1.6713 (27.58%)
	HC_2	(0.70, 0.88, 0.98)	(0.86, 0.98, 1.00)	(0.74, 0.90, 0.98)	0.8587	0.9517	0.8786	0.7180	
	HC_3	(0.82, 0.96, 1.00)	(0.02, 0.10, 0.26)	(0.58, 0.78, 0.58)	0.9322	0.1214	0.7697	0.0871	
	HC_4	(0.46, 0.66, 0.84)	(0.70, 0.86, 0.96)	(0.54, 0.74, 0.90)	0.6549	0.8442	0.7297	0.4034	
Biological	HB_1	(0.04, 0.18, 0.38)	(0.46, 0.66, 0.84)	(0.54, 0.74, 0.90)	0.1956	0.6549	0.7297	0.0935	0.2803 (4.63%)
	HB_2	(0.26, 0.46, 0.66)	(0.46, 0.66, 0.84)	(0.42, 0.62, 0.82)	0.4600	0.6549	0.6200	0.1868	
Ergonomic	HE_1	(0.30, 0.50, 0.70)	(0.46, 0.66, 0.84)	(0.62, 0.82, 0.96)	0.5000	0.6549	0.8044	0.2634	1.1949 (19.72%)
	HE_2	(0.30, 0.50, 0.70)	(0.78, 0.94, 1.00)	(0.66, 0.86, 0.98)	0.5000	0.9127	0.8389	0.3828	
	HE_3	(0.50, 0.70, 0.86)	(0.66, 0.84, 0.96)	(0.34, 0.54, 0.74)	0.6897	0.8243	0.5400	0.3070	
	HE_4	(0.22, 0.42, 0.62)	(0.46, 0.66, 0.84)	(0.74, 0.90, 0.98)	0.4200	0.6549	0.8786	0.2417	
Psychosocial	HS_1	(0.34, 0.54, 0.74)	(0.50, 0.70, 0.88)	(0.62, 0.82, 0.96)	0.5400	0.6949	0.8044	0.3018	1.1044 (18.23%)
	HS_2	(0.26, 0.46, 0.66)	(0.66, 0.86, 0.98)	(0.58, 0.78, 0.94)	0.4600	0.8389	0.7697	0.2970	
	HS_3	(0.04, 0.18, 0.38)	(0.04, 0.16, 0.34)	(0.58, 0.78, 0.94)	0.1956	0.1757	0.7697	0.0265	

	HS_4	(0.50, 0.70, 0.88)	(0.62, 0.82, 0.96)	(0.62, 0.82, 0.96)	0.6949	0.8044	0.8044	0.4496	
	HS_5	(0.00, 0.06, 0.22)	(0.26, 0.46, 0.66)	(0.54, 0.74, 0.92)	0.0873	0.4600	0.7349	0.0295	
Overall health hazard risks								6.0597	

Table 4.10: Risk rating (crisp) values for linguistic risk assessment scale

Triangular fuzzy numbers	Consequence of exposure (C)	Period of exposure (E)	Probability of exposure (P)	Risk rating (R=C×E×P)
(0.9, 1, 1)	0.9707	0.9707	0.9707	0.9146
(0.7, 0.9, 1)	0.8732	0.8732	0.8732	0.6658
(0.5, 0.7, 0.9)	0.7000	0.7000	0.7000	0.3430
(0.3, 0.5, 0.7)	0.5000	0.5000	0.5000	0.1250
(0.1, 0.3, 0.5)	0.3000	0.3000	0.3000	0.0270
(0, 0.1, 0.3)	0.1268	0.1268	0.1268	0.00195
(0, 0, 0.1)	0.0293	0.0293	0.0293	0.0000251

Table 4.11: Risk level rating

Risk rating ranges (crisp)	Risk level
(0.9146-0.6658)	Critical
(0.6658-0.3430)	High
(0.3430-0.1250)	Moderate
(0.1250-0.0270)	Low
(0.0-0.0270)	Very Low

Table 4.12: Health hazards belonging in various risk level ratings and suggested action requirement plan for controlling the risks

Risk level rating	Health hazards	Required action
Critical	HC_2	Immediate action required. Access to the hazard should be restricted until the risk can be lowered to an acceptable level. Short term action may be required to lower the risk level and then medium and long term plans to control the risk to as low as reasonably practicable using the Hierarchy of controls.
High	HP_1, HC_1, HS_4, HP_3, HC_4, HE_2	Action needed quickly (within 1-2 days). The task should not proceed unless the risk is assessed and control options selected based on the Hierarchy of controls.
Moderate	HP_6, HE_3, HS_1, HS_2, HP_2, HE_1, HE_4, HP_4, HB_2	Action required within a week to eliminate or minimize the risk using the Hierarchy of controls.
Low	HB_1, HC_3, HP_5, HS_5	Action required within a reasonable timeframe (2-4 weeks) for eliminating or minimizing the risk using the Hierarchy of controls.
Very Low	HS_3	Risk to be eliminated or lowered when possible using the Hierarchy of controls.

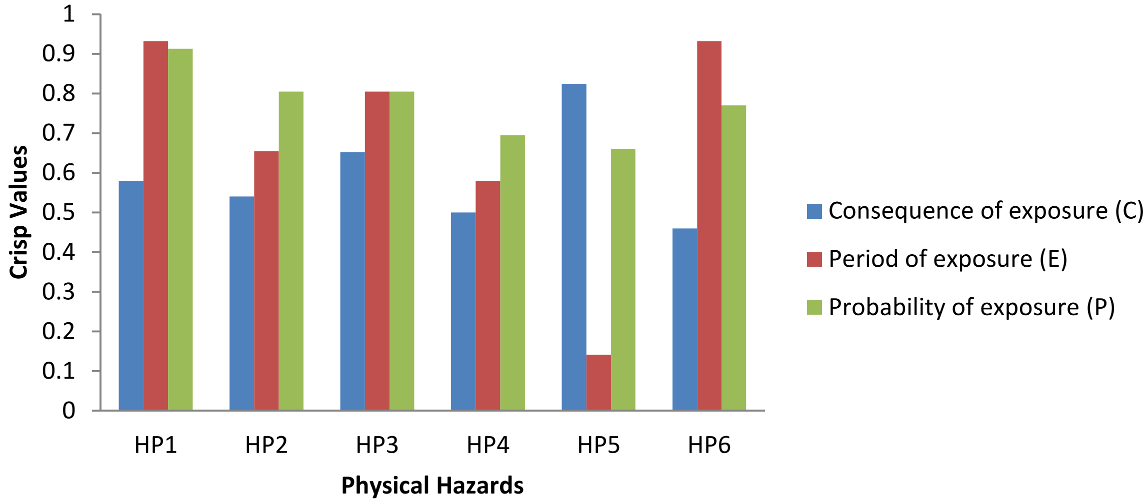

Fig. 4.5: Variation of level of exposure measures in relation to physical hazards

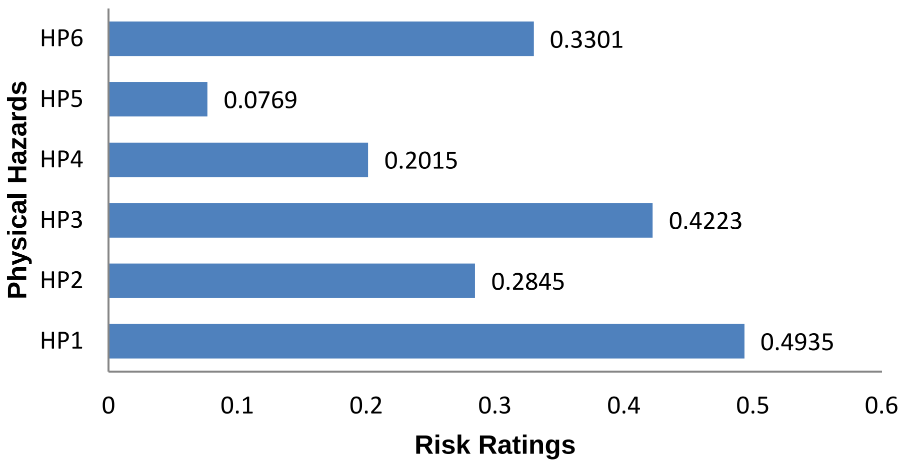

Fig. 4.6: Risk rating of various physical hazards

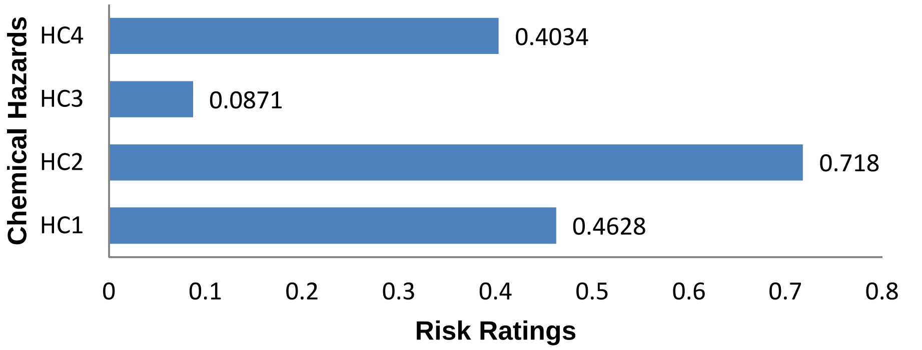

Fig. 4.7: Risk rating of various chemical hazards

Fig. 4.8: Risk rating of various bio-logical hazards

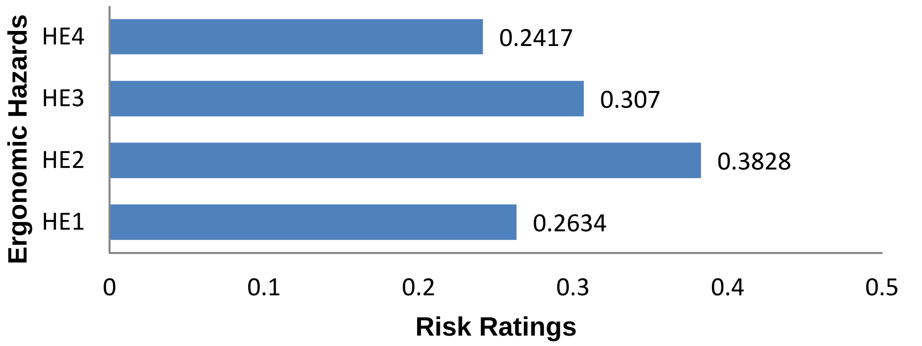

Fig. 4.9: Risk rating of various ergonomic hazards

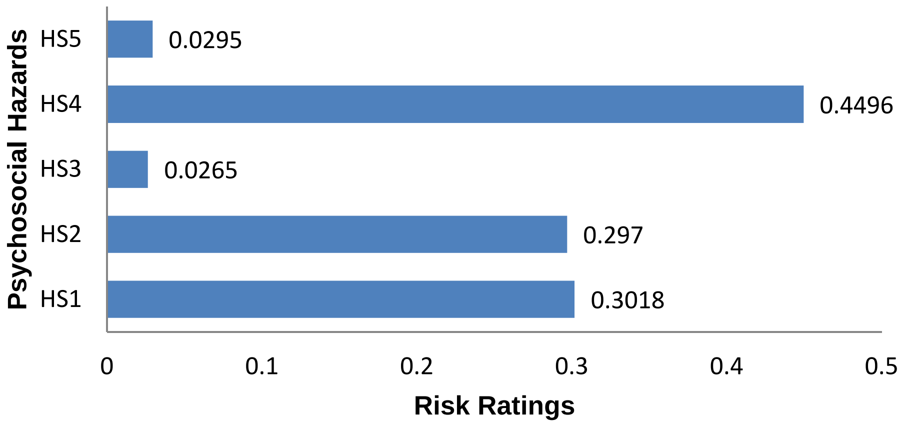

Fig. 4.10: Risk rating of various psychosocial hazards

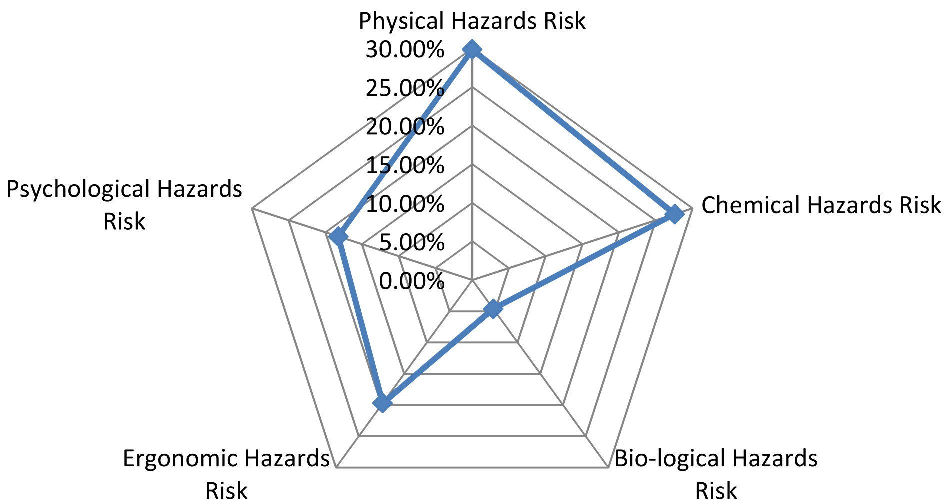

Fig. 4.11: Percentage of contribution of various hazard agents to the overall hazard risk

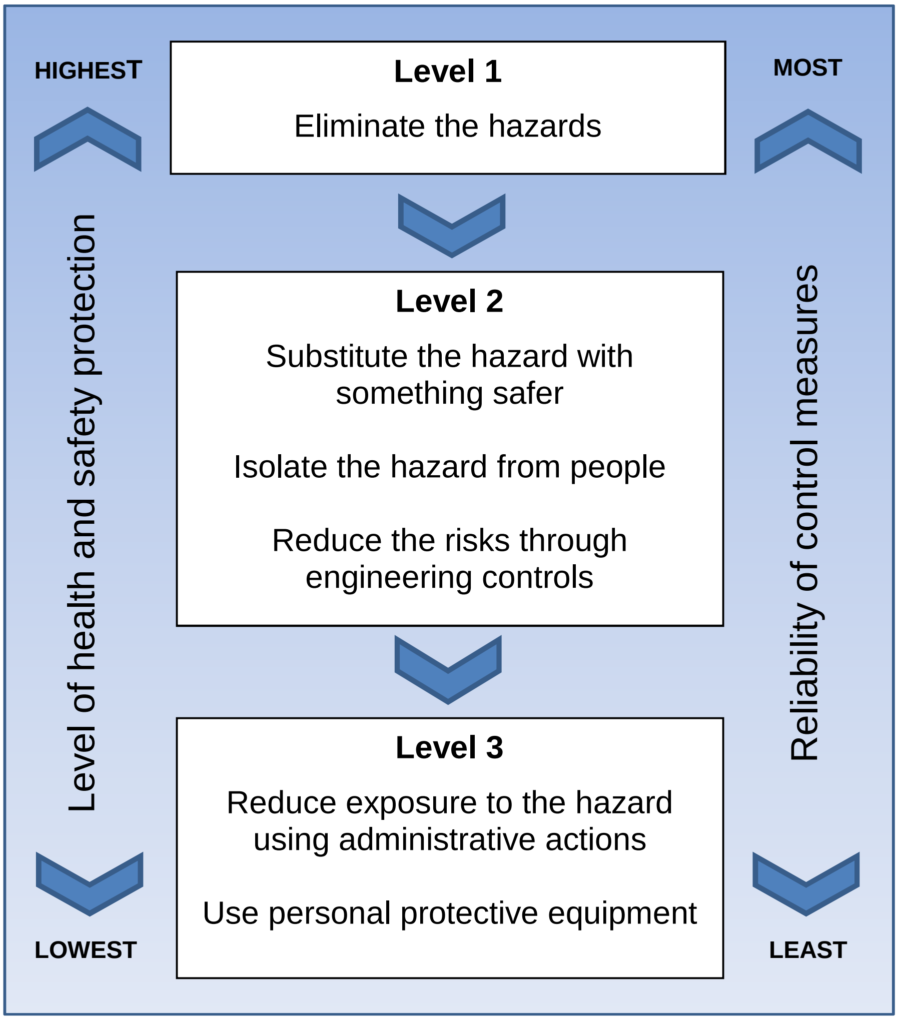

Fig. 4.12: Hierarchy of controls (SWA, 2011)

CHAPTER 5

A RISK-BASED DECISION SUPPORT FRAMEWORK FOR SELECTION OF APPROPRIATE SAFETY MEASURE SYSTEM FOR UNDERGROUND COAL MINES

5.1 Coverage

In the context of underground coal mining industry, the increased economic issues regarding implementation of additional safety measure systems, along with growing public awareness to ensure high level of workers safety has put great pressure on the managers towards finding the best solution to ensure safe as well as economically viable alternative selection. Risk-based decision support system plays an important role in finding such solutions amongst candidate alternatives with respect to multiple decision criteria. Therefore, in this work, a unified risk-based decision making methodology has been proposed for selecting an appropriate safety measure system in relation to an underground coal mining industry with respect to multiple risk criteria such as financial risk, operating risk, and maintenance risk. The proposed methodology uses interval-valued fuzzy set theory for modeling vagueness and subjectivity in the estimates of fuzzy risk ratings for making appropriate decision. The methodology is based on the aggregative fuzzy risk analysis and Multi-Criteria Decision Making (MCDM). The selection decisions are made within the context of understanding the total integrated risk that is likely to incur while adapting the particular safety measure system alternative. Effectiveness of the proposed methodology has been validated through a real time case study. The result in the context of final priority ranking is seemed fairly consistent.

5.2 Problem Statement

Although mining is the most hazardous sector because of its dangerous work ambience (ILO, 2010); Directorate General of Mines Safety (DGMS) India reports that coal mines are evidently dangerous than metal mines. However, underground mines appear to be more dangerous than open cast mines. Coal mining is ranked at the top in the list of hazardous workplaces, wherever, statistics are maintained the potential for a major incident involving multiple loss of life which is always present in underground mining operations (DGMS, 2011). Although there has been substantial improvement in ensuring coal mining safety and health since past few years; still the workers involved in the underground mining operations such as coal extraction, transportation, and processing may expose to a wide range of hazards that may cause adverse incidents, injury, death, ill-health or disease, if not properly controlled.

Incidence of accidents being an important indicator of the safety status, it is relevant to examine the accident scenario. According to DGMS (2011), total 385 underground coal mines having gassy seams have been operating in India. Total 65 fatal accidents involving 67 fatalities have occurred during the year 2011. 23(35%) fatal accidents have occurred in below ground workings with fatality rate of 0.13; 29(45%) fatal accident in opencast workings with fatality rate of 0.36

and 13(20%) in surface operation with fatality rate of 0.12 during the year 2011. Survey depicts that 508 numbers of persons have been injured due to the occurrence of 486 numbers of serious accidents. The major causes of accidents are spontaneous heating of below ground, ground movement, contamination of coal dusts, gases and explosives and transportation of machinery (Khanzode et al., 2012). The frequency of disasters due to fires and gas explosions has been terrifyingly increased in the recent past. Methane emissions in coal mines have triggered explosion leading to death and injury to the miners and also, it contributes the maximum percentage to the greenhouse gas emission (Copur, et al., 2012; Cheng et al., 2011). Methane gas is inherently adsorbed by coal and usually liberated during mining operation. Moreover, coal dusts and its inadequate ventilation may experience increased mortality to the miners from both occupationally induced lung diseases and accidental deaths (Kursunoglu and Onder, 2015). In contrast, coal dust and methane gas explosions in underground coal mines remain as serious risks demanding adequate monitoring and control (Taylor et al., 2010). Hazard monitor and control is also a common issue in underground coal mines. Many modern coal mines have used information technology support for identifying and monitoring different hazards towards improving safety and health status at workplace (Lawrence, 2000). In addition, water and inundation management system is also necessary for controlling potential flooding situations as well as maintaining a safe working environment in deep underground coal mines (Mutton and Remennikov, 2011). The aforesaid issues in relation to workers safety concerns can be solved by adopting appropriate safety measure systems through the execution of advanced machineries, equipment, and improved technology systems as well (ILO, 2010; Liu, 2012). However, it requires substantial capital expenditure for maintaining a safe and productive underground working environment. Although many underground coal mines have been using various safety measure systems like methane drainage automation system, on-line ventilation and control system etc. for improving coal mine workers safety (Divya et al., 2012; Hartman et al., 1997; Liu, 2012) but multiple systems cannot be executed at the same time due to limited budget head. Thus, it is the responsibility of the managerial body to decide which safety measure system should be chosen first following by the next and so on. Therefore, whilst executing a particular safety measure system, it is essentially required to analyze the risks that incur in course of machine procurement, operating and maintenance (Lai and Chen, 2011). In this context, the aforementioned problem can be viewed as a risk-based multi-criteria group decision making problem where number of safety measure systems acts as multiple alternatives and multiple persons are involved to identify and to select the appropriate alternative based on multiple risk related decision criteria. Risk is a measure of potential future loss or undesirable outcome that may arise from some present action (Samantra et al., 2014). Here, potential loss can be considered as monetary loss that may incur in terms of cost associated with machine procurement, operation, maintenance, scheduling and others. Therefore, proper risk management is indeed required for the economic sustainability of any organization. The scope of risk management is protecting an organization from financial losses as well as protecting professionals from the stress and disruption that result from the possibility of litigation (Bower, 2002). In order to decrease the possibility of litigation, risk management focuses on risk-based decision support system to quantify the critical risks and make decisions based on accepting risks within a specified level of risk aversion. Risk-based decision making is a process of examining the entire risk environment of a decision issue and presenting not only a degree of risk to a decision-maker, but also gives the information about the severity of loss as well as possibility of failure for the solution options (Roberts and Fussell, 1999). Therefore, in multi-criteria decision making environment, risk involved in each criterion can be estimated by multiplying two main parameters such as possibility of failure and severity of loss (Zhi, 1995).

Generally, possibility of failure can be assessed in two ways: subjective judgment and objective analysis. Kou and Lu (2013) have pointed out that individual's knowledge; experience and intuitive judgment provide better assessment of risk than objective (probabilistic) approach. In addition, subjective judgment process is easy and practical than the objective analysis because it does not demand historical data; rather it needs some experience as well as scrutiny (Zhi, 1995). However, subjective information relies on impression, vagueness, and uncertainty due to the human intuitive assessment (Zadeh, 1965; Dubois and Prade, 1978; Chen and Hwang, 1992).

Subjective judgement in light of decision making arena persuade by a group of decision makers is easy and practical because it explores decision maker's knowledge and experience in the particular problem domain. Historical data in terms of survey report or statistical data are difficult to obtain unless a company maintains a strong data base. Many companies are not reluctant to share such confidential information. Thus, the proposed fuzzy based decision making approach for appropriate safety measure system selections seems fruitful in this context.

Hence, this work highlights the applicability of fuzzy set theory for capturing the individuals' intuitive assessment towards selecting the appropriate safety measure system for improving the coal mine worker safety. The objective of this work is to develop a unified risk-based decision model that can effectively be used to integrate multiple risk criteria with respect to each alternative into a common framework. The selection decisions are made within the context of understanding the total integrated risk to the particular safety alternative. Therefore, an improved and more practical approach has been proposed in this study to facilitate the appropriate safety measure system selection towards improving workers safety for an underground coal mine industry.

Exhaustive literature review reveals that limited studies have been reported so far highlighting appropriate safety measure system selection problem in the perspective of underground coal mine industry based on risk related decision criteria. Therefore, in this work, a decision making scenario has been conceptualized in which the case coal mining industry seeks to adapt/implement an appropriate safety measure system in order to ensure high level of workers safety. The selection is to be made based on analyzing different risks (financial, operating and maintenance risks) that are likely to incur for the industry in adapting that particular safety measure system. Since all the safety measure systems cannot be implemented simultaneously due to limited budget of the organization; hence, the appropriate selection must be made in view of minimum risk. In doing so, this work attempts a risk-based decision making module based on interval-valued fuzzy modified TOPSIS approach.

