CAPITAL UNIVERSITY OF SCIENCE AND TECHNOLOGY, ISLAMABAD

# Health and Safety Framework Using Analytic Hierarchy Process for Building Construction Projects in Pakistan

by

Muhammad Rashid Idrees

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in the

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*This work is dedicated to all my valuable treasures in life, to my*:

***Respected Mother***

*who is my paradise and love*:

***Respected Father***

*who is my strength and life*:

*Thank you for always helping me through every difficult time of my life and for encouraging me to move forward. You have been always a sign of love and happiness for me.*

*and*

***Beloved Sisters***

*who are very special to me*:

# CERTIFICATE OF APPROVAL

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**(Muhammad Rashid Idrees)**

# *Abstract*

The construction industry is one of the riskiest industry in all over the world. It is recognized to be highly risk prone, very complex and competitive where uncertainties emerge from a different source. Under-construction sites are loaded with numerous risks that possibly lead to countless accidents and a large number of deaths. Implementation of occupational health and safety standards at any working site is necessary to minimize such dangers. Health and safety risk and lack of protection of the workers are the major problems in the construction industry. Like many countries, health and safety risks and lack of protection of the workers are considered to be an important problem also in Pakistan. Therefore, the goal of this research work is to devise pre-empitive strategy for health and safety by identifying the risk factors which may affect the safety of the construction workers in Pakistan. To achieve the objectives, critical literature review was performed to identify the health and safety risk factors.

Delphi technique was used to point out the important factors to be included in the research. Delphi process was concluded in three phases and different experts of the construction industry were requested to take part in this process. Based on the experience of the industry professionals, 57 health and safety factors were shortlisted which were further categorized in 5 groups including accidents and hazards, unsafe acts, unsafe condition, management system and social groups, and natural factors. A questionnaire survey was developed which was used to attain the feedback from the different participants of the construction industry.

139 questionnaires were distributed and out of 139 questionnaires, 107 questionnaires were received back. The response rate was about 77%. The reliability data was examined using SPSS which satisfied the significance level, ensuring the reliability data to proceed for further analysis. A normality test was carried out to assess the data pattern, resulting in a non-parametric pattern. By using Kruskal Wallis test, the criteria for perception level of the respondents in the non-parametric pattern was evaluated which remained about positive. Using analytic hierarchy process, pairwise comparison matrix was constructed for each group as

well as overall, resulting in a weight, consistency index and consistency ratio which verified the data to proceed for further analysis. Fuzzy comprehensive evaluation method was used to determine evaluate the risk. An overall matrix, first and second level fuzzy relation and fuzzy comprehensive evaluation matrix on the basis of identified health and safety risk factors for risk evaluation was formulated. In case of accidents and hazards, the centesimal value was 67.237. For unsafe conditions, it was about 64.065 which remained greater than their overall threshold value which was 59.845. While for the rest of three groups like unsafe acts, management system and social groups, and natural factors, their magnitude of impact was remained 59.035, 58.162 and 53.282 respectively. The overall results of this research work helped in better understanding of health and safety framework for risk evaluation more effectively and at an early stage in construction industry. All the identified factors in this research are significantly occurring and have significant impact. The study has achieved a mile stone in development of health and safety framework in construction industry that will help the project managers to analyze the project risk more efficiently at an early stage. Based upon these analysis, proper remedial measures would be possible for incorporation at planning and strategy level to improve and manage these barriers.

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# Abbreviations

| | |
|---|---|
| **AHP** | Analytic Hierarchy Process |
| **CI** | Consistency Index |
| **CR** | Consistency Ratio |
| **CFR** | Code of Federal Regulations |
| **FCE** | Fuzzy Comprehensive Evaluation |
| **MCDM** | Multi Criteria Decision Making |
| **OHS** | Occupational Health and Safety |
| **OSHA** | Occupational Safety and Health Administration |
| **PPE** | Personal Protective Equipment |
| **RII** | Relative Importance Index |

# Chapter 1

# Introduction

## 1.1 Background

The construction industry is one of the riskiest industry in all over the world. It is recognized to be extremely risk prone and distinguished as very complex, competitive and special where uncertainties emerge from a different source [1]. According to Pinto et el. [2], occupational accidents and hazards had a serious impact on health and safety as well as economy due to high costs associated with work injuries. In the background of construction projects, accidents account for 7.9-15% of the costs of non-residential projects. Raheem and Hinze [3] stated that small building construction industries do not have a safety policy such that dangerous conditions occur at their worksites and workers are vulnerable to toxic conditions at construction sites. Construction-based OHS discernment of countries and causes for occupational accidents do not change substantially, considering the fact that certain global and habitual signs exist in workers. Pinto et el. [2] identified that the health and safety management is looking forward to taking into account all accidents and hazards that are likely to place project workers at risk. Therefore, advanced health and safety planning seems inevitable to address the safety concerns. Compliance with safety requires key health and safety measures which must be carried out by workers in order to ensure a minimum level of safety at the workplace.

Darko et al. [4] reported that different techniques or procedures are available for the assessment of health and safety policies i.e. Analytic Network Process and Functional Resonance Accident Model. Bakhoum and Brown [5] studied that a range of modeling methods used to explore effectiveness of multiple techniques; ELECTRE, TOPSIS, ENTROPY, SAW and AHP. The methodology of AHP is the same and similar to SAW than the other techniques. AHP is straight forward and easy to understand which can be used as weighting tool combined with other methods. AHP is robust and flexible for dealing with complex problem. ELECTRE is the least equal to SAW. TOPSIS is closer to AHP than to ELECTRE. The entropy solution measures the sum of the discrepancy using an entropy probability distribution taking all available data into account. The theory of entropy is systematic, resilient and effective. It makes it possible to determine the least partial distribution of the likelihood of random variable based on available data. AHP approach helped managers to make decisions on high risk project faster, more reliable and precise and to improve performance, reduce and control risks at workplace

According to Amin bakhsh et al. [1] modelling technique (AHP) is a methodology for forecasting health and safety measures in construction projects. This modelling technique (AHP) has gained more importance and attraction due to the accurate and quick prediction that customize the falsified method of forecasting modelling techniques. Due to these forecasting modelling techniques, the hazards and risks mis-assessment and time-consuming method with cheap predictive techniques and tools are eliminated for accurate prediction. Wu and Chau [7], stated that modeling techniques commonly used due to their high versatility and broad applicability and these modeling techniques can be minimized by 17%. Most of the Pakistan's construction industries follow responsive strategies and policies instead of pre-emptive strategies. According to Wang and Chan. [6] analysis of case study of construction projects with the assist of modeling technique (AHP) ensures that the health and safety policies are correctly measured.

To the best of author knowledge, study to investigate the assessment of safety management practices by using modelling technique Analytic Hierarchy Process for building construction projects still remains a grey area to be explored.

## 1.2 Research Motivation

Construction sites contains numerous hazards and risks that could cause hundreds of thousands of accidents and deaths every year. 40% of construction workers were got injured and work-related deaths and 25% out of 40% were got injured due to cuts [8]. Amin bakhsh et al. [1] estimated that the cost of workplace accidents and injuries could increase up to 15% of overall project cost. Pakistan has been suffering from health and safety problems for many decades. A proper framework detailing pre-emptive safety approach would not only lead to mitigate or minimize injuries and accidents related costs but also help to ensure a safe environment for the construction industry in Pakistan. The effect of early risk pro-active technique would boost the health and safety standards of the construction industry in Pakistan.