5.3 Fuzzy Preliminaries

To deal with vagueness in human thought, (Zadeh, 1965) first introduced the concept of fuzzy set theory, which has the capability to represent/manipulate data and information possessing based on non-statistical uncertainties. Moreover, fuzzy set theory has been designed to mathematically represent uncertainty and vagueness; and provide formalized tools for dealing with imprecision inherent to decision making problems (Yao and Su, 2000). In any decision making situation, candidate alternatives are generally evaluated based on qualitative as well as quantitative criteria. Quantitative criteria can easily be assessed by conventional tools and techniques. However, difficulty arises in dealing with subjective (qualitative) evaluation indices. As most of the risk characterizing parameters are subjective in nature, its assessment relies on decision-makers' linguistic judgment. Unless the linguistic evaluation information is transformed into logical mathematic base, it seems difficult to quantify the extent of risk. Therefore, in the present work, a unified risk-based decision making model has been postulated for selecting an appropriate safety measure alternative in fuzzy environment. A linguistic variable is the variable whose values are not expressed in numbers but words or sentences in a natural or artificial language (Zadeh, 1965). The concept of a linguistic variable is very useful in dealing with situations, which are too complex or not well defined to be reasonably described in conventional quantitative expressions (Zimmermann, 1991). A fuzzy number is a fuzzy subset in the universe of discourse X that is both convex and normal. Generally, various types of fuzzy numbers such as triangular, trapezoidal, bell-shaped numbers are used in type-1 fuzzy sets (Chen et al., 2006; Xia et al., 2006; Yang and Hung, 2007; Chen and Chen, 2009).

In a simple uncertain situation, type-1 fuzzy sets are preferably representing uncertainty by numbers in the range [0, 1]. However, it may not be sensible to use an accurate membership function for something that is not only uncertain but also complex (Sepulveda et al., 2007; Cornelis et al., 2006). The concept of type-2 fuzzy sets has thus been proposed by (Zadeh, 1975), which is capable of effectively tackling linguistic uncertainties in complex environment. Cornelis et al. (2006) and Karnik and Mendel (2001) have noted that the main reason for proposing this new concept was that in the linguistic modeling of a phenomenon, the presentation of the linguistic expression in the form of ordinary fuzzy sets (type 1) seemed not clear enough. Type 2 fuzzy set is an interval valued fuzzy set (IVFS) which can be defined by a fuzzy membership function (fuzzy grade) in the unit interval [0, 1] rather than a point in [0, 1] (Mizumoto and Tanaka, 1981). The interval valued fuzzy numbers (IVFNs) can be derived from IVFS aiming at capturing the imprecise decision information in complex uncertain situations (Zadeh, 1975; Gorzalczany, 1987). Some pioneers have been used IVFNs for solving risk assessment problems in decision making environment (Wang and Li, 1998; Ashtiani et al., 2009; Wei and Chen, 2009; Chen, 2012). The special characteristic of IVFNs is to represent the degree of certainty of opinions by an interval; which is the more appropriate way for dealing the uncertainty in real life problems (Gorzalczany, 1987).

5.3.1 Fuzzy Operational Rules for IVFNs

According to (Gorzalczany, 1987), an interval valued fuzzy set (IVFS) can be defined as:

$$\tilde{A}=\left\{\left(x,\left[\mu_A^L(x),\mu_A^U(x)\right]\right)\right\} \tag{5.1}$$

$$\mu_A^L,\mu_A^U : X \rightarrow [0,1] \quad \forall x \in X,\ \mu_A^L \le \mu_A^U$$

$$\tilde{\mu}_A(x)=\left[\mu_A^L(x),\mu_A^U(x)\right]$$

$$\tilde{A}=\left\{\left(x,\ \tilde{\mu}_A(x)\right)\right\},\quad x \in (-\infty,\ \infty)$$

where $\mu_A^L(x)$ the lower is limit of degree of membership and $\mu_A^U(x)$ is the upper limit of the membership degree.

As illustrated in Fig. 5.1, an triangular interval-valued fuzzy number $\tilde{A}$ can be represented by $\tilde{A}=\left[\tilde{A}^L,\tilde{A}^U\right]=\left[(a_1,a_1^{'});a_2;(a_3^{'},a_3)\right]$. It is worth noting that the use of triangular interval valued number facilitates to define lower and upper bound values as an interval for matrix elements and weights of criteria.

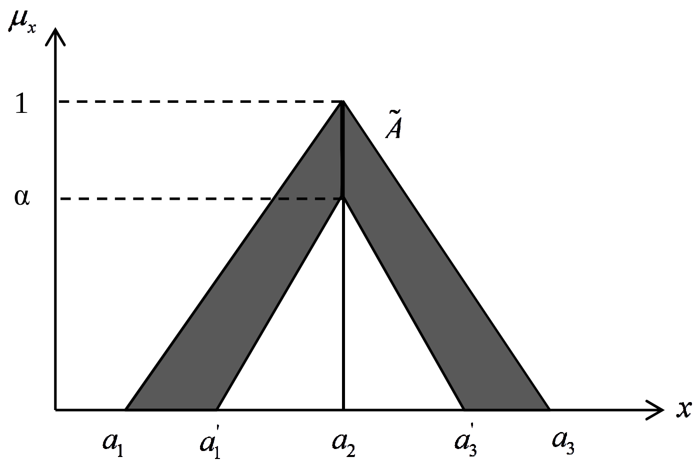

Fig. 5.1: Triangular interval-valued fuzzy number

Suppose $\tilde{N}_x=[\tilde{N}_x^L;\tilde{N}_x^U]$ and $\tilde{M}_y=[\tilde{M}_y^L,\tilde{M}_y^U]$ are two IVFNs then the operational rules of the $\tilde{N}_x$ and $\tilde{M}_y$ are shown as follows (Kuo, 2011; Hwang and Yoon, 1981):

Definition 1: If $\cdot\in(+,\times)$, then $\tilde{N}\cdot\tilde{M}(x,y)=\left[\tilde{N}_x^L\cdot\tilde{M}_y^L;\tilde{N}_x^U\cdot\tilde{M}_y^U\right]$, for a positive non-fuzzy number(v), $v\cdot\tilde{M}(x\cdot y)=\left[v\cdot\tilde{M}_y^L;v\cdot\tilde{M}_y^U\right]$.

Definition 2: The subtraction and division operations between two triangular interval-valued fuzzy numbers $\tilde{N}$ and $\tilde{M}$ are as follows (Kuo, 2011):

$$\begin{aligned}\tilde{N}-\tilde{M}&=\left[\left(N_1,N_1^{'}\right);N_2;\left(N_3^{'},N_3\right)\right]-\left[\left(M_1,M_1^{'}\right);M_2;\left(M_3^{'},M_3\right)\right]\\&=\left[\left(N_1-M_3,N_1^{'}-M_3^{'}\right);N_2-M_2;\left(N_3^{'}-M_1^{'},N_3-M_1\right)\right]\end{aligned}\tag{5.2}$$

and

$$\begin{aligned}\tilde{N}\div\tilde{M}&=\left[\left(N_1,N_1^{'}\right);N_2;\left(N_3^{'},N_3\right)\right]\div\left[\left(M_1,M_1^{'}\right);M_2;\left(M_3^{'},M_3\right)\right]\\&=\left[\left(N_1\div M_3,N_1^{'}\div M_3^{'}\right);N_2\div M_2;\left(N_3^{'}\div M_1^{'},N_3\div M_1\right)\right].\end{aligned}\tag{5.3}$$

Definition 3: The intersection of two IVFSs (Gorzalczany, 1987) is defined as the minimum of their respective lower and upper bounds of their membership intervals. Given two intervals of $[0,1]$ and $\tilde{N}_x = [\tilde{N}_x^L ; \tilde{N}_x^U] \subset [0,1], \tilde{M}_y = [\tilde{M}_y^L ; \tilde{M}_y^U] \subset [0,1]$ the minimum of both intervals is an interval $K = Min\left(\tilde{N}_x, \tilde{M}_y\right) = \left[Min\left(\tilde{N}_x^L, \tilde{M}_y^L\right), Min\left(\tilde{N}_x^U, \tilde{M}_y^U\right)\right]$.

Definition 4: The union of two IVFSs (Mousavi et al., 2013) is defined as the maximum of their respective lower and upper bounds of their membership intervals. Given two intervals of $[0,1]$ and, $\tilde{N}_x = [\tilde{N}_x^L ; \tilde{N}_x^U] \subset [0,1], \tilde{M}_y = [\tilde{M}_y^L ; \tilde{M}_y^U] \subset [0,1]$ the maximum of both intervals is an interval $K = Max\left(\tilde{N}_x, \tilde{M}_y\right) = \left[Max\left(\tilde{N}_x^L, \tilde{M}_y^L\right), Max\left(\tilde{N}_x^U, \tilde{M}_y^U\right)\right]$.

Definition 5: Absolute value: $\left|\tilde{N}_x\right| = Max\left\{\left|\tilde{N}_x^L\right|, \left|\tilde{N}_x^U\right|\right\}$.

Definition 6: Let $\tilde{N}$ and $\tilde{M}$ be two triangular interval-valued fuzzy numbers $\tilde{N} = \left[\left(N_1, N_1^{'}\right); N_2; \left(N_3^{'}, N_3\right)\right]$ and $\tilde{M} = \left[\left(M_1, M_1^{'}\right); M_2; \left(M_3^{'}, M_3\right)\right]$ can then be represented as follows:

$$h\left(\tilde{N}\right) = \frac{N_1 + N_1^{'} + 2N_2 + N_3^{'} + N_3}{6}, \tag{5.4}$$

and

$$h\left(\tilde{M}\right) = \frac{M_1 + M_1^{'} + 2M_2 + M_3^{'} + M_3}{6}, \tag{5.5}$$

We say $\tilde{N} > \tilde{\mathrm{M}}\ if\ \mathrm{h}\left(\tilde{N}\right) > \mathrm{h}\left(\tilde{M}\right)$.

5.3.2 Interval Valued Fuzzy Modified-TOPSIS (IVFM-TOPSIS) Approach

The MCDM methods are frequently used to solve risk-based selection problems with multiple decision criteria and multiple decision alternatives. The objective of the MCDM is to find the most desirable alternative(s) from a set of potential alternatives with respect to the selected criteria (Yue, 2011). Various types of MCDM methods (VIKOR, AHP, ELECTRE, and PROMETHEE) have been used for ranking of alternatives with respect to the multiple conflicting criteria (Opricovic and Tzeng, 2007; Caputo et al., 2013; Marbini et al., 2013; Behzadian et al., 2010). One of the well-known MCDM method is the technique for order preference by similarity to ideal solution (TOPSIS) developed by (Hwang and Yoon, 1981). The concept of this method is based on fact that the chosen alternative should have the shortest distance from the positive ideal solution (PIS) and the farthest from the negative ideal solution (NIS). Chen (2000) developed the TOPSIS method for the group decision making under fuzzy environment. The rating of each alternative and the weight of each criterion are provided by linguistic terms which can be expressed further in triangular fuzzy numbers. However, modeling a phenomenon in the traditional linguistic approach is not clear enough because of its presentation in the form of ordinary fuzzy sets (Cornelis et al., 2006; Grzegorzewski, 2004). Thus, it is more appropriate to represent this degree of certainty by an interval form. Therefore, (Vahdani et al., 2013) have developed an interval valued fuzzy modified-TOPSIS (IVFM-TOPSIS) approach where the rating of each alternative and the weight of each criterion were provided by linguistic terms which can be expressed in triangular interval-valued fuzzy numbers. This method has been explored in this research towards development of a risk-based decision making module. The basic concept of fuzzy decision matrix used in MCDM problem has been discussed below:

Let $\tilde{D} = \left[\tilde{x}_{ij} \right]_{m \times n}$ be a fuzzy decision matrix which can be expressed in a matrix format as

$$\tilde{D} = \begin{array}{c} \\ A_1 \\ A_2 \\ \vdots \\ A_m \end{array} \begin{array}{c} \begin{array}{cccc} C_1 & C_2 & \cdots & C_n \end{array} \\ \begin{bmatrix} \tilde{x}_{11} & \tilde{x}_{12} & \cdots & \tilde{x}_{1n} \\ \tilde{x}_{21} & \tilde{x}_{22} & \cdots & \tilde{x}_{2n} \\ \vdots & \vdots & \cdots & \vdots \\ \tilde{x}_{m1} & \tilde{x}_{m2} & \cdots & \tilde{x}_{mn} \end{bmatrix} \end{array},$$

$$\tilde{W} = [\tilde{w}_1 \quad \tilde{w}_2 \quad \cdots \quad \tilde{w}_n],$$

where $A_1, A_2, ..., A_m$, are possible alternatives, $C_1, C_2, ..., C_n$ are criteria with which alternative's performance can be measured, $\tilde{x}_{ij}$ is the rating of the alternative A_i with respect to criterion C_j, $\tilde{w}_j$ is the weight of the criteria C_j. Both $\tilde{x}_{ij}$, $\forall i, j$ and $\tilde{w}_j$, $j = 1, 2, ..., n$ are represented by fuzzy numbers. Now, the procedure of IVFM-TOPSIS method has been reproduced below.

Step 1: Establish a group of k decision makers (DMs).

Step 2: Define and describe a set of relevant criteria.

Step 3: Obtain the ratings of different alternative with respect to each criterion given by each DM.

Step 4: Aggregate the ratings of alternatives versus each subjective criterion $(\tilde{x}_{ij})$ and fuzzy weights of selected criteria $(\tilde{w}_j)$.

Assume, a decision group has K DMs, $K = 1,2,...,k$. Then the aggregated fuzzy rating of alternatives with respect to each criterion, and the aggregated fuzzy weight of each criterion can be computed as:

$$\tilde{x}_{ij} = \frac{1}{K}\left[\tilde{x}_{ij}^{1} + \tilde{x}_{ij}^{2} + \cdots + \tilde{x}_{ij}^{k}\right] \qquad i = 1,2,...,m, \quad j = 1,2,...,n, \tag{5.6}$$

$$\tilde{w}_{j} = \frac{1}{K}\left[\tilde{w}_{j}^{1} + \tilde{w}_{j}^{2} + \cdots + \tilde{w}_{j}^{k}\right] \qquad j = 1,2,...,n, \tag{5.7}$$

where $\tilde{x}_{ij}^{k}$ is the fuzzy rating of i^{th} alternative with respect to j^{th} criterion and $\tilde{w}_{j}^{k}$ is the fuzzy importance weight of the j^{th} criterion given by the K^{th} decision-maker.

Step 5: Compute the normalized decision matrix. Vector normalization is used to calculate n_{ij} and $\tilde{n}_{ij}$ as follows:

$$n_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} x_{ij}^{2}}}, \qquad i = 1,2,...,m, \; j = 1,2,...,n, \tag{5.8}$$

$$\tilde{n}_{ij} = \left[\left(\frac{a_{ij}}{c_{j}^{+}}, \frac{a_{ij}^{'}}{c_{j}^{+}}\right); \frac{b_{ij}}{c_{j}^{+}}; \left(\frac{c_{ij}^{'}}{c_{j}^{+}}, \frac{c_{ij}}{c_{j}^{+}}\right)\right], \qquad j \in \Omega_{b} \tag{5.9}$$

$$\tilde{n}_{ij} = \left[\left(\frac{a_{j}^{-}}{c_{ij}}, \frac{a_{j}^{-}}{c_{ij}^{'}}\right); \frac{a_{j}^{-}}{b_{ij}}; \left(\frac{a_{j}^{-}}{a_{ij}^{'}}, \frac{a_{j}^{-}}{a_{ij}}\right)\right], \qquad j \in \Omega_{c} \tag{5.10}$$

$$c_{j}^{+} = \underset{i}{Max}\, c_{ij}, \quad j \in \Omega_{b}$$

$$a_{j}^{-} = \underset{i}{Min}\, a_{ij}, \quad j \in \Omega_{c}$$

where Ω_{b} and Ω_{c} are associated with benefit and cost criteria, respectively. Hence, the normalized matrix $\tilde{N} = \left[n_{ij}\right]_{m\times n}$ can be obtained. The above-mentioned normalization method is to preserve the property that the ranges of normalized interval numbers fall within the interval [0, 1].

Step 6: Construct the weighted normalized matrix, $\tilde{V} = \left[v_{ij}\right]_{m\times n}$. The fuzzy weighted normalized decision matrix is calculated by multiplying each column of the matrix by the fuzzy weight $(\tilde{w}_{j})$. Thus,

$$\tilde{v}_{ij} = \tilde{w}_{j} \times \tilde{n}_{ij}. \qquad i = 1,2,...,m, \quad j = 1,2,...,n, \tag{5.11}$$

According to Definition 1, the multiply operator can be applied as:

$$\tilde{v}_{ij} = \left[\left(\tilde{w}_{1j} \times \tilde{n}_{1ij}, \tilde{w}_{1j}^{'} \times \tilde{n}_{1ij}^{'} \right); \tilde{w}_{2j} \times \tilde{n}_{2ij}; \left(\tilde{w}_{3j}^{'} \times \tilde{n}_{3ij}^{'}, \tilde{w}_{3j} \times \tilde{n}_{3ij} \right) \right] \tag{5.12}$$

Step 7: Determine the Positive Ideal Solution (PIS) and Negative Ideal Solution (NIS). The values for A^* and A^- are defined as

$$A^* = \left\{ \tilde{v}_1^*, ..., \tilde{v}_n^* \right\} = \left\{ \left(\max_i \tilde{v}_{ij} \mid j \in \Omega_b \right), \left(\min_i \tilde{v}_{ij} \mid j \in \Omega_c \right) \right\} \tag{5.13}$$

$$A^- = \left\{ \tilde{v}_1^-, ..., \tilde{v}_n^- \right\} = \left\{ \left(\min_i \tilde{v}_{ij} \mid j \in \Omega_b \right), \left(\max_i \tilde{v}_{ij} \mid j \in \Omega_c \right) \right\} \tag{5.14}$$

where Ω_b and Ω_c are the sets of benefit criteria and cost criteria respectively. For benefit criterion, the DM desires to have a maximum value among the alternatives. For cost criterion, however, the DM desires to have a minimum value among them. Obviously, A^* indicates the most preferable alternative or the positive ideal solution (PIS). Similarly, A^- indicates the least preferable alternative or the negative ideal solution (NIS).

Step 8: Construct ideal separation matrix $\left(D^*\right)$ and anti-ideal separation matrix $\left(D^-\right)$ which are defined as

$$D^* = \left[d_{ij}^* \right] = \begin{bmatrix} \left| \tilde{v}_{11} - \tilde{v}_1^* \right| & \left| \tilde{v}_{12} - \tilde{v}_2^* \right| & \cdots & \left| \tilde{v}_{1n} - \tilde{v}_n^* \right| \\ \left| \tilde{v}_{21} - \tilde{v}_1^* \right| & \left| \tilde{v}_{22} - \tilde{v}_2^* \right| & \cdots & \left| \tilde{v}_{2n} - \tilde{v}_n^* \right| \\ \vdots & \vdots & \vdots & \vdots \\ \left| \tilde{v}_{m1} - \tilde{v}_1^* \right| & \left| \tilde{v}_{m2} - \tilde{v}_1^* \right| & \cdots & \left| \tilde{v}_{mn} - \tilde{v}_n^* \right| \end{bmatrix} \tag{5.15}$$

According to Definition 2, the subtraction operator can be applied as:

$$D^* = \left[d_{ij}^* \right] = \begin{bmatrix} \left[\left(v_{1(1,1)}, v_{1(1,1)}^{'} \right); v_{2(1,1)}; \left(v_{3(1,1)}^{'}, v_{3(1,1)} \right) \right] - \left[\left(v_{1(1)}^{*}, v_{1(1)}^{'*} \right); v_{2(1)}^{*}; \left(v_{3(1)}^{'*}, v_{3(1)}^{*} \right) \right] & \cdots & \cdots & \left[\left(v_{1(1,n)}, v_{1(1,n)}^{'} \right); v_{2(1,n)}; \left(v_{3(1,n)}^{'}, v_{3(1,n)} \right) \right] - \left[\left(v_{1(n)}^{*}, v_{1(n)}^{'*} \right); v_{2(n)}^{*}; \left(v_{3(n)}^{'*}, v_{3(n)}^{*} \right) \right] \\ \vdots & \cdots & \cdots & \vdots \\ \left[\left(v_{1(m,1)}, v_{1(m,1)}^{'} \right); v_{2(m,1)}; \left(v_{3(m,1)}^{'}, v_{3(m,1)} \right) \right] - \left[\left(v_{1(1)}^{*}, v_{1(1)}^{'*} \right); v_{2(1)}^{*}; \left(v_{3(1)}^{'*}, v_{3(1)}^{*} \right) \right] & \cdots & \cdots & \left[\left(v_{1(m,n)}, v_{1(m,n)}^{'} \right); v_{2(m,n)}; \left(v_{3(m,n)}^{'}, v_{3(m,n)} \right) \right] - \left[\left(v_{1(n)}^{*}, v_{1(n)}^{'*} \right); v_{2(n)}^{*}; \left(v_{3(n)}^{'*}, v_{3(n)}^{*} \right) \right] \end{bmatrix} \tag{5.16}$$

$$D^{-}=\left[d_{ij}^{-}\right]=\begin{bmatrix} \left|\tilde{v}_{11}-\tilde{v}_1^{-}\right| & \left|\tilde{v}_{12}-\tilde{v}_2^{-}\right| & \cdots & \left|\tilde{v}_{1n}-\tilde{v}_n^{-}\right| \\ \left|\tilde{v}_{21}-\tilde{v}_1^{-}\right| & \left|\tilde{v}_{22}-\tilde{v}_2^{-}\right| & \cdots & \left|\tilde{v}_{2n}-\tilde{v}_n^{-}\right| \\ \vdots & \vdots & \vdots & \vdots \\ \left|\tilde{v}_{m1}-\tilde{v}_1^{-}\right| & \left|\tilde{v}_{m2}-\tilde{v}_1^{-}\right| & \cdots & \left|\tilde{v}_{mn}-\tilde{v}_n^{-}\right| \end{bmatrix} \tag{5.17}$$

According to Definition 2, the 'subtraction operator' can be applied as:

$$D^{-}=\left[d_{ij}^{-}\right]=\begin{bmatrix} \left[\left(v_{1(1,1)},v'_{1(1,1)}\right);v_{2(1,1)};\left(v'_{3(1,1)},v_{3(1,1)}\right)\right]-\left[\left(v^{-}_{1(1)},v'^{-}_{1(1)}\right);v^{-}_{2(1)};\left(v'^{-}_{3(1)},v^{-}_{3(1)}\right)\right] & \cdots & \left[\left(v_{1(1,n)},v'_{1(1,n)}\right);v_{2(1,n)};\left(v'_{3(1,n)},v_{3(1,n)}\right)\right]-\left[\left(v^{-}_{1(n)},v'^{-}_{1(n)}\right);v^{-}_{2(n)};\left(v'^{-}_{3(n)},v^{-}_{3(n)}\right)\right] \\ \vdots & \cdots & \vdots \\ \left[\left(v_{1(m,1)},v'_{1(m,1)}\right);v_{2(m,1)};\left(v'_{3(m,1)},v_{3(m,1)}\right)\right]-\left[\left(v^{-}_{1(1)},v'^{-}_{1(1)}\right);v^{-}_{2(1)};\left(v'^{-}_{3(1)},v^{-}_{3(1)}\right)\right] & \cdots & \left[\left(v_{1(m,n)},v'_{1(m,n)}\right);v_{2(m,n)};\left(v'_{3(m,n)},v_{3(m,n)}\right)\right]-\left[\left(v^{-}_{1(n)},v'^{-}_{1(n)}\right);v^{-}_{2(n)};\left(v'^{-}_{3(n)},v^{-}_{3(n)}\right)\right] \end{bmatrix} \tag{5.18}$$

According to Definition 5, ideal separation matrix (D^*) and anti-ideal separation matrix (D^-) are converted into a matrix with absolute numbers which are presented as follows:

$$D^*=\begin{bmatrix} d_{11}^* & d_{12}^* & \dots & d_{1n}^* \\ d_{21}^* & d_{22}^* & \dots & d_{2n}^* \\ \vdots & \vdots & \vdots & \vdots \\ d_{m1}^* & d_{m2}^* & \dots & d_{mn}^* \end{bmatrix}, \tag{5.19}$$

and

$$D^{-}=\begin{bmatrix} d_{11}^{-} & d_{12}^{-} & \dots & d_{1n}^{-} \\ d_{21}^{-} & d_{22}^{-} & \dots & d_{2n}^{-} \\ \vdots & \vdots & \vdots & \vdots \\ d_{m1}^{-} & d_{m2}^{-} & \dots & d_{mn}^{-} \end{bmatrix}, \tag{5.20}$$

Step 9: Calculate collective index (CI). This index is calculated by:

$$\Im_i(D^*,D^-)=\left(\sum_{j=1(A)}^{L}\frac{d_{ij}^*}{d_{ij}^-}\right)^{1/L}+Z_{ij'} \quad \forall i=1,2,\dots,m. \tag{5.21}$$

where the first summation $(\sum A)$ refers to all j for which $d_{ij}^{-} > 0$ while $(Z_{ij'})$ refers to all j' for which $d_{ij}^{-} = 0$. Also, L indicates the number of selected criteria, and $Z_{ij'}$ can be calculated such that $Z_{ij'} = (\max_{j'}(d_{ij}^{*} / d_{ij}^{-}))^{1/\max_j w_j}$ for which $d_{ij'}^{-} > 0$ and w_j for $d_{ij}^{-} = 0$.

$$\varsigma_i(D^*, D^-) = \left(\sum_{j=1}^{L} d_{ij}^{*}\right)^{1/L} + \left(\sum_{j=1(A)}^{L} \frac{1}{d_{ij}^{-}}\right)^{1/L} + Q_{ij'} \qquad \forall i = 1, 2, \ldots, m. \tag{5.22}$$

where the second summation $(\sum A)$ refers to all j for which $d_{ij}^{-} > 0$ while $Q_{ij'}$ refers to all j' for which $d_{ij}^{-} = 0$. Also, L indicates the number of selected criteria, and $Q_{ij'}$ can be calculated as $Q_{ij'} = (\min_{j'}(d_{ij'}^{-}))^{\max_j w_j}$ for which $d_{ij'}^{-} > 0$ and w_j for $d_{ij}^{-} = 0$.

The collective index is calculated as follows:

$$CI_i = \Im_i + \varsigma_i \tag{5.23}$$

Step 10: Rank the preference order. The best alternative can be determined according to preference rank order of CI. Minimum values of the CI indicate the better performance for the alternative (A_i).

5.4 Proposed Methodology

A more general representation of risk-based decision making scenario has been introduced to solve a safety measure alternative selection problem for underground coal mines. The scenario comprises a committee of k decision makers $(DM_1, DM_2, \ldots, DM_k)$ who are responsible for selecting the appropriateness of m safety measure alternatives $(A_1, A_2, \ldots, A_m)$, under each of n risk criteria $(RC_1, RC_2, \ldots, RC_n)$. Risk of each criterion can be quantified based on two evaluating parameters such as possibility of failure (P) and severity of loss (S). Therefore, decision makers are concerned with both severity of loss and possibility of failure for evaluating the fuzzy risk rating of each criterion under each alternative. In the present research, the task of safety measure alternative selection has been attempted in light of a decision making scenario. The generalized decision making methodology and the basic procedural steps of IVFM-TOPSIS method as proposed by (Vahdani et al., 2013) has been adapted here to suit the problem under consideration in which different safety measure systems have been considered as alternatives; whereas, different criteria have been selected in relation to different risks which are likely to incur to the host organization in applying those alternatives. Thus, a generalized decision making module has been modified in pursuit of the risk-based decision making.

The stepwise algorithm for proposed risk-based decision making approach has been presented as follows:

Step 1: Identification of possible safety measure alternatives and their risk characterizing criteria for developing a risk-based decision making model.

Step 2: Selection of appropriate linguistic scale (and corresponding fuzzy numbers representation) for alternative ratings in terms of both possibility of failure and severity of loss under each risk criterion, and also the linguistic scale with corresponding fuzzy representation for assigning importance weight of each risk criterion.

Step 3: Linguistic data (in relation to possibility of failure, severity of loss, and importance weights) for each risk criterion have been collected from the experts. Thereafter, linguistic data have been translated into appropriate triangular interval valued fuzzy numbers.

Step 4: Compute the aggregated fuzzy risk ratings of alternatives versus each risk criterion and corresponding fuzzy weights of the selected criteria.

Fuzzy risk rating for each risk criteria can be calculated by multiplying both possibility of failure and severity of loss which are expressed in triangular interval valued fuzzy numbers (Zhi, 1995). Thus, fuzzy risk rating can be calculated as

Fuzzy risk rating = $\tilde{P}_{ij} \times \tilde{S}_{ij}$ (5.24)

Where $\tilde{P}_{ij}$ and $\tilde{S}_{ij}$ are denoted as possibility of failure, and severity of loss for i^{th} alternative with respect to j^{th} risk criteria. The concept of integration of two risk evaluating parameters under each risk criterion has been described in Fig. 5.2.

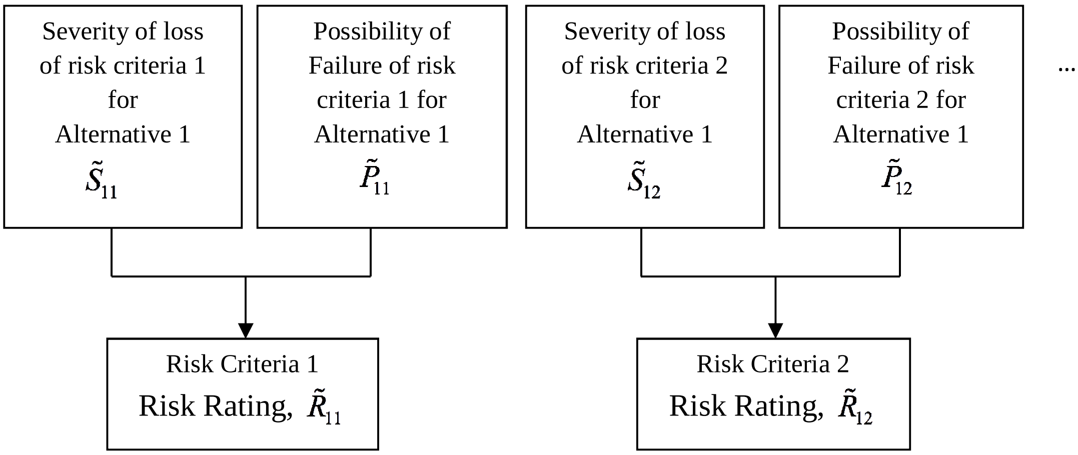

Fig. 5.2: Structure of integration of risk of each criterion for Alternative 1

Now, aggregated fuzzy risk rating can be computed by modifying Eq. (5.6) as follows,

$$\tilde{R}_{ij} = \tilde{x}_{ij} = \frac{1}{K}\left[\left(\tilde{P}_{ij} \times \tilde{S}_{ij}\right)^1 + \left(\tilde{P}_{ij} \times \tilde{S}_{ij}\right)^2 + \cdots + \left(\tilde{P}_{ij} \times \tilde{S}_{ij}\right)^k\right] \qquad i = 1, 2, \ldots, m, \;\; j = 1, 2, \ldots, n, \tag{5.25}$$

where $\tilde{R}_{ij}$ is denoted as aggregated fuzzy risk rating of i^{th} alternative with respect to the j^{th} risk criterion; and $\left(\tilde{P}_{ij} \times \tilde{S}_{ij}\right)^k$ is the fuzzy risk rating as given by the K^{th} decision maker.

The aggregated fuzzy weights of each risk criterion $(\tilde{w}_j)$ can be computed using Eq. (5.7).

Step 5: Normalize the aggregated fuzzy risk ratings using Eq. (5.10), and calculate the weighted normalized decision matrix using Eq. (5.12).

Step 6: Selection the positive ideal solution (PIS) and negative ideal solution (NIS) for alternative with respect to selected risk criteria.

The PIS is a solution that minimizes the cost criteria and maximizes the benefit criteria; whereas, the NIS maximizes the cost criteria and minimizes the benefit criteria. The best alternative is the one, which is closest to the PIS and farthest from the NIS. According to Lai and Chen (2011), fuzzy risk values for most preferable alternative (A^*) or PIS and the least preferable alternative (A^-) or NIS for each selected criterion can be determined as

$$A^* = \left[(0,0);0;(0,0)\right]$$

$$A^- = \left[(1,1);1;(1,1)\right]$$

Step 7: Calculate the collective index (CI) using Eqs. (5.15-5.23).

Step 8: Rank the preference order for safety measure alternatives. Minimum value of the CI indicates the minimum risk incurred by the alternative (A_i). The best alternative is one which has the minimum CI value.

5.5 Case Illustration

In order to validate the proposed methodology, a case study has been conducted using the data from an underground coal mine located in eastern part of India. The scope of the study includes selecting an appropriate safety measure system within the limited financial budget. A focus group survey has been conducted from safety managers and financial executives who were actively associated in occupational health and safety department of aforementioned coal mine. The group includes three experts (with more than ten years' experience in safety management fields) selected to participate in the survey. Due to anonymity reasons, experts' identity have not been wide-opened and therefore, they have been abbreviated as DM_1, DM_2, and DM_3. Experts have been requested to rate their personal opinion in a detailed questionnaire referring to a linguistic scale. A structured questionnaire have been explored contains four safety measure systems with each having three risk assessment criteria. Each risk criteria has been described by possibility of failure as well as severity of loss. The selected experts have been effectively involved in this survey, and their experience has aided a lot in pursuit of this case study.

5.5.1 Safety Alternative Identification and Risk Criteria Selection

Safety measure system is a safety system which can be installed or constructed to ensure adequate level of safety for workers at the workplace (Source: www.aesc.snspreview6.com.au). Therefore, this study identifies four possible safety measure systems such as methane drainage automation system, on-line ventilation monitor and control, water and inundation management system, and information technology for hazard monitor and control from the literature source (Divya et al., 2012; Liu, 2012; Mutton and Remennikov, 2011; Lawrence, 2000). The aforesaid safety measure systems are considered as four alternatives $(A_1, A_2, A_3, \text{and } A_4)$ for the proposed decision making problem. Methane drainage automation system (A_1) is an automated methane control system through which percentage of methane gas emission can be reduced to avoid/mitigate their adverse effect at workplace (Divya et al., 2012). Online ventilation monitor and control system (A_2) is a process which can be used for monitoring and controlling the coal gases as well as dust particles from the work environment (Liu, 2012). Water and inundation management system (A_3) is a set of mechanical equipment arranged in a systematic manner which can be used to channel the coal washing water as well as flood water from the workplace (Mutton and Remennikov, 2011). Information technology for hazard monitor and control (A_4) is a software oriented technology system which can be implemented for prompt identifying and controlling the hazards from the workplace (Lawrence, 2000). The aforediscussed alternatives can be used for increasing the safety status of underground coal mine. However, all the alternatives could not be executed simultaneously because of the limited budget of the said coal mine industry. Therefore, appropriateness of each alternative can be assessed based on three established risk criteria such as, financial risk (RC_1), operating risk (RC_2) as well as maintenance risk (RC_3).

This is very true that budget limitation should not be the sole cause for not using multiple safety measure systems. It also depends on geographical orientation of the workplace, environmental aspects etc.; but in this study, it has been assumed that budget is the only constraint for implementing multiple safety measure system. That is why the best alternative safety measure system has been selected in view of minimal financial risk, operating risk, and maintenance risk from the monetary viewpoint.

5.5.2 Selection of Fuzzy Linguistic Scale

Although many researchers have used various types of linguistic scales to carry out subjective assessments in a variety of fuzzy based decision-making problems. But, the type of the membership function corresponding to a fuzzy number representing a particular linguistic variable has to be selected in accordance with user needs. A commonly used, triangular interval-valued membership function has been found satisfactory for this application (Ashtiani et al., 2009). Table 5.1 presents the set of linguistic variables and corresponding fuzzy number representations that has been used for assessing risk rating of alternatives with respect to each criterion through the possibility of failure and severity of loss. The fuzzy linguistic scale for importance weights of each risk criterion are presented in Table 5.2. The linguistic variables such as Very low (VL), Low (L), Medium low (ML), Medium (M), Medium high (MH), High (H), and Very high (VH) have been used to rate the possibility of failure, severity of loss, and weights of the each criterion.

5.5.3 Data Collection

The linguistic data on possibility of failure, severity of loss, and weights of the risk criteria under each alternative has been collected from the experts. The data sets have been separately collected from the group of decision makers (experts). Table 5.3 presents the importance weight of each risk criterion assigned by the DMs. Also, possibility of failure as well as severity of loss of the alternatives with respect to each risk criterion has been presented in Table 5.4. Then, these linguistic information's have been transformed into appropriate triangular IVFNs referring to fuzzy linguistic scale (Tables 5.1 and 5.2). The importance weights of each risk criterion in terms of triangular IVFNs are presented in Table 5.5.

5.5.4 Decision Analysis

The present section follows the procedural steps (Step 4 to Step 8) of the proposed algorithm to solve the risk based decision making problem. The importance weights of selected risk criteria obtained by three DMs are aggregated by using Eq. (5.7) and shown in Table 5.5. Also, the fuzzy risk ratings of four safety measure systems (Alternatives) provided by all three DMs with respect to each risk criterion are aggregated by Eq. (5.25) and the results are presented in Table 5.6 (Step 4). Then, the aggregated fuzzy risk ratings are normalized by using Eq. (5.10) for constructing a normalized fuzzy decision making matrix and the results are illustrated in Table 5.7. The weighted normalized decision making matrix are constructed by using Eq. (5.12) and shown in Table 5.8 (Step 5). In addition, the fuzzy numbers representing positive ideal solution (A^*) and negative ideal solution (A^-) of each selected risk criterion are assumed based on Step 6 of the proposed algorithm, and shown in Table 5.8.

The ideal separation matrix $\left(D^*\right)$ and anti-ideal separation matrix $\left(D^-\right)$ are constructed by using Eq. (5.19) and Eq. (5.20), respectively. The respective results are furnished below:

$$D^* = \begin{bmatrix} 0.523 & 0.983 & 0.312 \\ 0.261 & 0.291 & 1 \\ 1 & 0.613 & 0.178 \\ 0.333 & 0.446 & 0.554 \end{bmatrix}$$

and

$$D^- = \begin{bmatrix} 0.976 & 0.967 & 0.989 \\ 0.979 & 0.976 & 0.984 \\ 0.964 & 0.967 & 0.990 \\ 0.975 & 0.974 & 0.986 \end{bmatrix}$$

Finally, the values of $\Im_i$, ς_i, and CI are calculated by using Eqs. (5.21–5.23), respectively, and shown in Table 5.9.

For example, $\Im_1 = [(0.523/0.976) + (0.983/0.967) + (0.312/0.989)]^{1/3} = 1.232$ and

$\varsigma_1 = (0.523 + 0.983 + 0.312)^{1/3} + \{(1/0.976) + (1/0.967) + (1/0.989)\}^{1/3} = 2.674$.

Therefore, the collective index for alternative (A_1) is calculated as:

$CI_i = \Im_i + \varsigma_i = 1.232 + 2.674 = 3.906.$

According to Table 5.9, the ranking order of four potential alternatives appears as $A_4 > A_2 > A_3 > A_1$ for the present problem of safety measure system selection. Therefore, information technology for hazard monitor and control (A_4) is found to be the best safety measure system as it has lowest risk value amongst the other systems (alternatives).

The applicability of the proposed methodology has been tested through a real time case study for selecting an appropriate safety measure system for an established Indian underground coal mine industry. The proposed methodology not only assesses risk that is likely to incur during the selection of safety measure system, its concept and procedure can also be utilized for risk-based decision making in a variety of engineering and management related problems.

In this research, the selected safety measure systems (alternatives) as well as risk criteria are explicitly industry specific. However, the proposed decision making approach is generic one. Therefore, this study could provide the guidance to the safety managers how the detailed procedure can be utilized in practice rather than universally accepted solution for risk-based selection problems.

The study recommends that information technology for hazard monitor and control (A_4) is found to be the best safety measure system as it has lowest risk value amongst the other systems (alternatives).

5.6 Managerial Implications and Conclusion

The proposed risk-based decision making framework facilitates for ranking and selecting an appropriate alternative based on minimal level of risk with respect to multiple risk criteria. This approach utilizes experts' risk perceptions in a subjective manner rather than probabilistic way. In this work, fuzzy set theory has been used to quantify fuzzy risk ratings where both the possibility of failure and severity of loss against individual alternatives with respect to each risk criteria have been evaluated by experts' subjective judgment.

This study has explored an interval-valued fuzzy modified TOPSIS method for solving risk-based decision making problems with multiple judges and multiple risk criteria in a fuzzy environment. This approach can effectively tackle uncertainty and vagueness in human opinions and representing the degree of certainty in an interval form. This is because, the linguistic modeling phenomenon of interval valued fuzzy sets is much accurate than the traditional fuzzy sets (Cornelis et al., 2006).

The applicability of the proposed methodology has been tested through a real time case study for selecting an appropriate safety measure system for an established Indian underground coal mine industry. The proposed methodology not only assesses risk that is likely to incur during the selection of safety measure system, its concept and procedure can also be utilized for risk-based decision making in a variety of engineering and management related problems.

In this research, the selected safety measure systems (alternatives) as well as risk criteria are explicitly industry specific. However, the proposed decision making approach is generic one. Therefore, this study could provide the guidance to the safety managers how the detailed procedure can be utilized in practice rather than universally accepted solution for risk-based selection problems.

In this work, a decision making problem has been formulated to select an appropriate safety measure system by considering minimal risks that are likely to incur to the particular industry while implementing the safety measure system in reality. In this problem, different safety measure systems have been considered as candidate alternatives and various risk dimensions like financial risks, operational risks, and maintenance risks have been considered as evaluation criteria. It has been assumed that all safety measure systems cannot be implemented simultaneously due to budget limitations. Therefore, the appropriate alternative that is to be implemented should correspond to minimal risks in monetary view point.

The same problem can be well articulated as a constraint optimization problem in which objective function is the risk (summation of financial risks, operating risks, and maintenance risks) and the alternative safety measure systems are possible solutions. The most appropriate solution will be one which can minimize risks subjected to the constraint (budget limitation).

Table 5.1: Definitions of linguistic variables for both possibility of failure and severity of loss with respect to risk criteria (Source: Ashtiani et al., 2009)

Linguistic variables	Triangular interval-valued fuzzy numbers
Very low (VL)	[(0,0);0;(1,1.5)]
Low (L)	[(0,0.5);1;(2.5,3.5)]
Medium low (ML)	[(0,1.5);3;(4.5,5.5)]
Medium (M)	[(2.5,3.5);5;(6.5,7.5)]
Medium high (MH)	[(4.5,5.5);7;(8.0,9.5)]
High (H)	[(5.5,7.5);9;(9.5,10)]
Very high (VH)	[(8.5,9.5);10;(10,10)]

Table 5.2: Definitions of linguistic variables for importance weights of the risk criteria (Source: Ashtiani et al., 2009)

Linguistic variables	Triangular interval-valued fuzzy numbers
Very low (VL)	[(0,0);0;(0.1,0.15)]
Low (L)	[(0,0.05);0.1;(0.25,0.35)]
Medium low (ML)	[(0,0.15);0.3;(0.45,0.55)]
Medium (M)	[(0.25,0.35);0.5;(0.65,0.75)]
Medium high (MH)	[(0.45,0.55);0.7;(0.8,0.95)]
High (H)	[(0.55,0.75);0.9;(0.95,1)]
Very high (VH)	[(0.85,0.95);1;(1,1)]

Table 5.3: Importance weights of each risk criterion provided by the DMs

Criteria	Decision makers		
	DM_1	DM_2	DM_3
Financial risk (RC_1)	VH	VH	H
Operating risk (RC_2)	H	MH	H
Maintenance risk (RC_3)	VH	H	H

Table 5.4: Linguistic data for evaluating fuzzy risk ratings of candidate alternatives versus each risk criterion assigned by the DMs

DMs	Items (A_i)	Financial risk (RC_1)		Operating risk (RC_2)		Maintenance risk (RC_3)	
		Severity of loss $(\tilde{S}_{ij})$	Possibility of failure $(\tilde{P}_{ij})$	Severity of loss $(\tilde{S}_{ij})$	Possibility of failure $(\tilde{P}_{ij})$	Severity of loss $(\tilde{S}_{ij})$	Possibility of failure $(\tilde{P}_{ij})$
DM_1	A_1	M	L	M	M	H	M
	A_2	H	M	H	H	M	L
	A_3	L	L	H	L	L	M
	A_4	VH	L	H	M	MH	M
DM_2	A_1	H	M	M	L	ML	L
	A_2	M	L	M	L	L	M
	A_3	ML	L	M	M	MH	M
	A_4	M	M	H	M	ML	L
DM_3	A_1	M	ML	ML	M	M	L
	A_2	M	M	M	M	ML	L
	A_3	H	M	L	M	M	L
	A_4	H	L	ML	L	L	L

Table 5.5: Triangular interval-valued fuzzy numbers for importance weights and the aggregated fuzzy weights

Criteria	Decision makers			Aggregated fuzzy weights
	DM_1	DM_2	DM_3	
RC_1	$[(0.85, 0.95); 1; (1,1)]$	$[(0.85, 0.95); 1; (1,1)]$	$[(0.55, 0.75); 0.9; (0.95,1)]$	$[(0.75, 0.883); 0.966; (0.983,1)]$
RC_2	$[(0.55, 0.75); 0.9; (0.95,1)]$	$[(0.45, 0.55); 0.7; (0.8, 0.95)]$	$[(0.55, 0.75); 0.9; (0.95,1)]$	$[(0.516, 0.683); 0.833; (0.9, 0.983)]$
RC_3	$[(0.85, 0.95); 1; (1,1)]$	$[(0.55, 0.75); 0.9; (0.95,1)]$	$[(0.55, 0.75); 0.9; (0.95,1)]$	$[(0.65, 0.816); 0.933; (0.966,1)]$

Table 5.6: Decision makers aggregated opinion transforming into triangular interval-valued fuzzy numbers and the aggregated fuzzy risk ratings

Criteria	Alternatives	Severity of loss ($\tilde{S}_{ij}$)	Possibility of failure ($\tilde{P}_{ij}$)	Aggregated risk ratings
RC_1	A_1	$[(3.5,4.833);6.333;(7.5,8.333)]$	$[(0.833,1.833);3;(4.5,5.5)]$	$[(2.915,8.858);18.999;(33.75,45.831)]$
	A_2	$[(3.5,4.833);6.333;(7.5,8.333)]$	$[(1.666,2.5);3.666;(5.166,6.166)]$	$[(5.831,12.082);23.216;(38.745,51.381)]$
	A_3	$[(1.833,3.166);4.333;(5.5,6.333)]$	$[(0.833,1.5);2.333;(3.833,4.833)]$	$[(1.526,4.749);10.108;(21.081,30.607)]$
	A_4	$[(5.5,6.833);8;(8.666,9.166)]$	$[(0.833,1.5);2.333;(3.833,4.833)]$	$[(4.581,10.249);18.664;(33.216,44.299)]$
RC_2	A_1	$[(1.666,2.833);4.333;(5.833,6.833)]$	$[(1.666,2.5);3.666;(5.166,6.166)]$	$[(2.775,7.082);15.884;(30.133,42.132)]$
	A_2	$[(3.5,4.833);6.333;(7.5,8.333)]$	$[(2.666,3.833);5;(6.166,7)]$	$[(9.331,18.524);31.665;(46.245,58.331)]$
	A_3	$[(2.666,3.833);5;(6.166,7)]$	$[(1.666,2.5);3.666;(5.166,6.166)]$	$[(4.441,9.582);18.33;(31.853,43.162)]$
	A_4	$[(3.666,5.5);7;(7.833,8.5)]$	$[(1.666,2.5);3.666;(5.166,6.166)]$	$[(6.107,13.75);25.662;(40.465,52.411)]$
RC_3	A_1	$[(2.666,4.166);5.666;(6.833,7.666)]$	$[(0.833,1.5);2.333;(3.833,4.833)]$	$[(2.220,6.249);13.218;(26.190,37.049)]$
	A_2	$[(0.833,1.833);3;(4.5,5.5)]$	$[(0.833,1.5);2.333;(3.833,4.833)]$	$[(0.693,2.749);6.999;(17.248,26.581)]$
	A_3	$[(2.333,3.166);4.333;(5.666,6.833)]$	$[(1.666,2.5);3.666;(5.166,6.166)]$	$[(3.886,7.915);15.884;(29.270,42.132)]$
	A_4	$[(1.5,2.5);3.666;(5.0,6.166)]$	$[(0.833,1.5);2.333;(3.833,4.833)]$	$[(1.249,3.75);8.552;(19.165,29.800)]$

Table 5.7: Normalized interval-valued fuzzy decision matrix

Alternatives	RC_1	RC_2	RC_3
A_1	$[(0.033, 0.045); 0.080; (0.172, 0.523)]$	$[(0.065, 0.092); 0.174; (0.391, 1)]$	$[(0.018, 0.026); 0.052; (0.110, 0.312)]$
A_2	$[(0.029, 0.039); 0.065; (0.126, 0.261)]$	$[(0.047, 0.060); 0.087; (0.149, 0.297)]$	$[(0.026, 0.040); 0.099; (0.252, 1)]$
A_3	$[(0.049, 0.072); 0.150; (0.321, 1)]$	$[(0.064, 0.087); 0.151; (0.289, 0.624)]$	$[(0.016, 0.023); 0.043; (0.087, 0.178)]$
A_4	$[(0.034, 0.045); 0.081; (0.148, 0.333)]$	$[(0.052, 0.068); 0.108; (0.201, 0.454)]$	$[(0.023, 0.036); 0.081; (0.184, 0.554)]$

Table 5.8: Weighted normalized interval-valued fuzzy decision matrix

Alternatives	RC_1	RC_2	RC_3
A_1	$[(0.024, 0.039); 0.077; (0.169, 0.523)]$	$[(0.033, 0.062); 0.145; (0.352, 0.983)]$	$[(0.011, 0.021); 0.048; (0.106, 0.312)]$
A_2	$[(0.021, 0.034); 0.062; (0.123, 0.261)]$	$[(0.024, 0.040); 0.072; (0.134, 0.291)]$	$[(0.016, 0.032); 0.092; (0.243, 1)]$
A_3	$[(0.036, 0.063); 0.145; (0.315, 1)]$	$[(0.033, 0.059); 0.125; (0.260, 0.613)]$	$[(0.010, 0.018); 0.040; (0.084, 0.178)]$
A_4	$[(0.025, 0.039); 0.078; (0.145, 0.333)]$	$[(0.026, 0.046); 0.089; (0.181, 0.446)]$	$[(0.014, 0.029); 0.075; (0.177, 0.554)]$
Positive-ideal solution	$[(0, 0); 0; (0, 0)]$	$[(0, 0); 0; (0, 0)]$	$[(0, 0); 0; (0, 0)]$
Negative-ideal solution	$[(1, 1); 1; (1, 1)]$	$[(1, 1); 1; (1, 1)]$	$[(1, 1); 1; (1, 1)]$

Table 5.9: Values of $\Im_i$, ς_i and CI_i by proposed method

Alternatives	$\Im_i$	ς_i	CI_i	Final Ranking
A_1	1.232	2.674	3.906	4
A_2	1.165	2.610	3.775	2
A_3	1.228	2.669	3.897	3
A_4	1.108	2.553	3.661	1

CHAPTER 6

RISK ASSESSMENT FOR METROPOLITAN CONSTRUCTION PROJECT: A CASE STUDY

6.1 Coverage

Construction projects in metropolitan areas seems to be highly risky, competitive, and dynamic since their surrounding environments are complicated in terms of transportation, the number of stakeholders, the removal of existing pipelines utilities, and the existence of any other facilities. Therefore, a proactive risk assessment model is indeed a requirement so that the projects can be undertaken with an adequate planning. The increasing complexity and dynamism of construction projects under execution retains substantial uncertainty and subjectivities in the risk assessment process. To overcome this, the present work proposes an improved risk assessment methodology based on the fuzzy set theory. In this work, a hierarchical risk break-down structure has been conceptualized to represent a formal model towards qualitative risk assessment. The risk extent (rating) has been expressed as a function of two parameters: risk likelihood and risk impact. The concept of risk matrix has been explored to categorize various risk factors at different risk levels for the establishment of necessary action requirement plan. A case study of a metropolitan construction project for building an underground Metrorail station has been reported here to validate the proposed methodology.