- The prevalent health and safety requirements are not particular to the construction industry in Pakistan and are regulated by the factories Act of 1934, the worker's compensation Act of 1923 and the minimum wage ordinance of 1961 [9].

These acts mainly concerned with the worker's problems related to occupational health and safety but unfortunately, these basic factory laws do not apply to the construction industry. While it is an important part of the national economy and has undergone substantial growth in the last few years. Government is not taking action or any measures to monitor the health and safety risks posed by construction workers [9].

## 1.3 Problem Statement

Ahmad et al. [10]; Raheem et al. [9], reported that the construction industries in Pakistan do not comply with health and safety standards for their workers which contains many factors. The present position of construction industry in Pakistan is failing to achieve its true potential due to number of factors which make it one of the reasons are the lack of health and safety standards. Accidents occurred because of worker's incompetency, work at height, running tools and machinery without safety gears, poor site management and inability to use personal protective equipment (PPE). The construction industry hires 7.3% of the overall labor force of Pakistan [11], but its accidents and injuries rate is 17.3% which is higher than that of other industries [12]. The majority of construction industry's injuries are caused by a fall from height accompanied by lifting activity and electrocution [13]. Insufficient supply of fall safety equipment, lack of training, unrealistic construction time, and lack of availability of suitable anchorages points at construction sites have been found as causes of fall from height [14].

Unsafe acts and behavior along with unsafe conditions lead to 98% of construction accidents. Occupational health and safety (OHS) rules and regulation are very unsatisfactory in Pakistan's construction industry. Even certain construction industries have no health and safety standards and policies regulations [15]. The financial standing of an organization remains one of the grey aspects in health and safety arrangements of construction sector. Keeping in view this aspect, it is very important to explore viable solutions that would help to adopted health and safety factors by the stake holders keeping in view there own financial contraints.

## 1.4 Research Objectives

The objectives of the study are to:

- Identify and analyze major risk factors for health and safety in construction industry of Pakistan.
- Assess these health and safety major concerns. factor.
- Develop a framework to determine the severity of risk factors for health and safety.
- Adopt multi criteria decision making technique to highlight major concerns and propose a hierarchical safety management model.

## 1.5 Research Significance

Project managers and contractors face crucial accidents and hazards because of intrinsic dangerous risks of construction projects. Health and safety related risks and hazards are one of the major risks in the construction industry and the accidents ratio is comparatively high in construction industry to other different industries. So, it is a significant step toward the risk management of health and safety to adopt pre-empitive strategy for evaluation of risks and hazards. Health and safety framework risk evaluation for building construction projects is significant in order to assess the project risk more efficiently and prevent from accidents and hazards.

## 1.6 Scope of Work

Evaluation of health and safety measures and death, injuries and fatality ratio estimated by analytic hierarchy process (AHP). Scope of sork include construction buildings, current health and safety status, modelling technique AHP and logical hierarchy for building factors. For this, by Delphi method, health and safety policies and percentage of accidents at construction workplace are analyzed to present a conceptual hierarchy or network for construction industry. For data collection, survey tool in the form of a questionnaire is developed using the above-mentioned technique. High and low rise (more than three story height) buildings projects construction sites are selected for data acquisition.

## 1.7 Study Limitations

The research work is limited to local condition of construction industry of Pakistan. AHP technique has been adopted to propose the health and safety framework for building sector. Keeping in view, health and safety factors have been investigated for building construction projects in current research.

## 1.8 Brief Methodology

The following procedure is adopted.

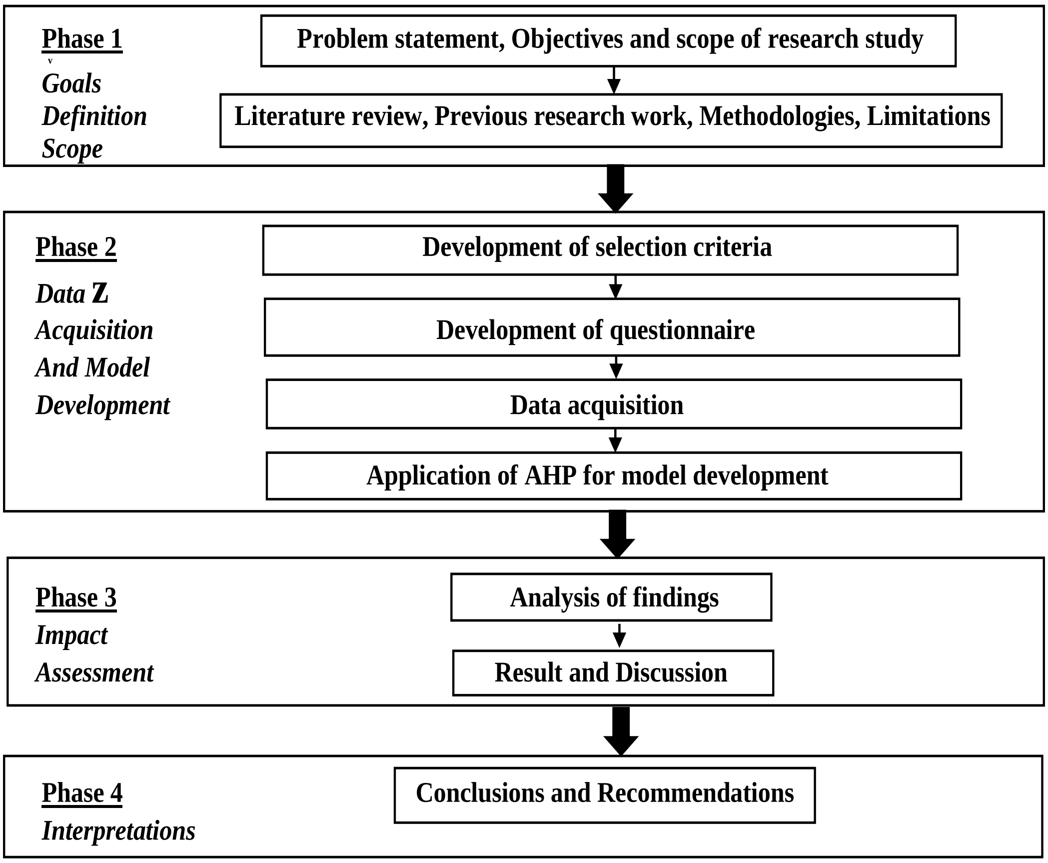


Figure 1.1: Adopted research methodology

## 1.9 Thesis Structure

This thesis is structured into five chapters

**Chapter 1:** It is entitled as introduction. It presents the context of health and safety problems and causes during construction activity, research motivation, problem statement, research objectives, scope of work, study limitations and methodology.

**Chapter 2:** This chapter includes a literature review of several literature on the OHS aspects related to the subject of the thesis and its aim as well as a summary of numerous concepts and terminologies relevant to the aim and objectives of this research.

**Chapter 3:** This chapter describes the methodology used to conducting the research as well as modeling technique and data collection are discussed.

**Chapter 4:** This chapter discusses the results and conclusions. It contains the tests detail and analysis, findings and detailed discussions on achieved results and their significance.

**Chapter 5:** This chapter deals with the conclusions along with future recommendations.

# Chapter 2

# Literature Review

This chapter provides the theoretical context for the analysis by examining the relevant literature on regulatory frameworks. This context would identify and highlight the aspects with an emphasis on construction projects health and safety frameworks. This is an evaluative report of the knowledge recorded in the specific areas.

## 2.1 Introduction

The construction industry is one of the world's riskiest industry. It is one of the Pakistan's fastest growing industrial segments 11.30% rise in 2014. It is also worth sharing that out of the overall workers hired by the construction industry, majority of the workers 15.20% in construction industry are working. It is a fact which reflects the economic position of the construction industry [16]. Construction sites are full of various risks that could causes hundreds of thousands of injuries, accidents and even deaths each year. These worksites are loaded with heavy equipment and machines, hazardous chemical, explosives, and other unsafe factors, all of which can cause injuries or even death. Environmental risks are affected by contamination as a result of construction work such as exposure to high level of noise, smoke, dust, vibrations, potential energy and site wastes. Construction work of the sky scrapper includes the exposure of toxic fumes, dust particles and other work risks [17].

Construction workers face more injuries, accidents and fatality risks at the work sites than workers in any other industry and about one, out of every five workplace fatality involves a construction worker [18]. Zahoor et al. [19], reported that there are laws and regulation on construction sites in most developed countries that lead to reduce or mitigate the health and safety threats. Compliance with safety requires key health and safety measures which must be carried out by workers in order to ensure a minimum level of safety at the workplace, such as wearing personal protective equipment, following health safety standards with occupational safety regulations.

Zahoor et al. [19], reported that construction sites are perceived to be high-risk accident-prone areas and pose a great deal of health and safety issues. These problems can emerge from nearby activities, such as construction techniques, movement of heavy machinery etc. Kim et al [20], concluded that construction sites are unfortunate to be wounded by fires, blasts and falls from height or scaffolding. Health and safety management is expected to take into account of all hazards, risks and accidents that may possibly be expected to place project workers at risk. It is extremely important for the health and safety of the workers to reduce or mitigate these risks, legally and ethically.

## 2.2 Safety Culture of Construction Industry

Construction industry is examined not only to be one of the most important sectors for its contribution to economic development but also for its effect on the occupational safety and health (OSH) of the workers [21]. The construction industry (CI) with largest workers ratio in the world has accounted for about 11% of all workplace accidents and 20% of deaths. This happens primarily because of continuously changing site environment, complex human behavior and dangerous working procedures [16]. Irfan et al. [22]; Maqsoom and Charoenngam [23], stated that the construction industry of Pakistan has undergone various ups and downs over the last few decades with many obstacles and challenges facing it. This includes weak site safety record, insufficient environmental efficiency, extensive usage of conventional and adversarial culture inside the construction sector.

A strong safety culture is used as a gateway to both increased occupational health and safety and improved organizational performance. The hypothesis of a safety culture can be defined as a representation of the behaviors, opinions, expectations and values that workers and managers share regarding safety. Despite the recent rapid growth and development of the Pakistani construction industry, workers are still working under poor safety conditions. Although Pakistan has range of workplace health and safety laws and regulations, they are too large to be enforced directly to the construction industry. Due to the existence of cheap regulatory system, the health and safety of the workers is not the primary priority of the construction industry [9]. For achieving consistently high safety efficiency in construction industry, a strong safety culture is pivotal [24].

Pakistan is currently seeing a strong development in construction activities. For this cause, the construction sector makes a significant contribution to Pakistan's gross domestic product (GDP) and hires about 9% of the total workforce. Unfortunately, the current national safety laws do not apply to the construction sector [25]. Promoting a positive healthy safety culture is important and essential for maintaining the safety performance on a construction site. Geller's overall safety culture model is a common model that provided the basic goal and safety culture philosophy in the safety triad vision as seen in figure 2.1 [26].

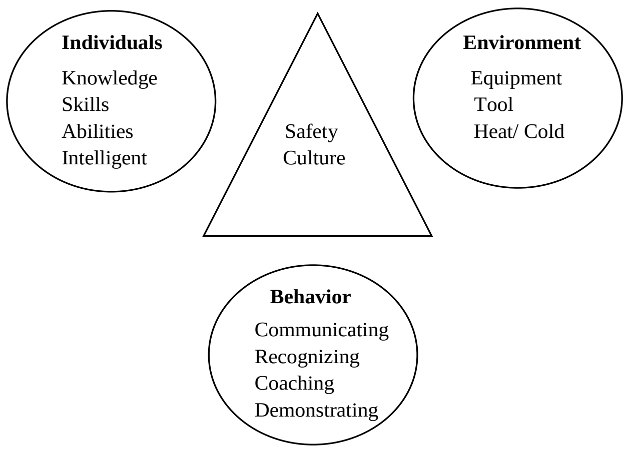


FIGURE 2.1: Safety culture hierarchical figure, [26]

The concept of total safety culture required continual attention to three domains namely environment factors, individual factors and behavior factors. The three safety related factors were described as dynamic and interactive, forming a triangle called "The Safety Triad" [26].

## 2.3 Occupational Health and Safety

Occupational Health and Safety (OHS) is a good strategy for promoting healthy and safe workplace environment. In the developed countries, the construction industries rely on the health and safety measures at workplace so as to minimize the adverse consequences for the human health, climate, economy, competitiveness, society and company's image. On the other hand, in developing countries like Pakistan, the construction industry is not adequately oriented on the OHS due to the high cost of personal protective equipment (PPE) and safety trainings [27]. Raheem and Issa. [9], stated that OHS framework was created to help the administrative officials of Pakistan properly enforce the OHS rules and regulations of workers and contractors to enhance their safety culture. The suggested framework for the OHS contained of three major components:

1. Framework for administrative officials
2. Corporate level framework
    2.1 Regulatory authorities
    2.2 Particular location
3. Framework for safety training
    3.1 Safety training for managers
    3.2 Safety training for workers

Occupational health and safety (OHS), is concerned with the health and safety of the workers, family members, customers, and other stakeholders. It studies all variables that affect the health and safety of the workers at work and at home while predicting, identifying, evaluating and managing hazards. The standard of occupational health and safety in all workplace is the key determinant of the health and safety of the workers [28]. The accidents and hazards have the potential to affect the health and safety of the workers. Occupational hazards can trigger immediate or delayed symptoms based on period of exposure, exposure severity and individual susceptibility. Industrial workers are faced multitude of hazards from physical, biological, mechanical, chemical, psycho-social and ergonomic issues that adversely affects workers, colleagues and the organization [29]. Khosravi et al. [17], reported that most of the workers are illiterate and ignorant about personal protective measures for their job.

About 7% of world's workers is working in the construction industry and fatality rate in the construction industry is 30-40% of overall fatality [30]. Tixier et al. [31], stated that the available literature identifies a variety of causes or factors that simply raise the risk of an accidents. These factors include inadequate safety knowledge, inadequate team leadership skills, lack of training, inability to invest in safety equipment, poor equipment condition, low standard of education and no implementation of safety regulations. Zahoor et al. [16], stated that the construction industry, not only in terms of its contribution to economic development but also in terms of its effect on workers occupational health and safety, is considered one of the most significance industry.