6.2 Problem Statement

Recently, metro construction has gained a powerful momentum for rapid economic development worldwide (Zhang et al., 2014). Though undertaking of construction projects in metropolitan areas is very appealing but it is highly risky, competitive, and more dynamic due to their complicated surrounding environments such as heavy traffic, transportation, multiple stakeholders' competency, removal of any existing pipelines utilities and other facilities (Kou and Lu, 2013). Underground construction in metro region is seemed to be a highly complicated project with large potential risks; it can eventually bring adverse consequence in terms of project delays and budget overruns. The term risk can be understood by the potential for complications and problems with respect to the completion of a project task and the achievement of a project goal (Mark et al. 2004). Risk is inherent in all project undertakings; it cannot be fully eliminated rather it can be effectively managed to mitigate the impacts onto the success of a project. Due to increasing complexity and dynamic characteristics, most of the large construction projects fail to complete within the stipulated timespan; as it involves lot of uncertainties which are not taken care of properly by the firm's risk management team leads.

In addition, ineffective management of project risks may lead to cost overruns, project delays, and even termination prior to completion, and also imposes ill-impact to the project team's reputation. In order to ensure project success, construction industries are required to adopt a proactive approach for managing inherent risks as well as uncertainties while carrying out construction tasks, especially in metropolitan areas. Therefore, if potential risk factors are carefully identified, assessed and monitored from the initial phase; the probability of project success can be increased effectively.

Risk analysis and risk assessment are the critical components of any project risk management process. Generally, two important approaches have frequently been applied in construction project risk assessment such as probabilistic approach (Zhang et al., 2014; Adams, 2008; Ye and Tiong, 2000) and possibilistic approach (Pinto, 2014; Li et al., 2013; Rezakhani, 2011; Dikmen et al., 2007; Carr and Tah, 2001). Probabilistic approach deals with the estimation of the likelihood and impact of any given risk based on the historical numeric data; whereas, possibilistic approach deals with estimating likelihood and impact of a given risk based on qualitative (descriptive) data. Many popular probability based techniques like sensitivity analysis, decision tree analysis, Bayesian network analysis, Monte Carlo simulation approach are usually used for the risk analysis of construction projects. However, the limitation of probability theory is that it cannot deal with important aspect of project uncertainty which may arise due to the existence of uncertain and vague (ill-defined) risk factors during the risk assessment phase of project management practice (Ebrat and Ghodsi, 2014; Pender, 2001). Therefore, in order to estimate construction project risks in a more precise way, fuzzy set theory has been used to address subjectively for uncertain characteristics of risk factors. In this work, an improved fuzzy based decision making approach has been proposed to estimate the magnitude of potential risks for a particular case metropolitan construction project.

In relation to the metro construction project, it has been observed that limited attempts have been made to establish a comprehensive risk assessment approach from a decision making viewpoint towards incorporating various issues like uncertainty, decision makers' attitudes (pessimistic, optimistic, moderate) during the risk assessment process. Also it is indeed necessary to develop a risk mitigation plan typically required for the successful management of construction project risks. Therefore, this work proposes an improved risk assessment procedure for assessing the metropolitan construction project risks using the combined strength of decision making science and fuzzy set concept. The proposed approach employs 'Circumcenter of centroid method' to quantify the crisp value of fuzzy risk rating considering the subjective evaluation of likelihood of occurrence and impact of risk. In addition, all identified risk factors are classified into different risk categories based on their quantifying value of risk ratings; then an action requirement plan is suggested which can be used for the effective management of construction project risks.

6.3 Basics of Risk Assessment

According to BSI (2007), risk assessment is defined as the process of evaluating risk(s) arising from hazard(s), taking into account the adequacy of any existing controls, and deciding whether the risk is acceptable or require some control actions. It includes identification of critical risk factors, and analysis of these factors to determine the risk rating. Risk rating is the process for estimating the likelihood of incident and severity of adverse effects likely to occur due to actual or predicted interaction with hazardous situations. It is the end product of risk assessment process that can be used by the management to develop control strategies for eliminating or mitigating the risks. In this work, risk has been described as a function of two parameters- (a) the likelihood, which is the possibility of an undesirable occurrence, and (b) the impact, which is the degree of seriousness if the undesirable things occur (Zhi, 1995). Therefore, using a mathematical description, risk rating can be calculated as follows:

$$R = L \times I \qquad (6.1)$$

where R is the risk rating (degree of risk), within [0, 1]; L is the likelihood of risk occurring, within [0, 1]; I is the degree of impact of the risk, within [0, 1] where greater value indicates higher impact.

From the above risk model i.e. Eq. (6.1), it has been observed that the risk rating is close to zero if a risk factor has either less impact or less likelihood of occurrence. Moreover, if a risk factor retaining high impact and high likelihood of occurrence, its risk rating appears to be very high i.e. close to one. Generally, likelihood of occurrence can be assessed in two ways such as subjective judgment and objective analysis. Subjective judgment process is easy and practical than the objective analysis; because, it does not demand historical data; rather it needs experts experience as well as scrutiny (Zhi, 1995). Therefore, this study focuses on subjective judgment process for assessing both the likelihood of occurrence as well as impact of each risk factor. The subjectivity of aforesaid risk evaluating parameters has been tackled by means of fuzzy set theory and risk has been estimated from fuzzy point of view rather than probabilistic conceptualization.

6.4 Fuzzy Set Approach

The fuzzy set concept was first introduced by (Zadeh, 1965) with prime intention to deal with vagueness in human thought. Fuzzy set theory has the capability to mathematically represent the uncertainty and vagueness, and provide formalized tools for dealing with subjectivity inherent to the decision making problems (Samantra et al., 2014). In risk based decision making environment, risk can be analyzed based on their evaluating parameters which may either be quantitative or qualitative in nature. Quantitative parameters rely on numerical data which can easily be assessed by traditional tools and techniques; whereas, qualitative parameters rely on subjective information data which cannot be assessed by statistical tools. In this work, both risk evaluating parameters (likelihood as well as impact) being subjective in nature; therefore, its assessment depends on the decision-makers' linguistic judgment. It seems very difficult to quantify the risk unless the linguistic information is converted into a quantitative form. However, fuzzy set theory plays an important role for transforming linguistic information into a logical mathematic base. In addition, fuzzy set theory has ability to effectively tackle the impression, vagueness as well as uncertainty involved in the linguistic information data. Therefore, present work proposes an efficient risk assessment model for quantifying the project risks in fuzzy environment. Linguistic variable can be understood by a variable whose values are not expressed in numbers rather it is expressed in words or sentences in a natural or artificial language (Zadeh, 1975). Linguistic concept is very useful dealing in the situations, which are too complex and ill-defined to be rationally described in traditional quantitative expressions (Zimmermann, 1991). For example, "risk impact" is a linguistic variable whose values are expressed in a natural language such as; VH (very high), H (high), and M (medium) etc. A fuzzy number can be defined as a fuzzy subset in the universe of discourse U that is both convex and normal. Fuzzy numbers are more expressive to quantify subjective information into a range rather than in an exact value (Chan et al., 2000). In decision making, various types of fuzzy numbers such as triangular, trapezoidal, Gaussian fuzzy numbers (membership functions) are frequently used for interpreting the linguistic data to quantitative form (Chen and Chen, 2009; Xia et al. 2006; Yang and Hung, 2007). However, trapezoidal fuzzy numbers are extensively used due to its simplicity in mathematical representation as well as easy computation. A trapezoidal fuzzy number can be represented in the form (a,b,c,d) which is the most generic class of fuzzy numbers with linear membership function (Bansal, 2011; Kaufmann and Gupta, 1991). Thus, due to its generic property, this class of fuzzy numbers is mostly used for modeling linear uncertainty in scientific as well as applied engineering problems rather than the class of triangular fuzzy numbers.

6.4.1 Method of 'Circumcenter of Centroids'

Ranking of fuzzy numbers can be viewed as an important aspect of decision making in fuzzy environment. In fuzzy decision making situations, fuzzy quantities have been used to define the performance of alternatives in modeling a real life problem. Jain (1976) has first proposed a ranking procedure for ordering the fuzzy quantities in decision making environment. In the literature, many authors have proposed various ranking methods for ranking fuzzy numbers by preference ratio (Modarres and Nezhad, 2001), left and right dominance (Chen and Lu, 2001), area between the centroid point and original point (Chu and Tsao, 2002), sign distance (Abbasbandy and Asady, 2006) and distance minimization (Asady and Zendehnam, 2007). Rao and Shankar (2011) have demonstrated an improved ranking method for ordering fuzzy numbers using the concept of 'Circumference of centroids'. The method provides a mathematical formulation for ranking the fuzzy numbers based on their crisp score. This concept has been explored in this research towards proposing an efficient risk assessment module. The basic concept of 'Circumference of centroids' has been reproduced below.

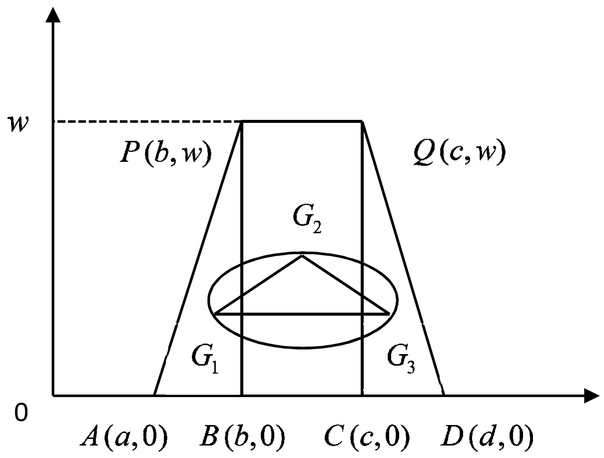

Fig. 6.1: Circumcenter of centroids

The centroid of a trapezoid is considered as the balancing point of the trapezoid. Firstly, the trapezoid is split into three plane figures like a triangle (APB), a rectangle (BPQC), and again a triangle (CQD), respectively (Fig. 6.1). Then the centroids of these plane figures are calculated followed by the calculation of the Circumcenter of these centroids. The Circumcenter of centroids is considered as the point of reference to define the ranking of generalized fuzzy numbers. The reason for selecting this point as a point of reference is that each centroid point (G_1 of triangle APB, G_2 of rectangle BPQC, and G_3 of triangle CQD) are balancing points of each individual plane figure, and the Circumcenter of these centroid points is equidistant from each vertex (i.e. centroids). Therefore, this point would be a better reference point than Centroid point of the trapezoid.

Consider a generalized trapezoidal fuzzy number $\tilde{A}=(a,b,c,d;w)$. The centroids of the three plane figures are $G_1=((a+2b)/3,w/3)$, $G_2=((b+c)/2,w/2)$, and $G_3=((2c+d)/3,w/3)$, respectively. Equation of the line $\overleftrightarrow{G_1G_3}$ is $y=w/3$ and G_2 does not lie on the line $\overleftrightarrow{G_1G_3}$. Therefore, G_1,G_2 and G_3 are non-collinear and they form a triangle.

Let us define the Circumcenter $S_{\tilde{A}}(\bar{x}_0,\bar{y}_0)$ of the triangle with vertices G_1,G_2 and G_3 of the generalized trapezoidal fuzzy number $\tilde{A}=(a,b,c,d;w)$ as

$$S_{\tilde{A}}(\bar{x}_0,\bar{y}_0)=\left(\frac{a+2b+2c+d}{6},\frac{(2a+b-3c)(2d+c-3b)+5w^2}{12w}\right) \quad (6.2)$$

As a special case, for triangular fuzzy number $\tilde{A}=(a,b,c,d;w)$, that is, $c=b$ the Circumcenter of centroids is given by

$$S_{\tilde{A}}(\bar{x}_0,\bar{y}_0)=\left(\frac{a+4b+d}{6},\frac{4(a-b)(d-b)+5w^2}{12w}\right) \quad (6.3)$$

The ranking function of the trapezoidal fuzzy number $\tilde{A}=(a,b,c,d;w)$ which maps the set of all fuzzy numbers to a set of real numbers is defined as:

$$R(\tilde{A})=\sqrt{\bar{x}_0^2+\bar{y}_0^2} \quad (6.4)$$

where $R(\tilde{A})$ is the Euclidean distance from the Circumcenter of the centroids and the original point.

When decision makers' attitude is considered, then the ranking function has been modified as follows:

$$I_\alpha(\tilde{A})=\alpha\bar{y}_0+(1-\alpha)\bar{x}_0 \quad (6.5)$$

where $\alpha\in[0,1]$ is the index of optimism which represents the degree of optimism of a decision maker. The value of α may vary with the change of decision makers view point. If decision makers view point is pessimistic $(\alpha=0)$, moderate $(\alpha=0.5)$, and optimistic $(\alpha=1)$. The lager the value of α is, the higher the degree of optimism.

6.5 Proposed Methodology

In this work, a hierarchical risk breakdown structure with two distinct levels (Table 6.1) has been used for assessing risks of metropolitan construction project. First level includes various potential risk factors which are identified from the source of different risk dimensions, and the second level highlights different risk dimensions which can be considered as major risk sources affecting to the overall project performance. A more general multi-criteria decision making scenario has been introduced for quantifying the construction project risks effectively. The scenario comprises a committee of k experts $(E_1, E_2, ..., E_k)$ who are responsible for assessing the risks of n risk influencing factors $(F_1, F_2, ..., F_n)$, under m risk dimensions $(D_1, D_2, ..., D_m)$.

In fuzzy decision making environment, risk of each influencing factor is quantified by multiplying two evaluating parameters such as likelihood of occurrence and its impact. The following procedural steps have been proposed for calculating fuzzy risk ratings, and also for categorizing as well as managing the identified risk factors.

Step 1: Identification of potential risk factors from the hierarchical risk breakdown structure of construction project.

Step 2: Selection of appropriate fuzzy linguistic scale for expressing both likelihood of occurrence and impact of risk.

Step 3: Linguistic data (in relation to likelihood of occurrence and impact of risk) have been collected from the experts through the focus group survey. Thereafter, linguistic data have been translated into appropriate trapezoidal fuzzy numbers.

Step 4: Aggregated fuzzy preferences have been computed by using fuzzy aggregation rules. Fuzzy risk rating of each project risk factor has been calculated by multiplying fuzzy likelihood of occurrence and fuzzy risk impact.

Step 5: Crisp risk rating corresponding to each project risk factor has been calculated using ‘Circumference of centroids’ (Rao and Shankar, 2011) method. Moreover, risk factors have been ranked based on their crisp ratings. Then, a comparative study on the ranking order of risk factors has been presented to analyze the variation of risk rating values with respect to the risk-bearing attitudes of different experts.

Step 6: Risk factors have been categorized based on the concept of risk matrix.

Step 7: An action requirement plan has been suggested for different risk factor categories.

The above procedure seems to be a generic one. However, the aforementioned risk ratings may vary due to different decision making environment as well as different risk management policies.

6.6 Case Application

In order to validate the proposed risk assessment approach, a case study has been conducted using the data from a metro system construction project in the city of Kolkata, India. The scope of the project includes building an underground station for the Kolkata Metro system, which necessitates deep excavation, excavation support system, and dewatering work. The undertaking project follows cut-and-cover construction plan in a heavy traffic area. A focus group survey has been conducted from construction executives and managers (profile displayed in Table 6.2) who have been actively associated in aforementioned construction project. The group including five experts with more than ten years' experience in construction project management and being familiar with construction project risks has been selected to participate in the survey. Due to anonymity reasons, experts' identity have not been wide-opened here and therefore, they have been abbreviated as E_1, E_2, E_3, E_4, and E_5. Experts have been requested to provide their personal opinion in a detailed questionnaire (Appendix D) referring to a linguistic scale. A structured questionnaire has been provided containing a total of twenty potential project risk factors, and each risk factor has been described by likelihood of occurrence as well as its impact. The selected experts being effectively involved in metro system construction projects; their experience and expertise have aided a lot in pursuit of this case study.

6.6.1 Risk Factor Identification

Risk factor identification is the primary phase of risk assessment. If risk factor is identified, then it becomes logical to pursue the information on the likelihood of occurrence as well as its impact for assessing the risk rating. According to the definition of risk as described in Section 6.3, the undesirable outcomes may arise due to the influence of various risk factors. The objective of risk identification in course of the present work is to identify and classify risk factors which could affect to the success of the construction project. The process of identifying risks promotes creativity thinking as well as leverage team experience. The outcome of this process articulates a hierarchical structure of project risk factors which possesses nature of risks for the metropolitan construction projects (Table 6.1). The hierarchy includes twenty potential risk factors classified into five risk dimensions such as: engineering design, construction management, construction safety related, natural hazards, and social and economic. This study focuses only twenty risk factors which are fairly common, important and sensitive to the aforesaid project identified from the various literature sources as described in Table 6.1.

6.6.2 Linguistic Scale Selection

A linguistic scale can be designed with a set of words of same grammatical category, which can be ordered by their semantic strength or degree of informativeness (Horn, 1972; Levinson, 1983). Fuzzy linguistic scale involves a set of linguistic variables which can be represented as a set of fuzzy numbers, resulting in fuzzy representation for each property. Although many researchers have used various types of linguistic scales for solving a variety of fuzzy based decision making problems. But, the type of fuzzy number for linguistic variables can be selected with the satisfaction of following properties: (a) available domain knowledge; (b) simplicity of the membership function; and (c) possible parametric optimization of the fuzzy sets (calibration of the membership function) (Yuen, 2014). In this work, a more general trapezoidal fuzzy number has been found suitable to carry out subjective assessment of construction project risks. As discussed earlier, risk assessment includes the evaluation of two parameters, the likelihood of occurrence and the impact of risk. Therefore, in this study, the likelihood of risk occurrence has been quantified by using the seven members' fuzzy linguistic scale, as described in Table 6.3. Similarly, the five members' fuzzy linguistic scale suggested by (Xia et al., 2006) has been employed here to evaluate the risk impact possibility and presented in Table 6.4. The linguistic variables such as Absolutely Certain (AC), Very Frequent (VF), Frequent (F), Probable (P), Occasional (O), Rare (R), and Very Rare (VR) are used to rate the likelihood of risk occurrence. Also, the following linguistic variables like Very high (VH), High (H), Moderate (M), Low (L), Very low (VL) have been used to rate the risk impact.

6.6.3 Data Collection

The linguistic data on likelihood of risk occurring and the risk impact of each identified risk factor have been collected from the expert group. The collected data have further been used to evaluate the risk extent of each individual risk factor affecting to the overall project performance. Experts have provided their judgment in linguistic terms rather than crisp scores. During the judgment process, the experts have been requested to keep confidential about their judgment and even not to share their personal opinion among themselves also (to avoid biasness). These linguistic information have been separately collected from the expert's and tabulated in a well-structured manner. Table 6.5 shows the linguistic data set expressing likelihood of occurrence of various risk factors assigned by the experts. Similarly, the information regarding the risk impact of corresponding risk factors has been presented in Table 6.6. Then, the above linguistic information has been translated into corresponding generalized trapezoidal fuzzy numbers as per (Tables 6.3-6.4) and used to carry out the evaluation of fuzzy risk rating.

6.6.4 Risk Rating Assessment

During the risk assessment process, experts' individual opinions have been combined to form a average (aggregated) preference using the fuzzy aggregation rule. At this stage, the concept of fuzzy arithmetic operations of generalized trapezoidal fuzzy numbers seems to be fruitful to form an aggregation rule. Aggregation is the process of combining the fuzzy numbers to obtain a single average fuzzy preference. Let k is the number of experts $\left(E_t, t=1,...,k\right)$, who are responsible to assess n risk influencing factors $\left(F_{i,j}, j=1,...,n\right)$, under m risk dimensions $\left(D_i, i=1,...,m\right)$. Therefore, the aggregated fuzzy preference of each risk influencing factors $\left(\tilde{F}_{ij}\right)$ in both form of likelihood as well as impact can be computed as follows (Chen, 2000):

$$\tilde{F}_{ij} = \frac{1}{k}\left[\tilde{F}_{ij1} \oplus \tilde{F}_{ij2} \oplus ... \oplus \tilde{F}_{ijk}\right] \tag{6.6}$$

Then, Eq. (6.7) can be used to obtain the corresponding fuzzy risk rating of each individual risk factor:

$$\text{Fuzzy risk rating} = \left(\tilde{F}_{ij}\right)_L \otimes \left(\tilde{F}_{ij}\right)_I \tag{6.7}$$

Then, the crisp risk rating of each identified risk factors can be analyzed by two ways: (a) without considering the experts attitudes (pessimistic, optimistic, and moderate); and (b) with considering the experts attitudes. Eq. (6.4) can be used to calculate the corresponding crisp risk rating of each individual risk factor without considering the experts attitude. The computed crisp rating describes the estimated level of risk for the investigated risk factors. The overall project risk can also be estimated by adding the risk rating values of all risk factors. The larger crisp value indicates the criticality of risk factors which may impose maximum negative impact on the metropolitan construction project performance. Therefore, the risk factors associated with the construction project have been ranked based on their crisp scores. The results of aggregated fuzzy preferences, fuzzy as well as crisp risk ratings, and risk factors ranking have been presented in Table 6.7. It can be seen that amongst twenty risk factors, ground water seepage, conflicting interfaces between work items, design drawing errors, inappropriate design and poor engineering, and super cyclonic storm are the five risk factors having highest risk ratings which can impose highest possible adverse effects on the construction project performance. Ineffective control of ground water seepage can produce serious damage to underground construction sites because it has a great influence on the soil structure in the excavation areas. Conflicting interfaces between work items can lead to construction project delay which may frequently occur due to the limited work area, where multiple groups have to work simultaneously. When construction work starts with a design drawing errors, there may be a huge loss of money as well as time due to the reconstruction of the same work. In addition, other construction processes may also be delayed due to the changes and corrections applied for the rework. Similarly, inappropriate design and poor engineering can damage the build structure even prior to completion of the project and offer reconstruction of the same. Moreover, inappropriate support design may also cause serious accidents during the underground construction work. The risk factor like super cyclonic storm has a significant influence on construction project performance. Super cyclonic storm is a natural hazard which usually occurs in the coastal region due to the effect of global climate change. In this study, the factor like ground water seepage has the highest risk rating (0.5441) contributing to overall project risks obtained on the combined analysis of impact as well as occurrence possibility of the investigated risk factors. Conflicting interference between work items and super cyclonic storm have the second and fifth highest risk rating, respectively. Similarly, design drawing errors, and inappropriate design and poor engineering have the third and fourth highest risk rating contributing to the overall risk value among the twenty identified risk factors.