Asad et al. [32], highlighted that significant barriers in the implementation of occupational health and safety are described as no cooperation between workers, lack of knowledge about safety management techniques and lack of regulatory authority such as the occupational health and safety administration. Robson et al. [33], observed that inadequate execution of safety standards at work sites were improperly enforced and required more attention. Working in a high position was represented by scaffolding and the space in the background. The lack of safety precautions were demonstrated by the working clothes of the workers, absence of caution signs within dangerous areas etc.

Jafari et al. [34], revealed that the safety environment at construction sites has found that the managerial support, work involvement, capability, attitude and communication have the key predictors of safety environment. In developed countries, the lack of conformity with occupational health and safety (OHS) has resulted in a comparatively higher rate of construction injuries and accidents. Asad et al. [32], concluded that despite the greatest need for legislation that secure worker's right with a viewpoint of occupational health and safety, no such unambiguous and precise legislation has been made yet that could resolve the health and safety problems. The biggest issue is that most of the rules and regulations that are enforce in Pakistan has been inherited from colonial era. Memon et al. [15], revealed that occupational health and safety in Pakistan are strongly unsatisfactory. Even some of the industries do not have health and safety rules and policies. Different countries have similar occupational health and safety (OHS) problems:

1. Unimportant events could lead to serious outcome
2. Inadequate knowledge about safety devices
3. Ignorance
4. Absence of safety precautions
5. Lack of professional competency

According to Nawaz et al. [35], the construction industry and workers are criticized for financial problem as well as fear of unemployment. The workers are forced to put their lives at risk and to neglect their health. The key argument is that working conditions and rights of the workers need to be changed and improved and occupational health and safety need to be properly regulated in the construction industry.

**Table 2.1** displays the occupational health and safety circumstances in Pakistan using the related statistical data from labour force surveys. The following table summarizes the data on occupational accidents and injuries from the past four workforce surveys [12].

Table 2.1: Percentage of occupational accidents and injuries [12]

| Major industry divisions | 2012-2013 | 2013-2014 | 2014-2015 | 2017-2018 |
|---|---|---|---|---|
| Agriculture, forestry and hunting | 49.1 | 51.2 | 48 | 41.6 |
| Construction | 15.2 | 14.1 | 16.3 | 17.3 |
| Manufacturing | 13.3 | 14.2 | 15.9 | 16.9 |
| Mining and quarrying | 0.2 | 0.3 | 0.3 | 0.3 |

Data reveals that almost 50% of workplace accidents in Pakistan are caused by the agriculture, forestry and hunting sector. However, according to the last survey, the number decreased by approximately 6%. In manufacturing and construction sectors, the percentage of workplace injury and deaths is about equal. According to the last survey, the manufacturing and construction sector faced the highest percentage increase. In the mining sector, the percentage of occupational injuries and accidents in mining industry remained below 0.5% and over the years trend has remained steady.

### 2.3.1 OSHA Act

The occupational safety and health (OSHA) Act 1970 were enacted by congress to ensure secure working environment for the workers. OSHA has a lot of knowledge to enable employers to perform their duties under OSHA law. A number of OSHA programs and resources support workers in identifying and correcting workplace risks and strengthening their accidents and fatality prevention policy. OSHA Act of 1970 ensure secure and healthy work environment for working men and women, by assisting and supporting construction industries to ensure safe and healthy working conditions through the provision of occupational safety and health research, knowledge, education, and training [36].

OSHA act 1992, contained the requirements of process safety management program in 29 CFR 1910.119, "Process Safety Management of Highly Hazardous Chemicals". Some regulatory standard for health, safety and environment have been identified but there are no clear requirements for process safety management. However, the current laws do not include clear criteria assigned to the process safety management in Pakistan [37]. The occupational safety and health act 1994 or act 514 lays out the legal structure for the safety, health and wellbeing of workers. The principle is to avoid and protect the workers from risks and injuries at workplace. The aim of Act 514 are as follows [36], [38]:

- To ensure the safety, health and wellbeing of workers at work against threats and dangers from work activities.
- To secure and avoid the workers from hazards and risks at workplace.
- To promote an occupational environment for workers at work that is tailored to their physiological and psychological needs.
- This act is intended to sustain or improve the health and safety standards.

### 2.3.2 Occupational Hazards

Construction-based OHS discernment of countries and causes for occupational accidents do not change substantially, considering the fact that certain global and habitual signs exist in workers [27]. Health and safety risks for any worker can be divided into six key categories i.e., physical hazards, chemical hazards, mechanical hazards, psycho-social hazards, ergonomic hazards and biochemical hazards. Indeed, these may trigger occupational incidents. These categories include almost each potential source of risks that a person can come across on workplace [39], [40]. Here are some hazards which are encountered in construction industry.

#### 2.3.2.1 Physical Hazards

Iftikhar et al. [41], revealed that a hazard that can be effect without holding any type of tool or machinery for instance. The physical hazards stated by Wald and Stave. [42], were to include heavy noise, no proper system of ventilation, warmth, vibration, electricity, poor light arrangement and radiations.

1. Vibration from Drilling and hammer vibration can cause white fingers due to musculoskeletal injuries and vascular spasm.

2. When a current pass through the body and interferes with an internal organ, an electrical injury occurs.

3. The worker's poor health is exacerbated by unsafe housing and contaminated environment.

#### 2.3.2.2 Chemical Hazards

Qaisrani et al. [43], identified that an amalgamation of chemicals or liquid which may cause a risk to the health and life of any worker.

1. Ammonia leads to irritation of nose and eyes.

2. Sterilize liquids and their vapors, rinsing and cleanse chemicals on farm cause skin diseases and irritation in respiratory tract.

3. Asthma, extreme allergic alveolitis and pulmonary diseases tend to cause suppressed immune system due to constant exposure to dust at work.

Ishtiaq et al. [44], found that the chemicals and their compounds like disinfectants, grease and solvents may cause dermatitis, asthma, burns on body and pneumoconiosis. Eating with dirty hands tend to lead poisoning.

#### 2.3.2.3 Mechanical Hazards

Mechanical hazards are the physical characteristics of different artifacts that are liable to cause human harm. Mechanical hazards in the form of injuries and accidents usually occurred in the construction workplace like being struck by equipment, manually handling, falling from height and slip and trip. Damage to the property Injuries and fatalities due to electrocution and fire caused improperly stored fuel are common in construction industries [45]. Examples of potential sources of mechanical hazards include [40]:

1. Moving object
2. Sharp points .
3. Rough edges
4. High-pressure fluids

#### 2.3.2.4 Psycho-social Hazards

Fear of losing job, tough working schedule, no balance among professional and personal life, management pressure, lack of career opportunities, infrequent contact with people, and no reasonable salary result in workplace stress [41]. Stress leads to different responses among workers based on age and gender. Psycho behavioral behavior manifests as anger, agitation, lack of job fulfillment, dispute, drug addicted, and sleep disturbances [46]. Psycho-social problems show up as headache, neck pain, nausea, tiredness, hypertension and cardiovascular disease. The signs of psychological tension on workplace are poor efficiency and increased injury rates [43].

#### 2.3.2.5 Ergonomic Hazards

Ergonomics is the science of adjusting working environment and the job pressure on the capabilities of the workers. Jobs like staying in one place all the day and execute repeated activities and other factors in the workplace can cause stress, exhaustion, tiredness, pains and aches in the body [42]. Boschman et al. [47], reported that musculoskeletal problems occur particularly when physical workload exceeds the human body' physical ability. Risk factors generally associated with construction workers during work include musculoskeletal problems are;

1. Awkward posture & Vibration
2. Bricklaying with a bent back
3. Lifting heavy weight above shoulder height

#### 2.3.2.6 Biological Hazards

A serious and increasing public health concern is posed by biological agents in the work environment. Biological agents originate from the surface of human, animal and plant species and from various environmental factors such as dirt, water, sewage, fertilizer, litter, oils, timber, dust and paints. Under conditions of occupational exposure, biological agents may have contagious, allergic, poisonous and irritative and can cause respiratory disorder [48].

## 2.4 3D Image of Construction Industry

In developed countries, the construction industry is frequently blamed for hiring unskilled and uneducated labor. Unfortunately, work in construction industry is known as dirty, difficult and dangerous (3D). 3D image of construction industry has shown in figure 2.2 and figure 2.3 [49], [50].

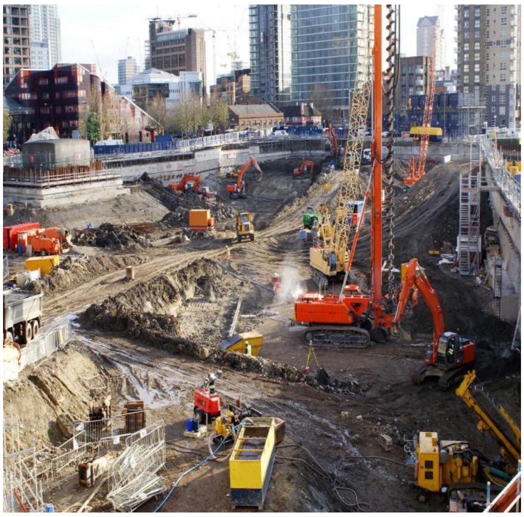

Figure 2.2: Dirty image of construction industry [49]

Figure 2.3: Difficult and dangerous image of construction industry [50]

Majority of the construction industries do not have controlling and monitoring management system to assess the safety devices and their performance ability. The workers have an incorrect image of the efficiency of the health and safety rules and regulations of the industry without reliable detailed report. As a result, issues can not be detected and solved and implementation of a health and safety laws which is critical to the workplace circumstances and avoids worker's injuries and death, is avoided from workers [51]. The dynamic existence of construction projects in Pakistan is still subjected to uncertain factors and problems that may impact the quality of existence of the structures [52].

In last few years, the health and safety condition of the construction industry is generally slightly stable. However, injuries and deaths are still happening annually more than 100 because of electric shock due to misuse of electric tool, fall from height, interaction with portable metal stairway and overhead power lines [19]. Construction industry is still concerned with labors all the time. In addition, workers not only pose a range of threats but are also vulnerable to health problems while they execute their work [35]. Construction industry is known as one of the world's difficult occupational industry. In many countries around the world, many injuries and accidents occur among health and safety problems in the construction industry. This is why the construction industry, especially in developing countries such as Pakistan is called the poor industry when it comes to health and safety standards enforcing [53]. Health and safety statistics in several countries are listed in table 2.2 [54].

TABLE 2.2: Statistics of health and safety in some countries [54]

| **Countries** | **Description** |
|---|---|
| USA | In the construction industry, a total of 774 workers had died, representing 16.5% of all industries. The fatality rate 9.8% was ranked fourth in every industry. |
| UK | The fatal injury rate is four times higher for all industries and the largest number of fatalities for workers. |
| China | The number of fatalities was 2538 in the construction industry. |
| Singapore | In 2006, there were 24 deaths in the construction industry which constituted 39% of fatalities in all industries. |
| Australia | A total of 30 fatalities were registered in 2012, the fourth highest fatality rate in construction industry. |

| Countries | Description |
|---|---|
| Pakistan | Consistent changes in accidents and fatalities were observed from 16.3% in 2014 to 17.3% in 2018 in construction industry. |

## 2.5 Safety Concerns in Construction Sector

The construction industry is known as a risky industry due to extremely threatening circumstances. Construction industries commonly classified amid all other industries with bad health and safety records in terms of worker's death and accidents in developed countries. The lack of concern paid to the efficiency of the construction projects work has resulted in low construction quality work [55]. Sometimes, workers face ergonomic risks because of physically lifting and bearing heavy loads [56]. Most repeated activities at construction sites like pulling something over and down, throwing bricks, carrying weight on head or back and took unsafe posture to do work can lead to ergonomic hazards [57].

### 2.5.1 Airborne Fibers and Toxins

According to HSE figure [58], 12,000 deaths due to lung disease are reported per year and 18,000 new cases of respiratory problems are reported. Khokhar et al. [59], indicated that there are many possible causes of lung diseases at construction sites. These comprise:

- Harmful fabric which is found in carpet and isocyanates that are found in varnishes, glues, paints, etc.
- Residue from construction sites, dust, debris removal and clean-up of worksite.
- Numerous wood powder and dust.

Construction workers are suffering more musculoskeletal disabilities and mental health problems compared to the workers in the other industries due to threats and risks at any time and at any place. The worker's inhalation to dust and asbestos is responsible for other problems including lung disease and cancer. The new trend is running in Pakistan's construction industry is to complete project in a short time period as soon as possible that leads the major accidents, fatalities, stress and mental disorder amid workers [57], [59].

### 2.5.2 Materials Handling

Many countries have developed and introduced their own health and safety measures and performance assessment methods and monitoring frameworks. Key performance indicators (KPIs) and safety considerations related to health and safety have been developed and applied in the construction industries of the developed countries [60]. In term of procurement, health and safety is often reported as an integral aspect of the suggested regulatory frameworks. Lifting materials or tools by hand are those activities that include raising carrying, pulling and pushing. Lifting materials and heavy loads manually are known to be an incredibly dangerous. The accidents are primarily attributed to health and safety risk factors like musculoskeletal disabilities. Although there are a number of kinds of hazards and risks involved with manually handling such as bruises and broken bones [61]. Kamal et al. [62], observed that soft tissue trauma, i.e., damage to muscles, ligaments, cartilage and nerves is the most common injuries at workplace. Usually, the damage of soft tissues impacts the spine, chest, arms, hands, thighs, legs and feet. They can appear suddenly or begin as a twinge which gets steadily worse over time. Adebiyi et al. [63], found that access to health and safety records minimizes risks and hazards at construction sites. it is also important to remember that workers must have proper knowledge related to health and safety records. Ray et al. [61], argued that during construction work, the severity of the injury can also range from forbearing to ordinary, distress to extreme pain and the potential to permanent disorders. Injuries can take days, months or even years to heal that leads the impact at your working ability, earning money and also your personal activities.