The factors other than aforementioned have reasonable negative impact on project performance (as a whole) but also highly influence to the particular risk dimension in which they belong to. Therefore, the risk rating of each identified risk dimensions can be calculated by summing of their risk rating values of associated risk factors. The results are furnished in Table 6.7. It can also be seen that engineering design has the highest risk rating (2.0427) which can impose highest negative impact on project performance among the five risk dimensions. Its percentage of contribution is about 21.11% to the overall metropolitan construction project risks. The risk dimensions like natural hazard risks are contributing second highest percentage; and construction management risks have lowest contribution to the overall risk value. The percentage of contribution of each identified risk dimension on project performance can be understood by Fig. 6.2.

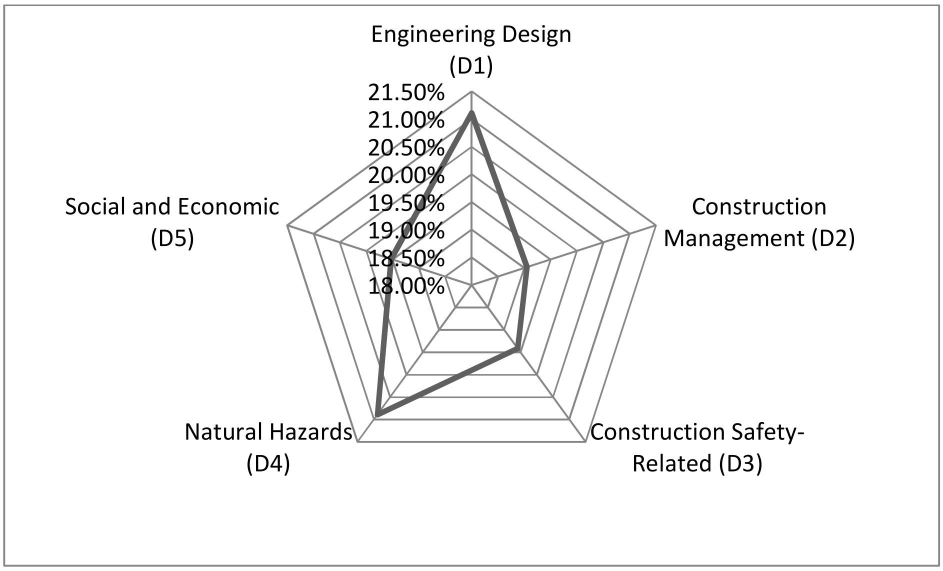

Fig. 6.2: Percentage of contribution of various risk dimensions to the overall project risk

The risks of the each individual dimension can be controlled by managing their risk factors associated within the dimension. However, the risk factors with high risk ratings are essentially required to be controlled immediately for effective management of overall construction project risks.

It is obvious that, the above crisp risk rating of each identified risk factor may vary, when experts' attitude is considered. Therefore, this study further analyses the ranking order of risk factors considering experts different risk bearing attitude or view point (pessimistic, optimistic, and moderate). Eq. (6.5) can be used to calculate corresponding crisp risk rating of twenty identified risk factors considering experts view point. The results considering experts pessimistic, optimistic and moderate view point are presented in Table 6.8. It can be observed that, although the computed risk values of each individual risk factor is changed, but the ranking order with expert's moderate viewpoint is closely matched with the previous risk factors ranking (without considering experts attitudes). Hence, it is confirmed that the obtained risk assessment result is more reliable as well as practical, and it can further be used to establish a risk management plan for managing overall construction project risks effectively.

6.6.5 Risk Factor Categorization

In order to prioritize the risk control measures, the identified risk factors are required to be classified in different risk categories. The risk matrix concept has been used in this study to categorize the investigated risk factors in different risk categories based on the risk rating range.

Risk matrix defines various levels of risk as the product of the variables associated with the likelihood categories and impact categories. Table 6.3 and Table 6.4 have been used here to construct the risk matrix. In linguistic scales, the crisp values of likelihood parameter (L) have been multiplied by the impact parameter (I), resulting as risk ratings. The crisp values of fuzzy numbers (described in linguistic scales) can also be calculated by using Eq. (6.4). The maximum rating range can be decided on the highest possible risk rating which may be assigned to a risk factor from the risk matrix values. The results have been presented in Table 6.9. It can be seen that, 0.9536 is the highest possible risk rating, and 0.1734 being the lowest possible risk rating that can be assigned to a particular risk factor by the experts. Thus, the identified risk factors have been categorized in five different categories (0-5) with the specified rating range from the range of (0 - 0.9536) as shown in Table 6.10. Subsequently, an improved action requirement plan has been suggested by the risk management team lead, risk owner, and risk committee for effectively controlling the risks associated with the factors appeared in different risk categories. Table 6.10 presents various risk factors under each risk category and their control action plans for successfully managing the metropolitan construction project.

6.7 Managerial Implications

This work presents a case empirical study on important issues of risks and their control measures associated with the long-term total project risk management practice, in the context of an Indian metro station construction system. The case study analyses overall project risks considering twenty identified potential risk factors associated with the metropolitan construction project and subsequent risk management plan for controlling the risks towards overall success of the project. It is obvious that, effective management of risks requires a robust risk management process which includes risk identification, risk assessment and risk mitigation/control. A hierarchical risk break-down structure has been proposed here to facilitate the process of risk identification for the construction project. Twenty potential risk factors from the five important risk dimensions such as engineering design, construction management, construction safety-related, natural hazards and social and economic have been identified from the survey of past literature (Kuo and Lu, 2013; Tah and Carr, 2000; Dey, 2001).

A real case study has been conducted in an underground metro system construction project towards assessing overall project risks using the subjective data of twenty identified risk factors. In this work, an improved methodology has been proposed to conduct risk assessment as well as to chalk out risk management plan at the early stage of the construction projects. The methodology has been based on the fuzzy multi-criteria decision making approach to support the process of quantifying the degree of risk of each identified risk factors associated with the project. The Circumcenter of centroids method proposed by (Rao and Shankar, 2011) have been found fruitful for calculating the crisp score of fuzzy risk ratings and thereby enhancing the risk management process.

The fuzzy concept has been utilized herewith to assist the process of converting the linguistic data on likelihood of risk occurring as well as risk impact into a fuzzy numeric quantity. In addition, the application of fuzzy set theory has successfully tackled the uncertainty as well as vagueness arising to the expert's perception during the subjective judgment process. The crisp values of corresponding fuzzy risk ratings has been found helpful to perceive the significance of risk that need to be controlled for increasing the effectiveness of the construction project management practice. The risk factors with high degree of risk need to be controlled immediately for reducing the overall project risks.

This research also focuses a robust risk management plan which can be employed for identifying the risk factors with different specific risk category and suggests the subsequent control actions requirement. This could provide the guidelines to the managers for successfully controlling, monitoring, and managing the risks associated in the metropolitan construction projects.

In this work, the proposed methodology used for the construction project risk assessment is generic one. The model as well as the identified risk factors described here are explicitly industry specific.

In order to confirm the validity of the proposed risk management process, twelve project managers with more than fifteen years' experience in metropolitan construction fields have been interviewed regarding the (a) applicability of proposed risk assessment approach for metro system construction project, (b) advantage of operating the proposed risk assessment steps, (c) completeness of identified risk factors for metropolitan construction project, (d) effectiveness of the suggestive control actions plan for controlling risks effectively in real life projects. Nighty five percent interviewees answered positive to the above questions after clear examination of the proposed risk assessment operational steps as well as risk treatment plan.

6.8 Concluding Remarks

This study provides a comprehensive risk management approach for effective management of metropolitan construction project risks. The twenty identified risk factors under five important risk dimensions has been modeled as a hierarchical risk break-down structure to facilitate the risk assessment for metropolitan construction project. In this work, individual risk factors on project performance have been estimated by multiplying the likelihood of risk occurrence and its impact. It has been concluded that, five important risk factors like ground water seepage, conflicting interfaces between work items, design drawing errors, inappropriate design and poor engineering, and super cyclonic storm have been found significantly influencing to the overall metropolitan construction project.

This work explores the risk matrix concept which seems to be effective for categorizing the risk factors in different risk level ratings. The proposed methodology not only evaluates the overall construction project risks, its concept and operational steps can also be used to assess the risks in different industrial projects. The applicability of the proposed methodology has been validated through a real time case study. This study has explored the expert's mental attitudes like pessimistic, optimistic and moderate to test the reliability of the risk assessment results.

The contribution of this research is the systematic and logical categorization of various risk factors in different risk rating levels followed by a robust action requirement plan which seems quite useful for effectively managing risks in metropolitan construction project. The exploration of proposed risk assessment module and risk treatment plan would definitely help to the project managers towards understanding of various risk factors associated with the construction project and their risk impact on the overall success of the project.

Table 6.1: Hierarchical risk-breakdown structure for a metropolitan construction project

Risk Dimensions, D_i	Risk Factors, F_{ij}	Sources
Engineering Design (D_1)	Inappropriate design and poor engineering (F_{11})	(Kuo and Lu, 2013; Tah and Carr, 2000; Dey, 2001)
	Design drawing errors (F_{12})	(Nieto-Morote and Ruz-Vila 2011; Dikmen et al., 2007; Zayed et al., 2008)
	Conflicting interfaces of work items (F_{13})	(Iyer and Jha, 2005; Kuo and Lu, 2013)
	Poor construction site surveys (F_{14})	(Bunni, 2003; Shen et al., 2001; Zeng et al., 2007)
Construction Management (D_2)	Poor construction plan (F_{21})	(Shen et al., 2001; Dikmen et al., 2007; Kuo and Lu, 2013)
	Insufficient experience and skill in construction works (F_{22})	(Zayed et al., 2008; Wang and Yuan, 2011; Zou et al., 2007)
	Delay in relocating existing pipelines and facilities (F_{23})	(Kuo and Lu, 2013; Zayed et al., 2008)
	Unstable supply of critical construction materials (F_{24})	(Tah and Carr, 2000; Eybpoosh et al., 2011; Zayed et al., 2008)
Construction Safety-Related (D_3)	Insufficient protection of adjacent buildings and facilities (F_{31})	(Carr and Tah, 2001; Kuo and Lu, 2013)
	Inadequate worker safety (F_{32})	(Carr and Tah, 2001; Zayed et al., 2008; Kuo and Lu, 2013)
	Ineffective protection of surrounding environment (F_{33})	(Kuo and Lu, 2013; Bunni, 2003)
	Ineffective control and management of traffic (F_{34})	(Kuo and Lu, 2013; Carr and Tah, 2001)
Natural Hazards (D_4)	Heavy rainfall (F_{41})	(Carr and Tah, 2001; Kuo and Lu, 2013; Dey, 2001)
	Super cyclonic storm (F_{42})	(Kuo and Lu, 2013; Dey, 2001; Carr and Tah, 2001)
	Earthquake (F_{43})	(Carr and Tah, 2001; Kuo and Lu, 2013; Dey, 2001)
	Ground water seepage (F_{44})	(Kuo and Lu, 2013; Zayed et al., 2008; Ghosh and Jintanapakanont, 2004)

Social and Economic (D_5)	Political interference (F_{51})	(Tah and Carr, 2000; Dey, 2001; Zayed et al., 2008; Zavadskas et al., 2010; Kuo and Lu, 2013)
	Increases in prices of construction materials (F_{52})	(Dey, 2001; Tah and Carr, 2000; Zou et al., 2007)
	Increases in labours and employee salaries (F_{53})	(Baloi and Price, 2003; Assaf and Al-Hejji, 2006)
	Protest and interference of nearby residents (F_{54})	(Kuo and Lu, 2013; Dey 2001; Baloi and Price, 2003)

Table 6.2: Profile of experts in the decision group

Experts	Abbreviation
Construction Project Manager	E_1
Senior Execution Engineer	E_2
Senior Design Engineer	E_3
Site Engineer with 15 year Experience	E_4
Expert Presented by Clients	E_5

Table 6.3: Seven point fuzzy linguistic scale for quantifying likelihood of occurrence (Source: Chen et al., 2006)

Likelihood	Description	Fuzzy number
Absolutely certain (AC)	Expected to occur with absolute certainty	(0.8,0.9,1,1; 1)
Very frequent (VF)	Much frequent to occur	(0.7,0.8,0.8,0.9; 1)
Frequent (F)	Likely to occur frequently	(0.5,0.6,0.7,0.8; 1)
Probable (P)	Likely to occur several times in the life of the operation	(0.4,0.5,0.5,0.6; 1)
Occasional (O)	Likely to occur sometime in the life of the operation	(0.2,0.3,0.4,0.5; 1)
Rare (R)	Unlikely but possible to occur sometime in the life of the operation	(0.1,0.2,0.2,0.3; 1)
Very rare (VR)	So unlikely that it can be assumed that the possibility of occurrence is negligible	(0,0,0.1,0.2; 1)

Table 6.4: Five point fuzzy linguistic scale for quantifying risk impact (Source: Xia et al., 2006)

Impact (I)	Fuzzy number
Very high (VH)	(0.7,0.8,0.9,1; 1)
High (H)	(0.5,0.6,0.7,0.8; 1)
Moderate (M)	(0.3,0.4,0.5,0.6; 1)
Low (L)	(0.1,0.2,0.3,0.4; 1)
Very low (VL)	(0,0.1,0.2,0.3; 1)

Table 6.5: Likelihood of occurrence (L) for individual risk factors according to subjective judgments of five experts

F_{ij}	E_1	E_2	E_3	E_4	E_5
F_{11}	P	P	P	O	P
F_{12}	O	P	O	P	P
F_{13}	O	P	F	P	O
F_{14}	O	O	R	P	R
F_{21}	P	P	P	F	O
F_{22}	O	O	P	O	O
F_{23}	P	P	P	F	P
F_{24}	R	O	R	R	VR
F_{31}	P	O	O	F	P
F_{32}	P	O	O	P	O
F_{33}	O	R	R	R	O
F_{34}	P	O	O	O	R
F_{41}	O	O	P	P	O
F_{42}	P	O	O	P	P
F_{43}	O	R	R	O	O
F_{44}	P	P	O	P	P
F_{51}	P	P	R	O	R
F_{52}	O	O	O	P	O
F_{53}	R	P	O	O	O
F_{54}	P	P	P	O	O

Table 6.6: Impact of risk (I) for individual risk factors according to subjective judgments of five experts

F_{ij}	E_1	E_2	E_3	E_4	E_5
F_{11}	H	M	H	H	H
F_{12}	H	VH	VH	H	H
F_{13}	VH	VH	H	H	VH
F_{14}	H	H	VH	VH	H
F_{21}	M	H	M	H	M
F_{22}	VH	VH	H	VH	VH
F_{23}	M	L	M	M	L
F_{24}	H	M	M	H	H
F_{31}	H	H	H	M	M
F_{32}	H	VH	H	H	H
F_{33}	M	H	M	H	M
F_{34}	H	H	H	M	VH
F_{41}	H	H	H	M	H
F_{42}	H	H	VH	H	H
F_{43}	VH	VH	H	VH	VH
F_{44}	VH	VH	VH	H	H
F_{51}	H	H	VH	M	H
F_{52}	H	VH	H	H	VH
F_{53}	H	M	M	H	H
F_{54}	H	M	H	M	H

Table 6.7: Aggregated preferences by five experts in terms of fuzzy numbers and their crisp ratings

D_i	F_{ij}	Likelihood (L)	Impact of risk (I)	Fuzzy risk rating $(L \times I)$	x_0	y_0	Crisp risk rating	Ranking order	Risk percentage
D_1	F_{11}	(0.40,0.50,0.56,0.66; 1)	(0.46,0.56,0.66,0.76; 1)	(0.18,0.28,0.37,0.50; 1)	0.3308	0.3962	0.5161	4	2.0427 (21.11%)
	F_{12}	(0.32,0.42,0.46,0.56; 1)	(0.58,0.68,0.78,0.88; 1)	(0.19,0.29,0.36,0.49; 1)	0.3279	0.3996	0.5169	3	
	F_{13}	(0.34,0.44,0.50,0.60; 1)	(0.62,0.72,0.82,0.92; 1)	(0.21,0.32,0.41,0.55; 1)	0.3694	0.3936	0.5398	2	
	F_{14}	(0.20,0.30,0.34,0.44; 1)	(0.58,0.68,0.78,0.88; 1)	(0.12,0.20,0.27,0.39; 1)	0.2403	0.4039	0.4699	13	
D_2	F_{21}	(0.38,0.48,0.52,0.62; 1)	(0.38,0.48,0.58,0.68; 1)	(0.14,0.23,0.30,0.42; 1)	0.2717	0.4021	0.4853	10	1.8434 (19.05%)
	F_{22}	(0.28,0.38,0.44,0.54; 1)	(0.46,0.56,0.66,0.76; 1)	(0.13,0.21,0.29,0.41; 1)	0.2576	0.4009	0.4765	12	
	F_{23}	(0.42,0.52,0.54,0.64; 1)	(0.22,0.32,0.42,0.52; 1)	(0.09,0.17,0.23,0.33; 1)	0.2019	0.4059	0.4533	18	
	F_{24}	(0.10,0.18,0.22,0.32; 1)	(0.42,0.52,0.62,0.72; 1)	(0.04,0.09,0.14,0.23; 1)	0.1221	0.4106	0.4283	20	
D_3	F_{31}	(0.34,0.44,0.50,0.60; 1)	(0.42,0.52,0.62,0.72; 1)	(0.14,0.23,0.31,0.43; 1)	0.2754	0.3998	0.4855	9	1.8783 (19.41%)
	F_{32}	(0.28,0.38,0.44,0.54; 1)	(0.54,0.64,0.74,0.84; 1)	(0.15,0.24,0.33,0.45; 1)	0.2904	0.3986	0.4932	7	
	F_{33}	(0.14,0.24,0.28,0.38; 1)	(0.38,0.48,0.58,0.68; 1)	(0.05,0.12,0.16,0.26; 1)	0.1445	0.4093	0.4340	19	
	F_{34}	(0.22,0.32,0.38,0.48; 1)	(0.50,0.60,0.70,0.80; 1)	(0.11,0.19,0.27,0.38; 1)	0.2350	0.4019	0.4656	16	
D_4	F_{41}	(0.24,0.34,0.42,0.52; 1)	(0.66,0.76,0.86,0.96; 1)	(0.16,0.26,0.36,0.50; 1)	0.3161	0.3919	0.5035	6	2.0217 (20.89%)
	F_{42}	(0.32,0.42,0.46,0.56; 1)	(0.54,0.64,0.74,0.84; 1)	(0.17,0.27,0.34,0.47; 1)	0.3103	0.4006	0.5067	5	
	F_{43}	(0.16,0.26,0.32,0.42; 1)	(0.66,0.76,0.86,0.96; 1)	(0.11,0.20,0.28,0.40; 1)	0.2424	0.3997	0.4674	15	
	F_{44}	(0.36,0.46,0.48,0.58; 1)	(0.62,0.72,0.82,0.92; 1)	(0.22,0.33,0.39,0.53; 1)	0.3677	0.4010	0.5441	1	
D_5	F_{51}	(0.24,0.34,0.36,0.46; 1)	(0.50,0.60,0.70,0.80; 1)	(0.12,0.20,0.25,0.37; 1)	0.2333	0.4069	0.4690	14	1.8889 (19.52%)
	F_{52}	(0.24,0.34,0.42,0.52; 1)	(0.58,0.68,0.78,0.88; 1)	(0.14,0.23,0.33,0.46; 1)	0.2857	0.3950	0.4875	8	
	F_{53}	(0.22,0.32,0.38,0.48; 1)	(0.42,0.52,0.62,0.72; 1)	(0.09,0.17,0.24,0.35; 1)	0.2070	0.4040	0.4539	17	
	F_{54}	(0.32,0.42,0.46,0.56; 1)	(0.42,0.52,0.62,0.72; 1)	(0.13,0.22,0.29,0.40; 1)	0.2575	0.4033	0.4785	11	
Overall project risk							9.6751		

Table 6.8: Comparative study of risk factor ranking with the consideration of expert's attitude

Risk factors (F_{ij})	Expert's attitude					
	Pessimistic $(\alpha = 0)$	Ranking order	Optimistic $(\alpha = 1)$	Ranking order	Moderate $(\alpha = 0.5)$	Ranking order
F_{11}	0.3308	3	0.3962	17	0.3635	4
F_{12}	0.3279	4	0.3996	15	0.3637	3
F_{13}	0.3694	1	0.3936	19	0.3815	2
F_{14}	0.2403	14	0.4039	6	0.3221	13
F_{21}	0.2717	10	0.4021	8	0.3369	10
F_{22}	0.2576	11	0.4009	11	0.3292	12
F_{23}	0.2019	18	0.4059	4	0.3039	18
F_{24}	0.1221	20	0.4106	1	0.2663	20
F_{31}	0.2754	9	0.3998	13	0.3376	9
F_{32}	0.2904	7	0.3986	16	0.3445	7
F_{33}	0.1445	19	0.4093	2	0.2769	19
F_{34}	0.2350	15	0.4019	9	0.3185	16
F_{41}	0.3161	5	0.3919	20	0.3540	6
F_{42}	0.3103	6	0.4006	12	0.3554	5
F_{43}	0.2424	13	0.3997	14	0.3210	14
F_{44}	0.3677	2	0.4010	10	0.3844	1
F_{51}	0.2333	16	0.4069	3	0.3201	15
F_{52}	0.2857	8	0.3950	18	0.3404	8
F_{53}	0.2070	17	0.4040	5	0.3055	17
F_{54}	0.2575	12	0.4033	7	0.3304	11

Table 6.9: Risk matrix for categorizing risk

Impact									
	0.9376	VH	0.3840	0.4305	0.4954	0.6082	0.7135	0.8443	0.9536
	0.7610	H	0.3117	0.3495	0.4021	0.4937	0.5791	0.6853	0.7740
	0.5993	M	0.2455	0.2752	0.3167	0.3888	0.4561	0.5397	0.6095
	0.4682	L	0.1918	0.2150	0.2474	0.3037	0.3563	0.4216	0.4762
	0.4233	VL	0.1734	0.1944	0.2237	0.2746	0.3221	0.3812	0.4305
	Crisp Values		VR	R	O	P	F	VF	AC
			0.4096	0.4592	0.5284	0.6487	0.7610	0.9005	1.0171

Likelihood

Table 6.10: Risk categories and suggested action requirement plan

Risk category/Risk rating	Risk factors	Action required
Category 4 Rating 0.7741 – 0.9536	Not Identified	• Immediate notification is required by risk owner to RM Team lead with proper documentation. • Immediate investigation is required by RM Team Lead. • Decision team is placed on alert. • An action plan is defined and implemented immediately to eliminate or minimize the risk as low as reasonably practicable. • RM Team Lead tracks action plan results. • Risk committee reviews monthly action plan results.
Category 3 Rating 0.4955 – 0.7740	F_{41}, F_{42}, F_{11}, F_{12}, F_{13}, F_{44}	• Immediate investigation is required by RM Team Lead. • Action needed quickly (within 1-2 days). • Decision Team reviews, approves, and or revises action plan to eliminate or minimize the risk as low as reasonably practicable. • Risk committee reviews monthly action plan results.
Category 2 Rating 0.4306 – 0.4954	F_{33}, F_{23}, F_{53}, F_{34}, F_{43}, F_{51}, F_{14}, F_{22}, F_{54}, F_{21}, F_{31}, F_{52}, F_{32}	• Risk Owner need to notify risk to the RM Team Lead. • RM Team investigates the risk in a timely manner. • Action plan is determined. • Action required within a week to eliminate or minimize the risk as low as reasonably practicable by Risk Owner. • Risk committee reviews monthly action plan results.
Category 1 Rating 0.2238 – 0.4305	F_{24}	• Timely investigation is required by RM Team Lead. • Action Plan is defined for minimizing the risk as low as reasonably practicable and also action required within a reasonable timeframe (2-4 weeks). • Risk can be reviewed and evaluated at monthly Risk Committee meeting.
Category 0 Rating 0.0000 – 0.2237	Not Identified	• No action required. • Risk placed on Watch List and reviewed by Risk Committee. • Risk can be tracked for further possible action if risk rating increases.