### 2.5.3 Hearing and Visibility

The progress of a construction project is strongly depending on the management of health and safety and its goal is to ensure a clear and efficient work at construction sites without any accidents and deaths of the workers and construction sites managers [35]. Health and safety policy in the construction industry in influenced by many factors. The consideration may be well known, such as health and safety checks, knowledge full session regarding health and safety, project completion period and risk evaluation [64]-[65]. Kamal et al. [62], concluded that majority of the construction industries do not offer hearing protections to their workers. Most of the construction industries are less concerned with the health and safety rules because they claimed that it is the government duty to conduct hearing and eye tests on an annual basis.

### 2.5.4 Lack of Health and Safety Regulations

Construction industry is growing quickly and therefore it is recognized as significant source of employment for different types of work. Though, at the same time it is known as one of the dangerous industries [66]. The other key concern is that health and safety laws are not enforced in construction industry among different types of accidents. Contractors do not organize training sessions to give their workers health and safety advices about how to secure themselves when at work [67]. Rahim [68], indicated that workers are not motivated to try to stick to safety measures and rules while work at construction sites.

## 2.6 Health and Safety Issues in Construction Industry

The construction industry is recognized as riskiest industry for workers. Accidents in construction industry in all over the world have impacted the machinery, health and safety of the workers and economy of the world. Change in workers attitude and condition of workplace are cause to increase the range of accidents and fatality [69]. Workers attitude and unsafe acts are the key points to accidents and hazards. Uneducated and non-serious workers raise voice on health and safety devices and personal protective equipment non-compliance. During the period of 2011 to 2012, 18% workers were died and 40% got injured at construction site [70]. Factors that affect the safety level of the workers and their health in construction industry are described in table 2.3.

TABLE 2.3: Factors Affecting the Health and Safety of the Workers in Construction Industry

| Sr. No | Authors | Year | Factors |
|---|---|---|---|
| 1 | Zahoor et al. [16] | 2016 | 1. Lack of organizational commitment<br>2. Uncontrolled operations or equipment<br>3. Lack of safety regulations |
| 2 | Abas et al. [71] | 2020 | 1. Inadequate safety enforcement<br>2. Poor attitude towards safety<br>3. Insufficient monitoring framework<br>4. Low level education of labor<br>5. Lack of teamwork spirits |
| 3 | Raheem and Issa [9] | 2016 | 1. Working at height in strong windy conditions<br>2. Ignore safety measures<br>3. Performance pressure<br>4. Lack of professional competency<br>5. Negligence in regulatory authority |
| 4 | Yap and Lee. [24] | 2019 | 1. Non serious attitude<br>2. Failure to obey work procedures<br>3. Failure to use personal protective equipment<br>4. Equipment without safety devices<br>5. Harsh work operation |

| Sr. No | Authors | Year | Factors |
|---|---|---|---|
| 5 | Nawaz et al. [35] | 2020 | 1. Unsafe work practices<br>2. Lack of technical and material support<br>3. Limited information<br>4. Poor project planning |
| 6 | Yap and Lee. [24] | 2019 | 1. Equipment without safety devices<br>2. Poor site management<br>3. Harsh work operation<br>4. Lack of materials availability at site |
| 7 | Wali and Mahdi. [72] | 2020 | 1. Lack of communication between site personnel<br>2. Improper project co-ordination<br>3. Clarification in technical specifications<br>4. Work area restrictions<br>5. Ineffective monitoring of the site<br>6. Slippery and rough surface<br>7. High level of noise<br>8. Poor ventilation<br>9. Invalid working process |
| 8 | Kamal et al. [62] | 2019 | 1. Lack of consultant experience<br>2. Inadequate project management<br>3. Changes in rules and legislations<br>4. Delays in design documentation<br>5. Electric power crisis<br>6. Undocumented change orders<br>7. Bureaucracy and Political instability<br>8. Discrepancy between design specification and building code<br>9. Absence of quality assurance |
| 9 | Zahoor et al. [19] | 2017 | 1. Poor implementation of safety rules and regulations by the government authorities<br>2. No process to reduce or mitigate the accidnets |

| Sr. No | Authors | Year | Factors |
|---|---|---|---|
| | | | 3. Management's focus on productivity than safety<br>4. Bureaucratic problems |
| 10 | Zhao and Guo. [73] | 2014 | 1. Natural catastrophes<br>2. Force majeure<br>3. Unexpected weather and environmental situations<br>1. Acts of God |

## 2.7 Health and Safety Condition in Pakistan

Construction industry is known one of the dangerous industry because of numerous risks and hazards that lead the number of accidents and deaths. Majority of the accidents are caused by construction execution activities that include fall from height, struck between object, lack of safety knowledge, reluctant to invest safety devices [22]. Implementation of health and safety standards in construction industry of Pakistan is at lowest level. Few of the large construction organizations follow health and safety standards. However, the accidents rate is still increasing due to lack of health and safety policies. Hence, there is a need to explore the current safety practices and safety management system of construction industry, so as to identify the weaknesses in their existing system and develop future safety guidelines [19]. In the developing countries like Pakistan, health and safety of the workers in construction industry has not been given much attention resulting in a higher accident rate. Stakeholder's emphasis is primarily on improving the construction quality, and reducing cost and time, whereas safety remains least on their agenda [51].

Safety regulatory authority are ineffective and contractors are reluctant to share the actual record of injuries and fatalities. Most of the constructors consider safety as a liability. Workers also consider health and safety as a limitation to their efficiency. No safety initiatives have been implemented by the government. Though Pakistan Engineering Council has incorporated safety clauses in its contract documents, they are not conforming to the latest technological advancement. So, a robust safety program is needed to facilitate safety performance improvements [62].

## 2.8 Tools and Methods to Address the Health and Safety Issues

The project management institute [74], reports that the effective execution of project management system has been closely concerned with risk management planning, risk inspection, assessment and risk controlling that have been important in construction industries. It is an organized method for pinpointing, assessing and responding to construction projects threats. Majority of the researchers have endorsed numerous techniques for analyzing and evaluating the relative importance index (RII) values of management system, health and safety, socio-economic and environmental risk factors [71]. Kamal et al. [62], performed a risk evaluation analysis and identified risks from previous research and carried out the questionnaire survey in order to obtain the impact values of the identified health and safety risk factors. The established risk factors were further ranked by using the formula of relative importance index (RII). In the course of risk assessment, Zhao and Guo. [73], used a Fuzzy Evaluation method to measure the frequency and level of impact for all the risk factors. Yap and Lee. [24], used the technique that was consisted of risk factors and classified those risk factors by using questionnaire survey. Nawaz et al. [35], used statistical package for social sciences (SPSS) to conduct data collection analysis for the questionnaire survey.

Wali and Mahdi [72], developed a questionnaire to be answered on a 1-5 scale for assess the impact value of the identified factors. Survey was carried out by using ordinal scale and analysis of all the risk factors was conducted to measure the impact on the work efficiency, cost and health and safety of the workers. Significance level and ranks of all the risk factors were determined by (RII) formula. Zahoor et al. [16], executed the questionnaire data to evaluate the impact value of all the risk factors using relative importance index formula. Raheem and Issa

[9], pointed out the risk factors from the literature and by means of questionnaire survey, find out the risk impact values and ranked the factors on the basis of calculated impact values. By using average formula firstly, the total sum of all the factors were calculated and then percentage values.

### 2.8.1 Multi Criteria Decision Making Techniques

Multi criteria decision making (MCDM) is an operational research analysis that is typically used to solve the complex decision making problems. MCDM allows evaluation and multiple expert judgements and is used to resolve the existence of imprecision and ambiguous information in the evaluation process [75]. Multi criteria decision making (MCDM) requires more than one set of criteria for establishing of qualitative judgement. MCDM method choose and rank the alternatives using numerous decision criteria [76]. AHP approach has been widely used to solve MCDM problem in numerous sectors such as industry, education and engineering [77]. Multi criteria decision-making (MCDM) is interpreted as the procedure of identifying the supreme alternatives amid all the viable options. Multi criteria decision-making is particular the most major branch of decision making and is used to determine the right solution from the available alternatives [4]. General flow chart of multi criteria decision-making technique follows eight steps for decision making process figure 2.4 [78].

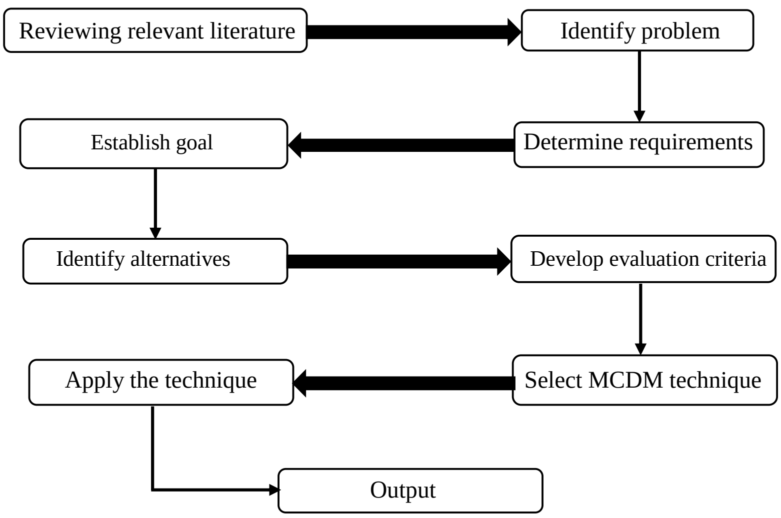


FIGURE 2.4: General flow chart of MCDM technique, [78]

Figure 2.4 demonstrate that select the pertinent decision-making method is the first step in decision making process to accomplish the goal and objectives. In second stage, criteria must be decided on the basis of expert's judgments. In third step, goal must be comprehensible and interpreted favorably. The fourth step is to identify alternatives. Alternatives are the strategies that turn the preliminary condition into preferred condition. Stage five includes the defining and evaluation of the requirements in the decision-making process. In sixth step, decision method is chosen.

### 2.8.2 AHP in Health and Safety of Construction Sector

Analytic hierarchy process (AHP) is a multi criteria decision-making approach. So, to assess the severe health and safety risks in construction projects and the principles of numerical risks relevant to health and safety, a strategic approach analytic hierarchy process (AHP) is proposed [79]. Pouresghandyani and Naji-azarpour [80], used AHP as decision support system, to identify, to evaluate the severity of risks at workplace and control and mitigate the risks related health and safety and suggested a multi criteria decision making approach to rank the risks according to their significance. This approach helped managers to make decisions on high risk project faster, more reliable and precise and to improve performance, reduce and control risks at workplace. Aminbakhsh et al. [1], have revealed that AHP is being used to develop a decision-making approach to rank the risk factors associated with musculoskeletal issues in the shoulder and neck. AHP was also adopted to compare the risk factors associated with human error and with the causes of accidents.

Bakhoum and Brown [5], Investigated numerous decision making processes like TOPSIS, ENTROPY and ELECTRE but in this research work analytic hierarchy process (AHP) has been used. AHP is efficient and easier than any other decision making tool. It is widely used for prioritization and selection of the projects. Alternatives are to be evaluated against the most appropriate evaluation criteria in the last phase. The framework for determining the health and safety weights of construction projects based on AHP is shown in figure 2.5.

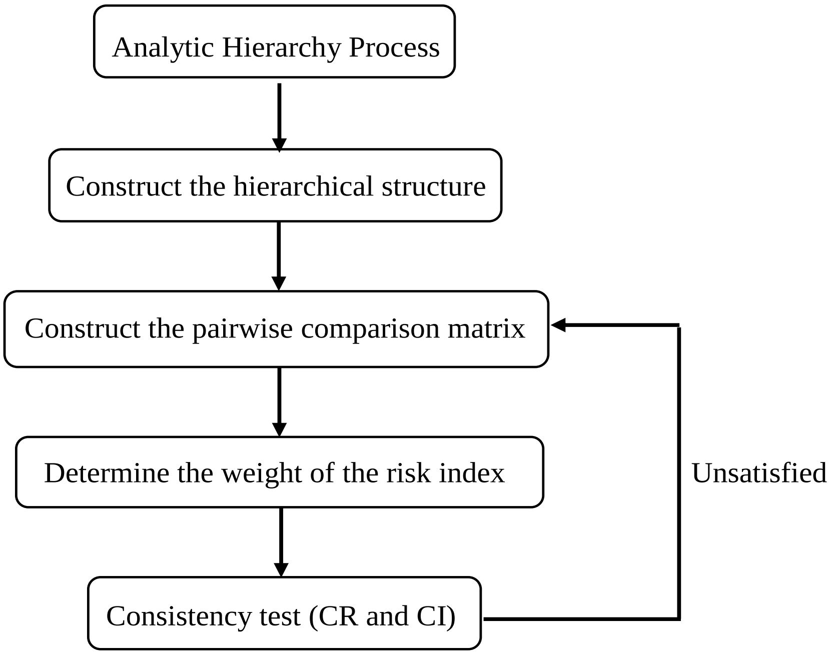


FIGURE 2.5: Flow chart of AHP, [73]

Raviv et al. [81], identified that AHP's basic approach is to about break down a major problem into a set of smaller problems that are easier to handle. AHP approach is based on identifying the major problem in the form of hierarchy in which the smaller problems are placed at the lower level. Thus, the solution to the small problems are aggregated to provide a solution to the major problem. Zhao and Guo [73], have stated that the analytic hierarchy process is considered a more common and realistic method because it scrutinizes the complex problems by breaking down the complicated and ambiguous problems into the following four stages: developing a hierarchy, pairwise comparisons, priority vectors and alternatives.

The analytic hierarchy process (AHP) methodology is commonly used for multi-criteria decision-making. AHP has been successfully used to solve a variety of realistic decision-making system. AHP offers the methodology for testing alternatives in a comparatively simple way but technically strong multi-criteria method for determining the alternatives. It helps decision makers to use a fundamental hierarchical structure to solve a complicated problems and to evaluate both qualitative and quantitative data in a structured approach under contradictory multi criteria [1]. Badri et al. [82]; Jato-Espino et al. [83], identified a risk management technique to assess the workplace safety and health (OSH) risks based upon the multi criteria decision making technique, analytic hierarchy process (AHP) and expert judgment. AHP has been applied to decision-making problems related to health and safety. AHP is helpful for making strategic decision in a wide range of construction management areas. The goal of Darko et al. [4], was to decrease the hazards and risk of construction projects by constructing the AHP based model. The first step contained of collected data and information about hazards and risk and causes that could have an impact on the construction project. The AHP method was then used to develop an assessment model and to evaluate the risk index by adding score weights previously collected.