CHAPTER 7

SUMMARY AND FINDINGS

The present study not only put emphasis on some aspects of risk management in relation to software engineering project, IT outsourcing, and metro-construction project but also investigates aspects of safety as well as occupational health hazard risk management for underground coal mining industry. This study provides extent body of knowledge towards understanding the comprehensive risk management process including risk identification, risk assessment, and risk control measures for solving the research problems in industrial context.

Some of the major findings of this dissertation have been discussed in the following paragraphs.

From the study of understanding of interrelationships amongst critical risk factors in relation to software engineering project (as depicted in **Chapter 2**), it has been observed that among twenty three investigated risk factors, five important risk factors: software cost risks, software quality risks, software scheduling risks, software requirement risks, and lack of project standard have been found placed at the top level as presented in ISM model. Moreover, it has been observed that lower level risks strongly influence the middle level risk factors; while the middle level risk factors influence the top level risk factors in the ISM diagraph. Top level risk factors are more harmful as they are influenced by the preceding levels of risk factors, and likely to impose serious impact to the overall project. However, lower as well as middle level risk factors are mainly responsible for increasing risk extent of the top level risk factors. In this regard, it has been observed that interdependency among various risk factors plays an important role for assessment of risk impact on the software development projects. In addition to this, all identified risk factors have further been classified into four clusters (autonomous, dependent, linkage, independent) based on their driving and dependence power using MICMAC analysis approach. The risk factors like software cost risks, software quality risks, software scheduling risks, software requirement risks, and lack of project standard has been found as the dependent factors significantly affecting overall project performance. Understanding on impact of risk at each level is indeed important as it helps managers to develop and implement effective risk management strategies towards achieving success of software projects.

From the study of risk assessment in IT outsourcing (as presented in **Chapter 3**), it has been found that among sixty eight identified risk influencing factors under eleven risk dimensions, eight risk influencing factors viz. ineffective bidding mechanisms ($F_{10,7}$), less manpower ($F_{11,4}$), inadequate terms and ambiguous contract with supplier ($F_{10,1}$), suppliers' service quality ($F_{10,2}$), lack of experience and expertise of the enterprise with the activity ($F_{4,2}$), lack of technical knowledge and education ($F_{3,4}$), complexity of new and emerging technology and interface ($F_{3,2}$), and interdependence of activities ($F_{2,4}$) have been found imposing highest impact to the performance of IT outsourcing exercise. Moreover, strategic, technical, and relationship risks have been found possessing very negative impact on the project performance amongst the eleven risk dimensions. Although technical risks which correspond to the second highest risk rating, could cause extensive loss for IT outsourcing projects. Among the eleven risk dimensions, business risks have been found possessing reasonable impact on overall project performance. Thus, the risk dimensions with high risk ratings have come out as the major areas that necessitate managing their risk influencing factors.

From the case illustration of occupational health hazards in relation to underground coal mines (as described in **Chapter 4**), it has been observed that among twenty one identified health hazards under five hazard agents, coal dust (HC_2) has been found to be the critical having the highest risk rating (0.7180), which can impose adverse effects to the workers' health. Moreover, the hazards like noise (HP_1), heat and humidity (HP_3), crystalline silica (HC_1), diesel particulate exposure (HC_4), awkward working posture (HE_2), and alcohol abuse (HS_4) have been found imposing very negative impact on workers' health; as these hazards have been placed at the category of high level of risk rating. However, the hazard under psychosocial hazard agent, expatriate placements (HS_3) has been found possessing the minimal impact on workers' health due to its very low risk rating (0.0265). Therefore, the hazards which correspond to critical as well as high level of risk ratings should carefully be controlled using effective control action plans as well as appropriate control measure options.

From the study of appropriate safety measure system selection problem for underground coal mining (as illustrated in **Chapter 5**), it has been observed that among the four possible safety system alternatives viz. methane drainage automation system (A_1), online ventilation monitor and control system (A_2), water and inundation management system (A_3), and information technology for hazard monitor and control (A_4), alternative (A_4) has been found as the appropriate one due to its minimal degree of risk. If this particular safety measure system is implemented by the case industry, the risks (financial, operating and maintenance risks) that are likely to incur would be minimal. So, from economic point of view the organization should opt for implementing the same in order to improve workers' safety. The aforesaid risk-based decision making problem has been solved by IVFM-TOPSIS approach. From the case study, it has been found that, information technology for hazard monitor and control system corresponds to the minimal (3.661) closeness value amongst available four safety system alternatives.

From the study of risk assessment for metropolitan construction project (as highlighted in **Chapter 6**), it has been found that among the twenty identified risk factors under five risk dimensions, the following six risk factors viz. ground water seepage (F_{44}), conflicting interfaces between work items (F_{13}), design drawing errors (F_{12}), inappropriate design and poor engineering (F_{11}), super cyclonic storm (F_{42}), and heavy rainfall (F_{41}) have been found possessing highest risk ratings which in turn can impose very negative impact on the project performance. Ground water seepage has been appeared as the factor which corresponds to the highest risk rating (0.5441) thereby contributing to the overall project risks. Conflicting interference between work items and heavy rainfall have been found possessing the second and the sixth highest risk rating among the twenty investigated risk factors. Similarly, among the five risk dimensions, engineering design has been found possessing the highest risk rating (2.0427) contributing 21.11% to the overall risk value. Although natural hazard risks, with the second highest percentage (20.89%) contributing to the overall project risks, could cause severe damage to construction projects. However, construction management risks have been found possessing the minimal (lowest) contribution (19.05%) to the overall construction project risks.

The limitations of the present study are pointed out below.

Although different types of risks are analyzed by assessing exposure to each risk factors and by prioritizing the risks based on fuzzy-decision making approach; the obtained results are purely approximated. The study explores different hierarchical risk-breakdown structure consisting of various risk influencing factors (at first level), and risk dimensions (at second level) towards developing risk assessment framework applicable for IT outsourcing project risk assessment, health hazard risk assessment, and construction project risk assessment. However, it is realized that the cause-and-effect relationships of risk factors need to be analyzed further to test overall performance of the project. In addition to this, interdependencies among identified risk factors in relation to software engineering project are also investigated in Chapter 2. However, factor analysis approach can be used further to describe variability among observed, correlated risk variables in terms of a potentially lower number of unobserved risk variables. The information gained about the interdependencies between observed risk variables can be used later to reduce the set of variables in a dataset. Therefore, this study can be extended to investigate the variability of risk factors using factor analysis approach.

The risk assessment frameworks thus proposed in this study are based on decision makers' subjective judgement expressed in terms of linguistic variables. Linguistic information is transformed into different fuzzy numbers in reference to standard fuzzy linguistic scale for establishing a logical mathematic base in order to quantify the degree of risks. The fuzzy based linguistic assessment scales used in this study are adopted from the past literature. However, relative sensitivity of fuzzy linguistic scales is not verified. In this study, the linguistic variables are represented by different fuzzy numbers with membership functions like triangular, trapezoidal, and interval valued membership functions. However, sensitivity of using different fuzzy membership functions is not tested. The present study explores knowledge of fuzzy set theory for quantifying the risk extent during risk assessment process. However, this study can be extended to make a comparative analysis on the obtained results by exploring either grey numbers set theory or vague set theory with respect to that of fuzzy risk assessment module.

This study explores general hierarchy of controls for controlling identified risks at different risk levels. However, this work can further be extended by proposing specific control measures to the individual risks based on their consequence priority.

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LIST OF PUBLICATIONS

Journal Publications

Chitrasen Samantra, Saurav Datta, Siba Sankar Mahapatra, 2014, *Risk Assessment in IT Outsourcing using Fuzzy Decision-Making Approach: An Indian Perspective*, **Expert Systems with Applications**, 41(8): 4010-4022, Elsevier Science.

Chitrasen Samantra, Saurav Datta, Siba Sankar Mahapatra, Bikash Ranjan Debata, *Interpretive Structural Modelling of Critical Risk Factors in Software Engineering Project*, **Benchmarking: An International Journal**, Emerald Group Publishing, UK. **(Accepted)**

Chitrasen Samantra, Saurav Datta, Siba Sankar Mahapatra, *A Risk-based Decision Support Framework for Selection of Appropriate Safety Measure System for Underground Coal Mines*, **International Journal of Injury Control and Safety Promotion**, Taylor and Francis. **(Published Online)**

Publications in Proceedings of International Conferences

Chitrasen Samantra, Saurav Datta, and Siba Sankar Mahapatra, *Evaluation of Risk Responses Based on Fuzzy Multi-Criteria Group Decision Making: An Integrated Approach to Supply Chain Risk Management*, **XVI Annual International Conference of the Society of Operations Management (Theme: Emerging Paradigms in Operations and Supply Chain Management)** Jointly hosted by IIT Delhi and IIM Lucknow, during 21-23 December 2012 in IIT Delhi, New Delhi-110016.

Chitrasen Samantra, Saurav Datta, Siba Sankar Mahapatra, *Alternative Selection Towards Improving Workers' Safety in Coal Mining Industry: A Novel Interval-Valued Modified Fuzzy-TOPSIS Approach*, **XVII Annual International Conference of the Society of Operations Management**, December 20-22, 2013, Indian Institute of Technology Madras, Chennai, India.

Papers under Review

Chitrasen Samantra, Saurav Datta, Siba Sankar Mahapatra, *Analysis of Occupational Health Hazards and Associated Risks in Fuzzy Environment: A Case Research in an Indian Underground Coal Mining Industry*, **International Journal of Injury Control and Safety Promotion**, Taylor and Francis.

Chitrasen Samantra, Saurav Datta, Kannan Govindan, Siba Sankar Mahapatra, *Alternative Selection Towards Enhancing Coal Mine Workers Safety: A Fuzzy Based Decision Support Framework*, **Journal of Cleaner Production**, Elsevier Science.

Chitrasen Samantra, Saurav Datta, Siba Sankar Mahapatra, *Risk Assessment for Metropolitan Construction Project: A Fuzzy Based Decision Making Approach*, **Computers and Industrial Engineering**, Elsevier Science.

APPENDIX-A

Feedback of survey questionnaires

Let '**P**' and '**Q**' are two different software project risks, then the experts are required to use the following symbols against their relationship that;

Symbol	Description of relationship
V	If 'P' risk will increase 'Q' risk.
A	If 'Q' risk will increase 'P' risk.
X	If 'P' risk and 'Q' risk will increase each other.
O	If both 'P' and 'Q' risks are unrelated.

Experts' opinion

Relationship among the risk elements	Number of Experts opinion (out of 48)			
	V	A	X	O
1. Relationship between '**Lack of good estimation in projects**' and '**Unrealistic schedule**'.	2	2	3	41
2. Relationship between 'Lack of good estimation in projects' and 'Human errors'.	3	2	4	39
3. Relationship between 'Lack of good estimation in projects' and 'Lack of testing'.	2	2	0	44
4. Relationship between 'Lack of good estimation in projects' and 'Lack of monitoring'.	3	5	2	38
5. Relationship between 'Lack of good estimation in projects' and 'Complexity of architecture'.	1	7	5	35
6. Relationship between 'Lack of good estimation in projects' and 'Lack of reassessment of management cycle'.	7	6	5	30
7. Relationship between 'Lack of good estimation in projects' and 'Lack of employment of manager experience'.	4	42	2	0
8. Relationship between 'Lack of good estimation in projects' and 'Lack of enough skill'.	2	40	4	2
9. Relationship between 'Lack of good estimation in projects' and 'Inadequate design of documentation'.	3	12	9	24
10. Relationship between 'Lack of good estimation in projects' and 'Inadequate knowledge about tools, techniques and programming language'.	1	3	5	39
11. Relationship between 'Lack of good estimation in projects' and 'Lack of project standard'.	5	0	2	41
12. Relationship between 'Lack of good estimation in projects' and 'Inadequate budget'.	3	3	6	36
13. Relationship between 'Lack of good estimation in projects' and 'Inadequate of requirements'.	5	1	4	38
14. Relationship between 'Lack of good estimation in projects' and 'Lack of report for requirements'.	2	9	4	33
15. Relationship between 'Lack of good estimation in projects' and 'Lack of analysis for change of requirements'.	6	8	7	27
16. Relationship between 'Lack of good estimation in projects' and 'Lack of trust between partners'.	3	5	6	34
17. Relationship between 'Lack of good estimation in projects' and 'Heterogeneity of partners'.	3	14	4	27
18. Relationship between 'Lack of good estimation in projects' and 'Wrong	2	8	3	35

	partner/s selection'.				
19.	Relationship between 'Lack of good estimation in projects' and 'Software cost risks'.	40	0	6	2
20.	Relationship between 'Lack of good estimation in projects' and 'Software quality risks'.	32	4	5	7
21.	Relationship between 'Lack of good estimation in projects' and 'Software scheduling risks'.	30	3	5	10
22.	Relationship between 'Lack of good estimation in projects' and 'Software requirement risks'.	3	2	4	39
23.	Relationship between '**Unrealistic schedule**' and '**Human errors**'.	8	28	10	2
24.	Relationship between 'Unrealistic schedule' and 'Lack of testing'.	2	10	8	28
25.	Relationship between 'Unrealistic schedule' and 'Lack of monitoring'.	4	37	7	0
26.	Relationship between 'Unrealistic schedule' and 'Complexity of architecture'.	3	9	4	32
27.	Relationship between 'Unrealistic schedule' and 'Lack of reassessment of management cycle'.	7	12	5	24
28.	Relationship between 'Unrealistic schedule' and 'Lack of employment of manager experience'.	2	38	6	2
29.	Relationship between 'Unrealistic schedule' and 'Lack of enough skill'.	4	8	7	29
30.	Relationship between 'Unrealistic schedule' and 'Inadequate design of documentation'.	5	7	0	36
31.	Relationship between 'Unrealistic schedule' and 'Inadequate knowledge about tools, techniques and programming language'.	3	5	0	40
32.	Relationship between 'Unrealistic schedule' and 'Lack of project standard'.	2	4	6	36
33.	Relationship between 'Unrealistic schedule' and 'Inadequate budget'.	1	3	3	41
34.	Relationship between 'Unrealistic schedule' and 'Inadequate of requirements'.	3	4	4	37
35.	Relationship between 'Unrealistic schedule' and 'Lack of report for requirements'.	1	2	0	45
36.	Relationship between 'Unrealistic schedule' and 'Lack of analysis for change of requirements'.	2	8	8	30
37.	Relationship between 'Unrealistic schedule' and 'Lack of trust between partners'.	3	5	6	34
38.	Relationship between 'Unrealistic schedule' and 'Heterogeneity of partners'.	4	35	5	4
39.	Relationship between 'Unrealistic schedule' and 'Wrong partner/s selection'.	5	37	5	1
40.	Relationship between 'Unrealistic schedule' and 'Software cost risks'.	32	8	6	2
41.	Relationship between 'Unrealistic schedule' and 'Software quality risks'.	28	4	10	6
42.	Relationship between 'Unrealistic schedule' and 'Software scheduling risks'.	42	2	4	0
43.	Relationship between 'Unrealistic schedule' and 'Software requirement risks'.	10	10	5	23
44.	Relationship between '**Human errors**' and '**Lack of testing**'.	14	2	2	30
45.	Relationship between 'Human errors' and 'Lack of monitoring'.	2	41	4	1
46.	Relationship between 'Human errors' and 'Complexity of architecture'.	4	10	6	28
47.	Relationship between 'Human errors' and 'Lack of reassessment of management cycle'.	8	12	3	25
48.	Relationship between 'Human errors' and 'Lack of employment of manager experience'.	3	37	6	2
49.	Relationship between 'Human errors' and 'Lack of enough skill'.	3	39	4	2
50.	Relationship between 'Human errors' and 'Inadequate design of documentation'.	2	4	6	36

51.	Relationship between 'Human errors' and 'Inadequate knowledge about tools, techniques and programming language'.	5	3	6	34
52.	Relationship between 'Human errors' and 'Lack of project standard'.	2	2	0	44
53.	Relationship between 'Human errors' and 'Inadequate budget'.	1	1	1	45
54.	Relationship between 'Human errors' and 'Inadequate of requirements'.	6	5	1	36
55.	Relationship between 'Human errors' and 'Lack of report for requirements'.	12	6	5	25
56.	Relationship between 'Human errors' and 'Lack of analysis for change of requirements'.	5	8	6	29
57.	Relationship between 'Human errors' and 'Lack of trust between partners'.	2	40	2	1
58.	Relationship between 'Human errors' and 'Heterogeneity of partners'.	5	27	12	4
59.	Relationship between 'Human errors' and 'Wrong partner/s selection'.	3	37	6	2
60.	Relationship between 'Human errors' and 'Software cost risks'.	38	4	5	1
61.	Relationship between 'Human errors' and 'Software quality risks'.	32	8	6	2
62.	Relationship between 'Human errors' and 'Software scheduling risks'.	40	2	6	0
63.	Relationship between 'Human errors' and 'Software requirement risks'.	9	5	1	33
64.	Relationship between '**Lack of testing**' and '**Lack of monitoring**'.	2	2	2	42
65.	Relationship between 'Lack of testing' and 'Complexity of architecture'.	3	4	4	37
66.	Relationship between 'Lack of testing' and 'Lack of reassessment of management cycle'.	5	12	5	26
67.	Relationship between 'Lack of testing' and 'Lack of employment of manager experience'.	3	38	5	2
68.	Relationship between 'Lack of testing' and 'Lack of enough skill'.	2	35	9	2
69.	Relationship between 'Lack of testing' and 'Inadequate design of documentation'.	5	7	8	28
70.	Relationship between 'Lack of testing' and 'Inadequate knowledge about tools, techniques and programming language'.	2	14	32	0
71.	Relationship between 'Lack of testing' and 'Lack of project standard'.	7	12	6	23
72.	Relationship between 'Lack of testing' and 'Inadequate budget'.	3	8	7	30
73.	Relationship between 'Lack of testing' and 'Inadequate of requirements'.	4	2	1	41
74.	Relationship between 'Lack of testing' and 'Lack of report for requirements'.	3	5	8	32
75.	Relationship between 'Lack of testing' and 'Lack of analysis for change of requirements'.	6	7	6	29
76.	Relationship between 'Lack of testing' and 'Lack of trust between partners'.	2	4	2	40
77.	Relationship between 'Lack of testing' and 'Heterogeneity of partners'.	2	6	5	35
78.	Relationship between 'Lack of testing' and 'wrong partner/s selection'.	3	3	7	35
79.	Relationship between 'Lack of testing' and 'Software cost risks'.	26	3	10	9
80.	Relationship between 'Lack of testing' and 'Software quality risks'.	28	4	11	5
81.	Relationship between 'Lack of testing' and 'Software scheduling risks'.	3	4	0	41
82.	Relationship between 'Lack of testing' and 'Software requirement risks'.	2	2	1	43
83.	Relationship between '**Lack of monitoring**' and **'Complexity of architecture'.**	3	34	6	5
84.	Relationship between 'Lack of monitoring' and 'Lack of reassessment of management cycle'.	2	43	3	0
85.	Relationship between 'Lack of monitoring' and 'Lack of employment of manager experience'.	6	29	9	4
86.	Relationship between 'Lack of monitoring' and 'Lack of enough skill'.	2	42	3	1
87.	Relationship between 'Lack of monitoring' and 'inadequate design of documentation'.	6	7	8	27
88.	Relationship between 'Lack of monitoring' and 'inadequate knowledge about tools, techniques and programming language'.	3	6	5	34
89.	Relationship between 'Lack of monitoring' and 'Lack of project standard'.	4	14	3	27
90.	Relationship between 'Lack of monitoring' and 'inadequate budget'.	3	8	2	35

91.	Relationship between 'Lack of monitoring' and 'Inadequate of requirements'.	2	10	8	28
92.	Relationship between 'Lack of monitoring' and 'Lack of report for requirements'.	4	7	0	37
93.	Relationship between 'Lack of monitoring' and 'Lack of analysis for change of requirements'.	3	9	4	32
94.	Relationship between 'Lack of monitoring' 'Lack of trust between partners'.	8	28	10	2
95.	Relationship between 'Lack of monitoring' and 'Heterogeneity of partners'.	5	35	6	2
96.	Relationship between 'Lack of monitoring' and 'Wrong partner/s selection'.	3	4	2	39
97.	Relationship between 'Lack of monitoring' and 'Software cost risks'.	44	2	2	0
98.	Relationship between 'Lack of monitoring' and 'Software quality risks'.	2	9	5	32
99.	Relationship between 'Lack of monitoring' and 'Software scheduling risks'.	11	12	1	24
100.	Relationship between 'Lack of monitoring' and 'Software requirement risks'.	4	10	6	28
101.	Relationship between '**Complexity of architecture**' and '**Lack of reassessment of management cycle**'.	8	12	3	25
102.	Relationship between 'Complexity of architecture' and 'Lack of employment of manager experience'.	4	2	6	36
103.	Relationship between 'Complexity of architecture' and 'Lack of enough skill'.	6	3	5	34
104.	Relationship between 'Complexity of architecture' and 'inadequate design of documentation'.	2	2	1	40
105.	Relationship between 'Complexity of architecture' and 'inadequate knowledge about tools, techniques and programming language'.	5	12	4	27
106.	Relationship between 'Complexity of architecture' and 'Lack of project standard'.	2	3	6	37
107.	Relationship between 'Complexity of architecture' and 'inadequate budget'.	3	12	9	24
108.	Relationship between 'Complexity of architecture' and 'Inadequate of requirements'.	8	7	6	27
109.	Relationship between 'Complexity of architecture' and 'Lack of report for requirements'.	6	5	3	34
110.	Relationship between 'Complexity of architecture' and 'Lack of analysis for change of requirements'.	4	3	14	27
111.	Relationship between 'Complexity of architecture' and 'Lack of trust between partners'.	8	3	2	35
112.	Relationship between 'Complexity of architecture' and 'Heterogeneity of partners'.	13	22	10	3
113.	Relationship between 'Complexity of architecture' and 'Wrong partner/s selection'.	5	4	2	37
114.	Relationship between 'Complexity of architecture' and 'Software cost risks'.	30	8	7	3
115.	Relationship between 'Complexity of architecture' and 'Software quality risks'.	2	2	0	44
116.	Relationship between 'Complexity of architecture' and 'Software scheduling risks'.	3	4	3	38
117.	Relationship between 'Complexity of architecture' and 'Software requirement risks'.	5	7	1	35
118.	Relationship between '**Lack of reassessment of management cycle**' and '**Lack of employment of manager experience**'.	8	10	5	25
119.	Relationship between 'Lack of reassessment of management cycle' and 'Lack of enough skill'.	13	2	2	31
120.	Relationship between 'Lack of reassessment of management cycle' and 'inadequate design of documentation'.	4	3	4	37
121.	Relationship between 'Lack of reassessment of management cycle' and	1	1	0	46

'inadequate knowledge about tools, techniques and programming language'.				
122. Relationship between 'Lack of reassessment of management cycle' and 'Lack of project standard'.	4	6	8	30
123. Relationship between 'Lack of reassessment of management cycle' and 'inadequate budget'.	5	3	6	34
124. Relationship between 'Lack of reassessment of management cycle' and 'Inadequate of requirements'.	3	12	9	24
125. Relationship between 'Lack of reassessment of management cycle' and 'Lack of report for requirements'.	6	7	8	27
126. Relationship between 'Lack of reassessment of management cycle' and 'Lack of analysis for change of requirements'.	3	2	3	40
127. Relationship between 'Lack of reassessment of management cycle' and 'Lack of trust between partners'.	5	28	11	4
128. Relationship between 'Lack of reassessment of management cycle' and 'Heterogeneity of partners'.	4	37	5	2
129. Relationship between 'Lack of reassessment of management cycle' and 'Wrong partner/s selection'.	4	39	3	2
130. Relationship between 'Lack of reassessment of management cycle' and 'Software cost risks'.	36	5	5	2
131. Relationship between 'Lack of reassessment of management cycle' and 'Software quality risks'.	6	7	3	32
132. Relationship between 'Lack of reassessment of management cycle' and 'Software scheduling risks'.	8	8	2	30
133. Relationship between 'Lack of reassessment of management cycle' and 'Software requirement risks'.	10	8	6	24
134. Relationship between '**Lack of employment of manager experience**' and '**Lack of enough skill**'.	6	12	4	26
135. Relationship between 'Lack of employment of manager experience' and 'inadequate design of documentation'.	15	3	5	25
136. Relationship between 'Lack of employment of manager experience' and 'inadequate knowledge about tools, techniques and programming language'.	3	7	3	35
137. Relationship between 'Lack of employment of manager experience' and 'Lack of project standard'.	9	6	0	33
138. Relationship between 'Lack of employment of manager experience' and 'inadequate budget'.	7	4	0	37
139. Relationship between 'Lack of employment of manager experience' and 'Inadequate of requirements'.	9	3	4	32
140. Relationship between 'Lack of employment of manager experience' and 'Lack of report for requirements'.	4	36	4	4
141. Relationship between 'Lack of employment of manager experience' and 'Lack of analysis for change of requirements'.	5	38	4	1
142. Relationship between 'Lack of employment of manager experience' and 'Lack of trust between partners'.	2	4	6	36
143. Relationship between 'Lack of employment of manager experience' and 'Heterogeneity of partners'.	5	3	6	34
144. Relationship between 'Lack of employment of manager experience' and 'Wrong partner/s selection'.	2	2	0	44
145. Relationship between 'Lack of employment of manager experience' and 'Software cost risks'.	3	2	1	42
146. Relationship between 'Lack of reassessment of management cycle' and 'Software quality risks'.	6	5	1	36

147. Relationship between 'Lack of employment of manager experience' and 'Software scheduling risks'.	32	8	9	3
148. Relationship between 'Lack of employment of manager experience' and 'Software requirement risks'.	10	8	5	25
149. Relationship between '**Lack of enough skill**' and '**inadequate design of documentation**'.	4	36	6	2
150. Relationship between 'Lack of enough skill' and 'inadequate knowledge about tools, techniques and programming language'.	6	7	8	27
151. Relationship between 'Lack of enough skill' and 'Lack of project standard'.	3	6	5	34
152. Relationship between 'Lack of enough skill' and 'inadequate budget'.	4	14	3	27
153. Relationship between 'Lack of enough skill' and 'Inadequate of requirements'.	4	8	7	29
154. Relationship between 'Lack of enough skill' and 'Lack of report for requirements'.	5	7	0	36
155. Relationship between 'Lack of enough skill' and 'Lack of analysis for change of requirements'.	3	5	0	40
156. Relationship between 'Lack of enough skill' and 'Lack of trust between partners'.	6	8	6	28
157. Relationship between 'Lack of enough skill' and 'Heterogeneity of partners'.	3	1	0	44
158. Relationship between 'Lack of enough skill' and 'Wrong partner/s selection'.	12	24	8	4
159. Relationship between 'Lack of enough skill' and 'Software cost risks'.	10	7	0	31
160. Relationship between 'Lack of enough skill' and 'Software quality risks'.	32	4	12	0
161. Relationship between 'Lack of enough skill' and 'Software scheduling risks'.	37	4	4	3
162. Relationship between 'Lack of enough skill' and 'Software requirement risks'.	6	5	1	36
163. Relationship between '**Inadequate design of documentation**' and '**inadequate knowledge about tools, techniques and programming language**'.	12	6	5	25
164. Relationship between 'Inadequate design of documentation' and 'Lack of project standard'.	5	8	6	29
165. Relationship between 'Inadequate design of documentation' and 'inadequate budget'.	1	3	3	41
166. Relationship between 'Inadequate design of documentation' and 'Inadequate of requirements'.	3	4	4	37
167. Relationship between 'Inadequate design of documentation' and 'Lack of report for requirements'.	1	2	0	45
168. Relationship between 'Inadequate design of documentation' and 'Lack of analysis for change of requirements'.	8	3	2	35
169. Relationship between 'Inadequate design of documentation' and 'Lack of trust between partners'.	4	37	4	3
170. Relationship between 'Inadequate design of documentation' and 'Heterogeneity of partners'.	3	42	2	1
171. Relationship between 'Inadequate design of documentation' and 'Wrong partner/s selection'.	5	28	11	4
172. Relationship between 'Inadequate design of documentation' and 'Software cost risks'.	7	11	6	24
173. Relationship between 'Inadequate design of documentation' and 'Software quality risks'.	33	8	9	4
174. Relationship between 'Inadequate design of documentation' and 'Software scheduling risks'.	4	3	4	37
175. Relationship between 'Inadequate design of documentation' and 'Software requirement risks'.	2	1	0	45
176. Relationship between '**Inadequate knowledge about tools, techniques**	4	6	9	29

and programming language' and '**Lack of project standard**'.				
177. Relationship between 'Inadequate knowledge about tools, techniques and programming language' and 'inadequate budget'.	2	10	8	28
178. Relationship between 'Inadequate knowledge about tools, techniques and programming language' and 'Inadequate of requirements'.	4	7	0	37
179. Relationship between 'Inadequate knowledge about tools, techniques and programming language' and 'Lack of report for requirements'.	3	9	4	32
180. Relationship between 'Inadequate knowledge about tools, techniques and programming language' and 'Lack of analysis for change of requirements'.	3	2	3	40
181. Relationship between 'Inadequate knowledge about tools, techniques and programming language' and 'Lack of trust between partners'.	24	8	12	4
182. Relationship between 'Inadequate knowledge about tools, techniques and programming language' and 'Heterogeneity of partners'.	10	22	13	3
183. Relationship between 'Inadequate knowledge about tools, techniques and programming language' and 'Wrong partner/s selection'.	7	31	10	0
184. Relationship between 'Inadequate knowledge about tools, techniques and programming language' and 'Software cost risks'.	10	9	3	26
185. Relationship between 'Inadequate knowledge about tools, techniques and programming language' and 'Software quality risks'.	41	4	3	0
186. Relationship between 'Inadequate knowledge about tools, techniques and programming language' and 'Software scheduling risks'.	43	2	2	1
187. Relationship between 'Inadequate knowledge about tools, techniques and programming language' and 'Software requirement risks'.	2	2	0	44
188. Relationship between '**Lack of project standard**' and '**inadequate budget**'.	3	4	3	38
189. Relationship between 'Lack of project standard' and 'Inadequate of requirements'.	5	7	1	35
190. Relationship between 'Lack of project standard' and 'Lack of report for requirements'.	8	10	5	25
191. Relationship between 'Lack of project standard' and 'Lack of analysis for change of requirements'.	3	4	3	38
192. Relationship between 'Lack of project standard' and 'Lack of trust between partners'.	5	7	1	35
193. Relationship between 'Lack of project standard' and 'Heterogeneity of partners'.	8	9	5	26
194. Relationship between 'Lack of project standard' and 'wrong partner/s selection'.	12	2	2	32
195. Relationship between 'Lack of project standard' and 'Software cost risks'.	4	34	7	3
196. Relationship between 'Lack of project standard' and 'Software quality risks'.	38	2	8	0
197. Relationship between 'Lack of project standard' and 'Software scheduling risks'.	6	5	1	36
198. Relationship between 'Lack of project standard' and 'Software requirement risks'.	11	7	5	25
199. Relationship between '**Inadequate budget**' and '**Inadequate of requirements**'.	6	7	6	29
200. Relationship between 'Inadequate budget' and 'Lack of report for requirements'.	5	8	6	29
201. Relationship between 'Inadequate budget' and 'Lack of analysis for change of requirements'.	1	3	3	41
202. Relationship between 'Inadequate budget' and 'Lack of trust between partners'.	3	4	4	37
203. Relationship between 'Inadequate budget' and 'Heterogeneity of partners'.	10	12	1	25
204. Relationship between 'Inadequate budget' and 'Wrong partner/s selection'.	10	4	6	28

205. Relationship between 'Inadequate budget' and 'Software cost risks'.	8	12	4	24
206. Relationship between 'Inadequate budget' and 'Software quality risks'.	40	3	5	0
207. Relationship between 'Inadequate budget' and 'Software scheduling risks'.	10	7	0	31
208. Relationship between 'Inadequate budget' and 'Software requirement risks'.	12	4	0	32
209. Relationship between '**Inadequate of requirements**' and '**Lack of report for requirements**'.	5	28	11	4
210. Relationship between 'Inadequate of requirements' and 'Lack of analysis for change of requirements'.	8	24	13	3
211. Relationship between 'Inadequate of requirements' and 'Lack of trust between partners'.	4	3	4	37
212. Relationship between 'Inadequate of requirements' and 'Heterogeneity of partners'.	5	2	0	41
213. Relationship between 'Inadequate of requirements' and 'Wrong partner/s selection'.	2	9	5	32
214. Relationship between 'Inadequate of requirements' and 'Software cost risks'.	11	12	1	24
215. Relationship between 'Inadequate of requirements' and 'Software quality risks'.	4	10	6	28
216. Relationship between 'Inadequate of requirements' and 'Software scheduling risks'.	8	7	3	30
217. Relationship between 'Inadequate of requirements' and 'Software requirement risks'.	36	4	6	2
218. Relationship between '**Lack of report for requirements**' and '**Lack of analysis for change of requirements**'.	4	41	3	0
219. Relationship between 'Lack of report for requirements' and 'Lack of trust between partners'.	2	43	2	1
220. Relationship between 'Lack of report for requirements' and 'Heterogeneity of partners'.	5	35	7	1
221. Relationship between 'Lack of report for requirements' and 'Wrong partner/s selection'.	5	3	6	34
222. Relationship between 'Lack of report for requirements' and 'Software cost risks'.	3	12	9	24
223. Relationship between 'Lack of report for requirements' and 'Software quality risks'.	6	7	8	27
224. Relationship between 'Lack of report for requirements' and 'Software scheduling risks'.	3	2	3	40
225. Relationship between 'Lack of report for requirements' and 'Software requirement risks'.	37	4	4	3
226. Relationship between '**Lack of analysis for change of requirements**' and '**Lack of trust between partners**'.	5	36	5	2
227. Relationship between 'Lack of analysis for change of requirements' and 'Heterogeneity of partners'.	3	42	2	1
228. Relationship between 'Lack of analysis for change of requirements' and 'Wrong partner/s selection'.	3	2	1	42
229. Relationship between 'Lack of analysis for change of requirements' and 'Software cost risks'.	6	5	1	36
230. Relationship between 'Lack of analysis for change of requirements' and 'Software quality risks'.	29	6	9	4
231. Relationship between 'Lack of analysis for change of requirements' and 'Software scheduling risks'.	8	8	7	25
232. Relationship between 'Lack of analysis for change of requirements' and 'Software requirement risks'.	28	4	11	5
233. Relationship between '**Lack of trust between partners**' and	4	37	4	3

'**Heterogeneity of partners**'.				
234. Relationship between 'Lack of trust between partners' and 'Wrong partner/s selection'.	43	2	2	1
235. Relationship between 'Lack of trust between partners' and 'Software cost risks'.	7	8	5	28
236. Relationship between 'Lack of trust between partners' and 'Software quality risks'.	41	3	4	0
237. Relationship between 'Lack of trust between partners' and 'Software scheduling risks'.	3	4	4	37
238. Relationship between 'Lack of trust between partners' and 'Software requirement risks'.	29	8	7	4
239. Relationship between '**Heterogeneity of partners**' and **'Wrong partner/s selection'**.	36	5	7	0
240. Relationship between 'Heterogeneity of partners' and 'Software cost risks'.	34	0	12	2
241. Relationship between 'Heterogeneity of partners' and 'Software quality risks'.	36	5	6	1
242. Relationship between 'Heterogeneity of partners' and 'Software scheduling risks'.	37	4	5	2
243. Relationship between 'Heterogeneity of partners' and 'Software requirement risks'.	28	9	6	5
244. Relationship between **'Wrong partner/s selection'** and '**Software cost risks**'.	25	12	8	3
245. Relationship between 'Wrong partner/s selection' and 'Software quality risks'.	31	7	6	4
246. Relationship between 'Wrong partner/s selection' and 'Software scheduling risks'.	42	2	4	0
247. Relationship between 'Wrong partner/s selection' and 'Software requirement risks'.	39	3	4	2
248. Relationship between '**Software cost risks**' and '**Software quality risks**'.	8	7	28	5
249. Relationship between 'Software cost risks' and 'Software scheduling risks'.	3	42	2	1
250. Relationship between 'Software cost risks' and 'Software requirement risks'.	5	28	11	4
251. Relationship between **Software quality risks**' and '**Software scheduling risks**'.	3	4	38	3
252. Relationship between 'Software quality risks' and 'Software requirement risks'.	5	7	35	1
253. Relationship between '**Software scheduling risks**' and '**Software requirement risks**'.	3	5	6	34
How much are you confident about your answer?				
Low	04			
Medium	12			
High	32			

APPENDIX-B

Survey Questionnaires

IT outsourcing is the use of a third party to successfully deliver IT enabled business process, application service and infrastructure solutions for a cost effective business outcome.

IT OUTSOURCING RISK SURVAY

Thank you for participating in this survey. The results will be used to determine which IT outsourcing risk factors are most critical to consider outsourcing practice as well as help to build a risk management model to assess, manage and control the risks.

It is assured that all information will be treated as confidential and only be used for academic purposes.

The survey consists of **approximately 70 questions** and should take **few minutes** to complete. You are supposed to rate the "likelihood of occurrence" and "impact of risk" for different risk factors.
When assessing these values it is preferable that you should NOT focus on a particular product/service or project. Please think in general terms (from your experience) on projects/products/services (as a whole) related to your IT outsourcing.

IT Outsourcing Knowledge Assessment

Respondent's Name: ……………………………………………………………………………………………….………..

Job Title: ………..…

Company Name: ……………………………………………………………………………….…………………………..

Division: …………………………………………………………………………………………...……………………

City: …………………………… State: ……….................… Zip: ……………………… Country: ……….….……………..

E-mail: ……………………………………………………………..……   Telephone: ……………………………………...

General information [Please put √ mark]

1. My years of Experience in the IT/ outsourcing field is:

   (a) 0- 5 years, (b) 5- 10 years, (c) 10- 15 years, (d) 15- 20 years, (e) 20+ years

2. I would rate my knowledge pertaining IT/ outsourcing risk matters as:

   (a) Excellent (b) Good (c) Fair (d) Poor

IT Risk Factor Evaluations

Directions:

1. For each risk source please **evaluate the likelihood that risk would occur in your company** and the **associated impact on your company. For Example: The risk of a key supplier going out of business might have a low likelihood of occurrence, but a high impact if it occurs.**
2. Only answer the questions which you feel comfortable answering by **putting tick mark** in proper place.
3. A comment field is provided if you wish to clarify any responses. It is not mandatory.

Put [√] mark against your opinion.

A. Strategic risk

Characteristic- Possible loss from errors in direction or tactical mistakes

Influence- Internal/ External

1. Loss of organizational competency:

Risk that a lack of combining the skills, information, performance measures and the corporate culture that an organization uses to achieve its mission.

	Very rare	Rare	Often	Frequent	Very frequent
Likelihood of occurrence					
	Very low	Low	Moderate	Serious	Critical
Impact of risk					
Comment :					

2. Proximity of core competency:

Risk that close to the core competencies of the organization. Example: Outsourcing an activity at the core of the organization might impede organizational learning and reduce the competitiveness of the organization. Organizations also must keep the learning associated to their core activities in-house. However, this is often not an easy task since the core is not always a stable set.

	Very rare	Rare	Often	Frequent	Very frequent
Likelihood of occurrence					
	Very low	Low	Moderate	Serious	Critical
Impact of risk					
Comment :					

3. Interdependence of activities:

Risk that with a dispute over poor response of time. For example, the supplier in charge of computer operation blames the telecommunication firm for poor service, while the telecommunication firm blames the authority for not having the appropriate equipment, and the authority put the blame on the outsourcer responsible for computer operations for not providing good service. In such a situation, the real source of the problem might be very difficult and costly to determine.

	Very rare	Rare	Often	Frequent	Very frequent
Likelihood of occurrence					
	Very low	Low	Moderate	Serious	Critical
Impact of risk					
Comment :					

4. Technological indivisibility:

Outsourcing may be attractive and workable when it involves management of mature, legacy, or separate activities such as running data centers and corporate wide-area networks or commissioning separable application developments. Benchmarking, service-level agreements, efficiency incentives, annual reviews, and so on can help mitigate risks in these domains. However, much of IT is not divisible or capable of "ring-fencing." Risk that a lack of strategy in technically and environmentally feasible deposition.

	Very rare	Rare	Often	Frequent	Very frequent
Likelihood of occurrence					
	Very low	Low	Moderate	Serious	Critical
Impact of risk					
Comment :					

5. Endemic Uncertainty:

Risk which means uncertainty in a certain area. IT operations and development have always been inherently uncertain. Users are not sure of their needs, new technology is risky, business requirements may change, and implementation is full of doubts.

	Very rare	Rare	Often	Frequent	Very frequent
Likelihood of occurrence					
	Very low	Low	Moderate	Serious	Critical
Impact of risk					
Comment :					

6. Outdated Technology skill:

	Very rare	Rare	Often	Frequent	Very frequent
Likelihood of occurrence					
	Very low	Low	Moderate	Serious	Critical
Impact of risk					
Comment :					

7. Lack of information flow to support ITO (IT outsourcing) strategy:

	Very rare	Rare	Often	Frequent	Very frequent
Likelihood of occurrence					
	Very low	Low	Moderate	Serious	Critical
Impact of risk					
Comment :					

8. Lack of strategy focused on attaining reduction in cost:

	Very rare	Rare	Often	Frequent	Very frequent
Likelihood of occurrence					
	Very low	Low	Moderate	Serious	Critical
Impact of risk					
Comment :					

9. Fuzzy focus:

Risk, that appears due to lack of strategy on supply side of IT, not the demand side. It utilizes substantial management resources as well as executive time. It can unwittingly become another form of denominator management rather than revenue creation - not a prescription for long-term success.

	Very rare	Rare	Often	Frequent	Very frequent
Likelihood of occurrence					
	Very low	Low	Moderate	Serious	Critical
Impact of risk					
Comment :					

10. Poorly managed Mergers and Acquisitions (M&A) and partnerships:

Risk, that appears due to poorly managed corporate strategy, corporate finance and management dealing with the buying, selling, dividing and combining of different companies and similar entities.

	Very rare	Rare	Often	Frequent	Very frequent
Likelihood of occurrence					
	Very low	Low	Moderate	Serious	Critical
Impact of risk					
Comment :					

11. Loosing ownership of the client:

	Very rare	Rare	Often	Frequent	Very frequent
Likelihood of occurrence					
	Very low	Low	Moderate	Serious	Critical
Impact of risk					
Comment :					

B. Business risk

Characteristic- Possible loss from adverse changes in business

Influence- External

1. Business Uncertainty:

A stage of limited knowledge that may be difficult to predict future needs of the consumers', in a given project, due to inevitable changes in business environment like people, technology, and processes.

	Very rare	Rare	Often	Frequent	Very frequent
Likelihood of occurrence					
	Very low	Low	Moderate	Serious	Critical
Impact of risk					
Comment :					

2. Small number of suppliers:

	Very rare	Rare	Often	Frequent	Very frequent
Likelihood of occurrence					
	Very low	Low	Moderate	Serious	Critical
Impact of risk					
Comment :					

3. Asset specificity:

Asset specificity refers to the degree to which an asset can be redeployed without sacrificing its productive value if the contract is to be interrupted or prematurely terminated. Because the "next best use" value of a specific asset is much lower, the investor may lose part of its investment, if the transaction was not completed. This creates a **lock-in situation** where other party (not investing) may extract advantage from the investor by threatening to withdraw from the transaction.

	Very rare	Rare	Often	Frequent	Very frequent
Likelihood of occurrence					
	Very low	Low	Moderate	Serious	Critical
Impact of risk					
Comment :					

4. Interdependence of activities:

	Very rare	Rare	Often	Frequent	Very frequent
Likelihood of occurrence					
	Very low	Low	Moderate	Serious	Critical
Impact of risk					
Comment :					

C. Technical Risk

Characteristic- Possible loss from the use of existing and new technology
Influence- Internal

1. Lack of use of new technology:

	Very rare	Rare	Often	Frequent	Very frequent
Likelihood of occurrence					
	Very low	Low	Moderate	Serious	Critical
Impact of risk					
Comment :					

2. Complexity of new and emerging technology and interface:

	Very rare	Rare	Often	Frequent	Very frequent
Likelihood of occurrence					
	Very low	Low	Moderate	Serious	Critical
Impact of risk					
Comment :					

3. Loss of key technical person:

	Very rare	Rare	Often	Frequent	Very frequent
Likelihood of occurrence					
	Very low	Low	Moderate	Serious	Critical
Impact of risk					
Comment :					

4. Lack of technical knowledge and education:

	Very rare	Rare	Often	Frequent	Very frequent
Likelihood of occurrence					
	Very low	Low	Moderate	Serious	Critical
Impact of risk					
Comment :					

5. Lack of research on IT service:

	Very rare	Rare	Often	Frequent	Very frequent
Likelihood of occurrence					
	Very low	Low	Moderate	Serious	Critical
Impact of risk					
Comment :					

6. Task complexity:

Task complexity is a collection of properties inherited by a task. These properties (like priority, due date, duration, and urgency) define the difficulty of this tasks and its significance to a performer. For example, a task becomes more complex when it has a higher priority, a shorter duration, a closer due date, a reduced amount of available resources etc.

	Very rare	Rare	Often	Frequent	Very frequent
Likelihood of occurrence					
	Very low	Low	Moderate	Serious	Critical
Impact of risk					
Comment :					

7. Loss of innovative capacity:

	Very rare	Rare	Often	Frequent	Very frequent
Likelihood of occurrence					
	Very low	Low	Moderate	Serious	Critical
Impact of risk					
Comment :					

8. Technological discontinuity:

Risk that appears due to technological changes and breakthroughs may cause obsolescence of the technology which was a part of the contract. Technological discontinuity is closely related to uncertainty, since it refers to one aspect of the "volatility of the environment that cannot be anticipated".

	Very rare	Rare	Often	Frequent	Very frequent
Likelihood of occurrence					
	Very low	Low	Moderate	Serious	Critical
Impact of risk					
Comment :					

D. Financial risk

Characteristic- Possible loss from unbudgeted events

Influence- Internal

1. Hidden costs:

   Risk that affects to the objective of cost reduction due to the ignorance of costs related to finding a vendor, drafting the contract and managing the effort.

	Very rare	Rare	Often	Frequent	Very frequent
Likelihood of occurrence					
	Very low	Low	Moderate	Serious	Critical
Impact of risk					
Comment :					

2. Lack of experience and expertise of the enterprise with the activity:

	Very rare	Rare	Often	Frequent	Very frequent
Likelihood of occurrence					
	Very low	Low	Moderate	Serious	Critical
Impact of risk					
Comment :					

3. Lack of planning and inaccurate budgeting:

	Very rare	Rare	Often	Frequent	Very frequent
Likelihood of occurrence					
	Very low	Low	Moderate	Serious	Critical
Impact of risk					
Comment :					

4. Endemic uncertainty:

   Risk that mean uncertainty in a certain area. IT operations and development have always been inherently uncertain. Users are not sure of their needs, new technology is risky, business requirements change, and implementation is full of doubts.

	Very rare	Rare	Often	Frequent	Very frequent
Likelihood of occurrence					
	Very low	Low	Moderate	Serious	Critical
Impact of risk					
Comment :					

5. Ineffective infrastructure investment:

	Very rare	Rare	Often	Frequent	Very frequent
Likelihood of occurrence					
	Very low	Low	Moderate	Serious	Critical
Impact of risk					
Comment :					

6. Increased cost of services:

	Very rare	Rare	Often	Frequent	Very frequent
Likelihood of occurrence					
	Very low	Low	Moderate	Serious	Critical
Impact of risk					
Comment :					

E. Legal risk

Characteristic- Possible loss from legal disagreements or legal challenges
Influence-External/ Internal

1. Different rules and regulations in global trading:

	Very rare	Rare	Often	Frequent	Very frequent
Likelihood of occurrence					
	Very low	Low	Moderate	Serious	Critical
Impact of risk					
Comment :					

2. Dangers of eternal triangle:

Some years ago when IT specialists and users could not understand each other, a few companies created a new role for intermediaries or interpreters between the two parties. Often called **business analysts, client managers, or systems liaison officers**, they sought in theory to understand user needs and convey them to the specialists, while representing the specialists' concerns to the users. Risk that emotional relationship in which there are conflicts involving a business analysts and rest of two aforesaid officers.

	Very rare	Rare	Often	Frequent	Very frequent
Likelihood of occurrence					
	Very low	Low	Moderate	Serious	Critical
Impact of risk					
Comment :					

3. Lack of experience of the client with outsourcing:

	Very rare	Rare	Often	Frequent	Very frequent
Likelihood of occurrence					
	Very low	Low	Moderate	Serious	Critical
Impact of risk					
Comment :					

4. Uncertainty about the legal environment:

	Very rare	Rare	Often	Frequent	Very frequent
Likelihood of occurrence					
	Very low	Low	Moderate	Serious	Critical
Impact of risk					
Comment :					

5. Privacy, piracy and security:

	Very rare	Rare	Often	Frequent	Very frequent
Likelihood of occurrence					
	Very low	Low	Moderate	Serious	Critical
Impact of risk					
Comment :					

F. Operational risk

Characteristic- Possible loss from poor operations quality and mishap

Influence- Internal

1. Lack of experience and expertise of client with contract management:

	Very rare	Rare	Often	Frequent	Very frequent
Likelihood of occurrence					
	Very low	Low	Moderate	Serious	Critical
Impact of risk					
Comment :					

2. Measurement problem:

The inability to observe the process performance directly has given rise to different interpretations of IT outsourcing and poses a key set of questions that each interpretation must answer.

	Very rare	Rare	Often	Frequent	Very frequent
Likelihood of occurrence					
	Very low	Low	Moderate	Serious	Critical
Impact of risk					
Comment :					

3. Lack of talent and innovation:

	Very rare	Rare	Often	Frequent	Very frequent
Likelihood of occurrence					
	Very low	Low	Moderate	Serious	Critical
Impact of risk					
Comment :					

4. Possibility of weak management:

	Very rare	Rare	Often	Frequent	Very frequent
Likelihood of occurrence					
	Very low	Low	Moderate	Serious	Critical
Impact of risk					
Comment :					

5. Lack of organizational learning:

	Very rare	Rare	Often	Frequent	Very frequent
Likelihood of occurrence					
	Very low	Low	Moderate	Serious	Critical
Impact of risk					
Comment :					

6. Lack of experience and expertise of the supplier with the activities:

	Very rare	Rare	Often	Frequent	Very frequent
Likelihood of occurrence					
	Very low	Low	Moderate	Serious	Critical
Impact of risk					
Comment :					

G. Environmental risk

Characteristic- Possible loss from factors external to organization
Influence- External

1. Measurement problems:

	Very rare	Rare	Often	Frequent	Very frequent
Likelihood of occurrence					
	Very low	Low	Moderate	Serious	Critical
Impact of risk					
Comment :					

2. Social responsibility:

	Very rare	Rare	Often	Frequent	Very frequent
Likelihood of occurrence					
	Very low	Low	Moderate	Serious	Critical
Impact of risk					
Comment :					

3. Lack of experience and expertise of the organization and/or of the supplier with OS contracts:

	Very rare	Rare	Often	Frequent	Very frequent
Likelihood of occurrence					
	Very low	Low	Moderate	Serious	Critical
Impact of risk					
Comment :					

4. Poor cultural fit:

	Very rare	Rare	Often	Frequent	Very frequent
Likelihood of occurrence					
	Very low	Low	Moderate	Serious	Critical
Impact of risk					
Comment :					

5. Danger of eternal triangle:

	Very rare	Rare	Often	Frequent	Very frequent
Likelihood of occurrence					
	Very low	Low	Moderate	Serious	Critical
Impact of risk					
Comment :					

H. Information risk:

Characteristic- Possible loss from insufficient or inaccurate information

Influence- External

1. Interdependence of activities:

	Very rare	Rare	Often	Frequent	Very frequent
Likelihood of occurrence					
	Very low	Low	Moderate	Serious	Critical
Impact of risk					
Comment :					

2. Lack of experience and expertise of the supplier with the activities:

	Very rare	Rare	Often	Frequent	Very frequent
Likelihood of occurrence					
	Very low	Low	Moderate	Serious	Critical
Impact of risk					
Comment :					

3. Supplier size:

	Very rare	Rare	Often	Frequent	Very frequent
Likelihood of occurrence					
	Very low	Low	Moderate	Serious	Critical
Impact of risk					
Comment :					

4. Supplier financial stability:

	Very rare	Rare	Often	Frequent	Very frequent
Likelihood of occurrence					
	Very low	Low	Moderate	Serious	Critical
Impact of risk					
Comment :					

5. Task complexity:

	Very rare	Rare	Often	Frequent	Very frequent
Likelihood of occurrence					
	Very low	Low	Moderate	Serious	Critical
Impact of risk					
Comment :					

I. Managerial risk:

Characteristic- Possible loss from inefficient managerial quality
Influence- Internal

1. Lack of conflict management:

	Very rare	Rare	Often	Frequent	Very frequent
Likelihood of occurrence					
	Very low	Low	Moderate	Serious	Critical
Impact of risk					
Comment :					

2. Lack of upper management involvement:

	Very rare	Rare	Often	Frequent	Very frequent
Likelihood of occurrence					
	Very low	Low	Moderate	Serious	Critical
Impact of risk					
Comment :					

3. Lack of contingency plan:

	Very rare	Rare	Often	Frequent	Very frequent
Likelihood of occurrence					
	Very low	Low	Moderate	Serious	Critical
Impact of risk					
Comment :					

4. Lack of understanding individual authorities and responsibilities:

	Very rare	Rare	Often	Frequent	Very frequent
Likelihood of occurrence					
	Very low	Low	Moderate	Serious	Critical
Impact of risk					
Comment :					

5. Unclear decision making process:

	Very rare	Rare	Often	Frequent	Very frequent
Likelihood of occurrence					
	Very low	Low	Moderate	Serious	Critical
Impact of risk					
Comment :					

6. Lack of expertise and experience in IT field:

	Very rare	Rare	Often	Frequent	Very frequent
Likelihood of occurrence					
	Very low	Low	Moderate	Serious	Critical
Impact of risk					
Comment :					

J. Relationship risk

Characteristic- Possible loss from a practice used by different companies to reduce costs by transferring portions of work to outside suppliers rather than completing it internally.

Influence- External

1. Inadequate terms and ambiguous contract with supplier:

	Very rare	Rare	Often	Frequent	Very frequent
Likelihood of occurrence					
	Very low	Low	Moderate	Serious	Critical
Impact of risk					
Comment :					

2. Suppliers' service quality:

	Very rare	Rare	Often	Frequent	Very frequent
Likelihood of occurrence					
	Very low	Low	Moderate	Serious	Critical
Impact of risk					
Comment :					

3. Lack of buyer and supplier relationship:

	Very rare	Rare	Often	Frequent	Very frequent
Likelihood of occurrence					
	Very low	Low	Moderate	Serious	Critical
Impact of risk					
Comment :					

4. Suppliers' transparency in information sharing on its capabilities:

	Very rare	Rare	Often	Frequent	Very frequent
Likelihood of occurrence					
	Very low	Low	Moderate	Serious	Critical
Impact of risk					
Comment :					

5. Supplier hold-up, expropriation and loss of bargaining power:

	Very rare	Rare	Often	Frequent	Very frequent
Likelihood of occurrence					
	Very low	Low	Moderate	Serious	Critical
Impact of risk					
Comment :					

6. Misaligned incentives between supplier and buyer:

	Very rare	Rare	Often	Frequent	Very frequent
Likelihood of occurrence					
	Very low	Low	Moderate	Serious	Critical
Impact of risk					
Comment :					

7. Ineffective bidding mechanisms:

	Very rare	Rare	Often	Frequent	Very frequent
Likelihood of occurrence					
	Very low	Low	Moderate	Serious	Critical
Impact of risk					
Comment :					

K. Time management risk

1. No proper follow up:

	Very rare	Rare	Often	Frequent	Very frequent
Likelihood of occurrence					
	Very low	Low	Moderate	Serious	Critical
Impact of risk					
Comment :					

2. Not paying attention to details in the starting stages:

	Very rare	Rare	Often	Frequent	Very frequent
Likelihood of occurrence					
	Very low	Low	Moderate	Serious	Critical
Impact of risk					
Comment :					

3. Deadlines not met:

	Very rare	Rare	Often	Frequent	Very frequent
Likelihood of occurrence					
	Very low	Low	Moderate	Serious	Critical
Impact of risk					
Comment :					

4. Less manpower:

	Very rare	Rare	Often	Frequent	Very frequent
Likelihood of occurrence					
	Very low	Low	Moderate	Serious	Critical
Impact of risk					
Comment :					

5. Sorting delay:

	Very rare	Rare	Often	Frequent	Very frequent
Likelihood of occurrence					
	Very low	Low	Moderate	Serious	Critical
Impact of risk					
Comment :					

APPENDIX-C

QUESTIONNAIRE

I, Mr. Chitrasen Samantra conducting a questionnaire survey to assess factors influencing occupational health related risks in **Indian underground coal mining industries** as a part of my research work. The data so collected will be used purely for academic work. The data in part or full will not be published in any public media. The identity of the respondents will be kept confidential. I request you to spare few minutes of your valuable time for such an academic/research pursuit. Your participation will immensely help me to achieve the objectives of the work. Your experience, expertise and knowledge in the field will definitely contribute towards value addition and positive outcome of my research work.

Risk: Undesirable outcome

Risk Extent = (Consequence of exposure **x** Period of exposure **x** Probability of exposure)

Thank you very much indeed for your time and effort filling in this questionnaire.

Understanding on Occupational health hazards in underground coal mining

Hazard(s)	Disease (or consequences)	Happens due to condition(s)/circumstances
Physical		
Noise	Noise induced hearing loss, tinnitus	Rock drilling, blasting, cutting, materials handling, crushing, conveying and ore processing
Vibration	Spinal disorders Hand-arm vibration syndrome	Mobile equipment operational, such as load–haul–dump units, trucks, scrapers and diggers; vibrating tools such as air leg rock drills; rough roads and vehicles
Heat and humidity	Heat stroke; heat cramp; heat exhaustion; irritability	Deep underground work
Illumination	Loss of visual acuity,	Poor light conditions at underground work
Shock, burns and electrocution	Injuries	Improper layout of electricity supply
Abnormal pressure (low and high barometric pressure)	Bends (joint pain); chokes (chest pain); air embolism; neuralgia; toothache; paranasal sinusitis	Work in deep underground or high altitude mines
Chemical		
Crystalline silica	Silicosis; lung cancer	Underground mining work
Coal dust	Pneumoconiosis; black lung (anthracosis); chronic obstructive pulmonary disease	Underground mining work
Methane gas explosion	Fatal injury; fires	Underground Coal cutting; Inadequate ventilation and monitoring
Diesel particulate exposure	Lung cancer; human carcinogen	Diesel powered mobile equipment, used primarily for drilling and haulage
Biological		

Parasitic and fungal infection	Ankylostomiasis; sporotrichosis; tineapedis and/or capitis; leptospirosis	Pit work where parasites and fungi grow easily owing to high humidity and poor sanitation
Bacteria exposure	Dengue; malaria	Remote location
<u>Ergonomic</u>		
Manual handling	Trauma disorders; shoulder disorders; ankle injuries	Overhead work; handling continuous miner cable; Limited working space
Awkward working posture	Musculoskeletal disease and injury in hands, arms, shoulders, and back etc.	Work in narrow seams and in contorted positions, work with hands above the heads
Workstation design	Musculoskeletal disorders	Improper workplace design; Limited working space
Ergonomic stressors	Musculoskeletal disorders such as back pain, fatigue or muscle cramps and stiffness.	Limited working space
<u>Psychosocial</u>		
Frustration	Mental disorders	Improper job schedule like long working hours, shift patterns, and heavy workload
Prolonged Stress	Physical and mental disorders	Remote location; working away from family and friends
Expatriate placements	Physical and mental disorders	Restructuring of the organization; a change or redeployment of workers
Drug and Alcohol abuse	Mental disorders; liver injury	Remote location; fatigue
Indication of decreased morale	Physical and mental disorders	Unfavourable work culture like harassment, discrimination, bullying or violence

Questionnaire on Occupational Health Risk Assessment in Underground Coal Mining

Table 1C: Definition of linguistic terms w.r.t. consequence of exposure

CONSEQUENCE OF EXPOSURE	**LINGUSTIC VALUE**
Two or more mortalities from an occupational disease	Catastrophic
One mortality from an occupational disease	Critical
Life threatening illness. Multiple occupational disease cases	Very Serious
Serious, irreversible illness. Compensable occupational disease	Serious
Reversible illness. Occupational disease	Marginal
Minor illness	Minor
Very minor illness	Negligible

Please tick [√] in any one rating that you feel appropriate for each item. **(Refer to Table 1C)**

Sl. No.	HEALTH HAZARDS	**CONSEQUENCE OF EXPOSURE**						
1	**Physical**	Catastrophic	Critical	Very Serious	Serious	Marginal	Minor	Negligible
	Noise							
	Vibration							
	Heat and humidity							
	Illumination							
	Shock, burns and electrocution							
	Abnormal pressure (low and high barometric pressure)							
2	**Chemical**							
	Crystalline silica							
	Coal dust							
	Methane gas explosion							
	Diesel particulate exposure							
3	**Biological**							

	Parasitic and fungal infection							
	Bacteria exposure							
4	**Ergonomic**							
	Manual handling							
	Awkward working posture							
	Workstation design							
	Ergonomic stressors							
5	**Psychosocial**							
	Frustration							
	Prolonged Stress							
	Expatriate placements							
	Drug and Alcohol abuse							
	Indication of decreased morale							

Table 2C: Definition of linguistic terms w.r.t. period of exposure

PERIOD OF EXPOSURE	LINGUSTIC VALUE
Continuous exposure for a 8 hour shift or more	Prolonged
Continuous for between 4 – 6 hours – frequent, daily	Frequent
Continuous for between 2 – 4 hours – often, weekly	Often
Short periods of time, a few times per day – unusual, monthly	Seldom
Very unusually, a few times per week – a few times per year	Occasional
Rare, a few times per month – yearly	Rare
Exceptionally exposed, a few times per year	Exceptionally Rare

Please tick [√] in any one rating that you feel appropriate for each item. **(Refer to Table 2C)**

Sl. No.	HEALTH HAZARDS	**PERIOD OF EXPOSURE**						
1	**Physical**	Prolonged	Frequent	Often	Seldom	Occasional	Rare	Exceptionally Rare
	Noise							
	Vibration							
	Heat and humidity							
	Illumination							
	Shock, burns and electrocution							
	Abnormal pressure (low and high barometric pressure)							
2	**Chemical**							
	Crystalline silica							
	Coal dust							
	Methane gas explosion							
	Diesel particulate exposure							
3	**Biological**							
	Parasitic and fungal infection							
	Bacteria exposure							
4	**Ergonomic**							
	Manual handling							
	Awkward working posture							
	Workstation design							
	Ergonomic stressors							
5	**Psychosocial**							
	Frustration							
	Prolonged Stress							
	Expatriate placements							
	Drug and Alcohol abuse							
	Indication of decreased morale							

Please tick [√] in any one rating that you feel appropriate for each item **(Refer to Table 3C while putting on opinion against probability of exposure)**

Sl. No.	HEALTH HAZARDS	PROBABILITY OF EXPOSURE						
1	**Physical**	Very high	High	Medium	Low	Very Low	Absolutely Low	Not Applicable
	Noise							
	Vibration							
	Heat and humidity							
	Illumination							
	Shock, burns and electrocution							
	Abnormal pressure (low and high barometric pressure)							
2	**Chemical**							
	Crystalline silica							
	Coal dust							
	Methane gas explosion							
	Diesel particulate exposure							
3	**Biological**							
	Parasitic and fungal infection							
	Bacteria exposure							
4	**Ergonomic**							
	Manual handling							
	Awkward working posture							
	Workstation design							
	Ergonomic stressors							
5	**Psychosocial**							
	Frustration							
	Prolonged Stress							
	Expatriate placements							
	Drug and Alcohol abuse							
	Indication of decreased morale							

Table 3C: Definition of linguistic terms w.r.t. probability of exposure

PROBABILITY OF EXPOSURE					Linguistic value
Airborne pollutants	Noise	Thermal - Heat	Illumination	Other	
Exposure $>$ OEL-C or exceeding the TWA-OEL more than threefold or mixture of exposure with an index $>$ 3	$\geq$ 105 dB(A)	WB $>$ 35.0 °C DB $>$ 45.0 °C	0 lux	Exposure at **Very High** levels	**VH**
Exposure $\geq$ OEL-TWA $\leq$ three fold OEL-TWA or mixture of exposure with an index between 1 and 3	$\geq$ 85 $<$105 dB(A)	WB $>$ 32.5 $\leq$ 35.0 °C DB $>$ 37.0 $\leq$ 45.0 °C WBGT $\geq$ 30	$>$50% below the standard	Exposure at **High** levels	**H**
Exposure $\geq$ 50% of the OEL and $<$ OEL or mixture of exposure with an index between 0.5 and 1	$\geq$ 82 $<$ 85 dB(A)	WB $>$ 29.0 $\leq$ 32.5 °C DB $>$ 32.5 $\leq$ 37.0 °C WBGT $\geq$ 27 $<$ 30	Between 21 – 50% below the standard	Exposure at **Medium** levels	**M**
Exposure $\geq$ 25% of the OEL and $<$ 50% of the OEL or mixture of exposure with an index between 0.25 and 0.5	$<$ 82 dB(A)	WB $>$ 27.5 $\leq$ 29.0 °C DB $>$ 32.5 $\leq$ 37.0 °C	$<$ the standard to 20% below the standard	Exposure at **Low** levels	**L**
Exposure $\geq$ 10% of the OEL and $<$ 25% of the OEL or mixture of exposure with an index between 0.1 and 0.25		WB $\leq$ 27.5 °C DB $\leq$ 32.5 °C WBGT $<$ 27	$\geq$ standard	Limited exposure	**VL**
Exposure $<$ 10% of the OEL				No contact with/ exposure to	**AL**
Exposure virtually impossible				Not applicable	**NA**

Personal Information:

1. Name: ……………………………………………….
2. Sex: Male ☐ Female ☐
3. Age: Less than 30 ☐ 30 to 40 ☐ 41 to 60 ☐
4. Educational Level:
5. Position/ Title:
6. Seniority: ………………years

APPENDIX-D

QUESTIONNAIRE

I, Mr. Chitrasen Samantra conducting a questionnaire survey to assess factors influencing metropolitan construction project risks for building an underground **metro station system** as a part of my research work. The data so collected will be used purely for academic work. The data in part or full will not be published in any public media. The identity of the respondents will be kept confidential. I request you to spare few minutes of your valuable time for such an academic/research pursuit. Your participation will immensely help me to achieve the objectives of the work. Your experience, expertise and knowledge in the field will definitely contribute towards value addition and positive outcome of my research work.

Risk may be defined as the likelihood of occurrence of an event resulting in certain consequences or impacts.

Thus, Degree of Risk = (Likelihood of occurrence **x** Impact)

Risk Assessment for Metropolitan Construction Project

Table 1D: Linguistic scale for quantifying likelihood of occurrence

LIKELIHOOD OF OCCURRENCE	LINGUSTIC VARIABLE
Expected to occur with absolute certainty	Absolutely certain (AC)
Much frequent to occur	Very frequent (VF)
Likely to occur frequently	Frequent (F)
Likely to occur several times in the life of the operation	Probable (P)
Likely to occur sometime in the life of the operation	Occasional (O)
Unlikely but possible to occur sometime in the life of the operation	Rare (R)
So unlikely that it can be assumed that the possibility of occurrence is negligible	Very rare (VR)

Table 2D: Linguistic scale for quantifying risk impact

IMPACT OF RISK	LINGUSTIC VARIABLE
Very high	VH
High	H
Moderate	M
Low	L
Very low	VL

Please tick [√] in any one rating that you feel appropriate for each item. **(Refer to Table 1D)**

Risk Dimensions	Risk factors under specific dimensions	LIKELIHOOD OF OCCURRENCE						
D1	**Engineering Design**	Absolutely certain	Very frequent	Frequent	Probable	Occasional	Rare	Very rare
	Inappropriate design and poor engineering							
	Design drawing errors							
	Conflicting interfaces of work items							
	Poor construction site surveys							
D2	**Construction Management**							
	Poor construction plan							
	Insufficient experience and skill in construction works							
	Delay in relocating existing pipelines and facilities							
	Unstable supply of critical construction materials							
D3	**Construction Safety-Related**							
	Insufficient protection of adjacent buildings and facilities							
	Inadequate worker safety							
	Ineffective protection of surrounding environment							
	Ineffective control and management of traffic							
D4	**Natural Hazards**							
	Heavy rainfall							
	Super cyclonic storm							
	Earthquake							
	Ground water seepage							
D5	**Social and Economic**							
	Political interference							
	Increases in prices of construction materials							
	Increases in labours and employee salaries							
	Protest and interference of nearby residents							

Please tick [√] in any one rating that you feel appropriate for each item. **(Refer to Table 2D)**

Risk Dimensions	Risk factors under specific dimensions	**IMPACT OF RISK**				
D1	**Engineering Design**	Very high	High	Moderate	Low	Very low
	Inappropriate design and poor engineering					
	Design drawing errors					
	Conflicting interfaces of work items					
	Poor construction site surveys					
D2	**Construction Management**					
	Poor construction plan					
	Insufficient experience and skill in construction works					
	Delay in relocating existing pipelines and facilities					
	Unstable supply of critical construction materials					
D3	**Construction Safety-Related**					
	Insufficient protection of adjacent buildings and facilities					
	Inadequate worker safety					
	Ineffective protection of surrounding environment					
	Ineffective control and management of traffic					
D4	**Natural Hazards**					
	Heavy rainfall					
	Super cyclonic storm					
	Earthquake					
	Ground water seepage					
D5	**Social and Economic**					
	Political interference					
	Increases in prices of construction materials					
	Increases in labours and employee salaries					
	Protest and interference of nearby residents					

Personal Information:

1. Name: ……………………………………………..
2. Sex: Male ☐ Female ☐
3. Age: Less than 30 ☐ 30 to 40 ☐ 41 to 60 ☐
4. Educational Level:
5. Position/ Title:
6. Seniority: ………………years

Thank you very much for your time and effort in filling this questionnaire.

RESUME

NAME: CHITRASEN SAMANTRA

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PERSONAL INFORMATION

DATE OF BIRTH: 25th May 1983

FATHER'S NAME: Sri Subash Samantra

SEX: Male

AGE: 32+

NATIONALITY: Indian

RELIGION: Hinduism

EDUCATIONAL QUALIFICATION

Exam/Degree	School/College	Board/University	Field	Year of passing	% of marks/ CGPA
Ph. D. (Mech. Engg.)	NIT Rourkela	NIT Rourkela	Production Engineering	(Thesis submitted on 27th July 2015)	-
M. Tech (Mech. Engg.)	NIT Rourkela	NIT Rourkela	Production Engineering	2012	9.08 CGPA
B. Tech (Mech. Engg.)	SMIT Berhampur	BPUT Odisha	Mechanical Engineering	2008	7.22 CGPA
Diploma (Mech. Engg.)	SES Sundergarh	SCTE & VT Odisha	Mechanical Engineering	2003	65.72%
HSC	Lingaraj High School	BSE Odisha	General	1998	65.86%

M. TECH THESIS TITLE: Decision Making in Fuzzy Environment

PhD THESIS TITLE: Studies on Risk and Occupational Health Hazards in Industrial Context: Some Case Research

EMPLOYMENT RECORD AND EXPERIENCE

Organization	Period		Designation	Scale of Pay
	From (DD/MM/YY)	To (DD/MM/YY)		
SMIT Berhampur, (Degree Engg. College) Odisha-761003	08/07/2008	22/07/2010	Lecturer (Mechanical Engineering)	8000-275-13500

AREA OF RESEARCH

Modeling and Optimization of Production Processes, Industrial Engineering, Decision and Information Science, Agile Manufacturing, Risk Management, Supply Chain Management

MEMBERSHIP

1. Life Associate Member of IAENG International Association of Engineers
   Membership Number: 124562
2. Life Associate Member of IACSIT International Association of Computer Science and Information Science
   Membership Number: 80345287
3. Life Associate Member of International Society on Multiple Criteria Decision Making