### 2.8.3 AHP-FCE Approach

Fuzzy Comprehensive Evaluation (FCE) approach firstly proposed by Zadeh which was obtained from fuzzy set theory which determine the value of an evaluation objectives by membership matrix and factor weights. Fuzzy sets use fuzzy relation composite theory with a range of characteristics, an unclear boundary and difficult to fairly interpret and overall evaluation [84]. Framework of risk evaluation based on AHP-FCE approach is shown in figure 2.6.

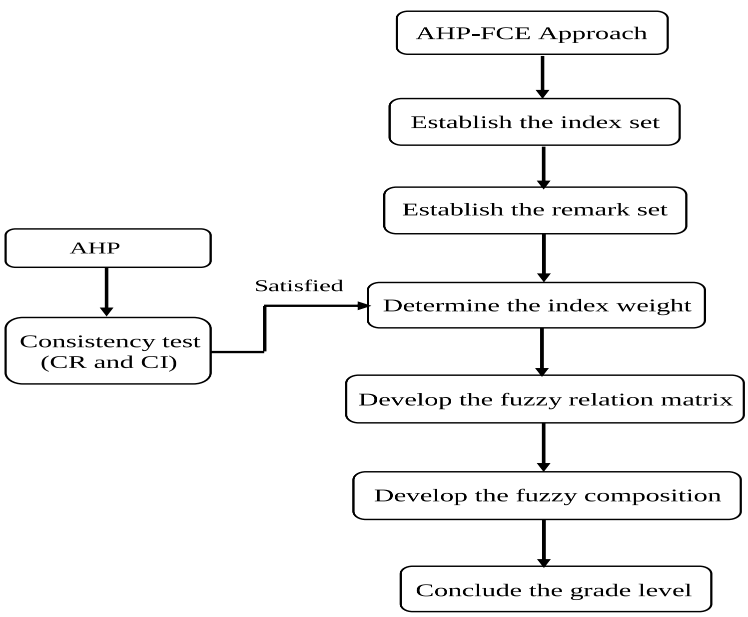


FIGURE 2.6: General flow chart of FCE, [73]

Zhang et al. [85], revealed that the combination of AHP and entropy method provides subjective and objective in determining index rather than AHP in order to measure the index weight, minimize the human factor intervention and improving the evaluation accuracy by zhang in 2016. Zhang et al. [84], stated that in various areas of study, the hybrid FCE-AHP method is commonly used to establish evaluation criteria, such as teaching performance assessment, mineral mapping, safety training for mining, human resource management, and construction. FCE-AHP approach is helpful to perform a risk evaluation for large-scale desalination projects. Zhao and Guo [73], revealed that the hybrid evaluation model based on AHP and FCE evaluates the risk of construction projects. AHP evaluate the factors weights in criteria layer and index layer while FCE approach determines evaluate the project risk. Zhang et al. [86] implemented the hybrid analytic hierarchy process (AHP) and principal component analysis to determine the safety of construction project. The findings indicated that decision dispersion normally occurring in AHP can be efficiently minimized when paired with principal component analysis. Zhang et al. [85], used the AHP technique to evaluate the weight of criteria and index layer and then used the fuzzy comprehensive evaluation (FCE) method for single index and multi-level comprehensive evaluation. This specifies that the hybrid AHP and FCE method is appropriate for complex and variable system modeling approach that combines qualitative and quantitative methods to explain complex problems. Zhao and Guo [73], stated that AHP approach can efficiently deal with the hierarchical structure and calculate the risk index weight. Risk assessment is the combination of quantitative and qualitative evaluation. It is not possible to describe the risk factors using quantitative approach in relation to the health and safety framework in building construction projects. Therefore, the risk needs to be evaluated by using FCE method.

### 2.8.4 Research Gap

A critical literature review has found that almost all the research studies involve in highlighting the construction hazards and threats. The health and safety related aspects of the construction industry have not been discussed and reported in depth.

Identified health and safety risk factors have been scrutinized and divided into categories by their contribution sources. Based on the findings, a health and safety framework in building construction project has been created to control the risks and hazards at an early stage of the project for the protection of the workers from major accidents, hazards and risks. In addition, most of the research work outlined have been undertaken outside the Pakistan. Majority of the features and aspects of construction industries are alike in all over the world and despite of this, still some particular factors in construction industry demand in depth analysis. The report, which discussed the key points that need greater attention for right supervision and monitoring, assists professionals in the preparation of the health and safety management framework for future construction projects.

## 2.9 Summary

This chapter provided the literature review on health and safety risk factors in the construction industry. It provided an overview of safety culture in construction industry and the importance of health and safety on construction sites. Then, occupational hazards and current dangerous condition of construction industry that might consistently lead to the countless accidents were discussed. Increasing importance for the risk evaluation and management mechanism for the construction industry was discussed. The construction industry has a higher risk level than other different industries, which is one of the most critical problem. OSHA Act 1970, 1992 and 1994 to promote the concept of safe environment for workers at workplace were also reviewed. OSHA Act 1970, 1992 and 1994 are workplace health and safety management system for the workers which are a key part of a safety risk management approach to address the severe health and safety risk factors in construction industry. Health and safety issues and obstacles in construction industry which affect the construction projects as well as the health and safety level of the workers were also discussed to identify the impact level of the issues. Multi criteria decision making (MCDM) technique that help to solve the complex and ambiguous problems was explored. MCDM tool analytic hierarchy process (AHP) was discussed which used to calculate the severity level of the final matrix judgements. At the last the combination of quantitative and qualitative approach AHP-FCE method was discussed which make complicated problem clear. Although, the index weight value is not directly relevant to the consistency of risk evaluation result and based on the literature review research gap was formulated.

# Chapter 3

# Research Methodology

## 3.1 Introduction

This chapter describes the methodology adopted in this research work. The methodology contained of a literature review accompanied by the health and safety preliminary study report for benchmarking in Pakistan and in other countries. In the development of a questionnaire for data collection, Delphi method was used and collected data was analyzed using the analytic hierarchy process. Moreover, the method adopted justify the aims and objectives. This research work would also contribute to the health and safety in construction industry. The following section describe the detailed methodology used in current research.

## 3.2 Research Design

The theory for this thesis is based on a detailed literature review which describes the health and safety problems in the construction industry of the Pakistan. This study has been outlined to highlight the health and safety risk factors impacting construction projects in order to meet the objectives of the OSHA guidelines related to health and safety at construction sites. A literature review was undertaken to study the relevant areas of current research work and to identify the risk factors of health and safety. Both survey and descriptive designs are used in this research. The survey methodology has been used to collect the information through questionnaire from site manager, construction professionals and construction workers at site. This study was conducted with descriptive research that assisted in evaluating the execution of health and safety rules and laws at construction sites. The Delphi method was used to short list the important health and safety factors and to develop a questionnaire. Statistical method has been used to examine the information obtained. After the data analysis, results and conclusions were derived. Figure 3.1, explains the schematic presentation of method used in this research.

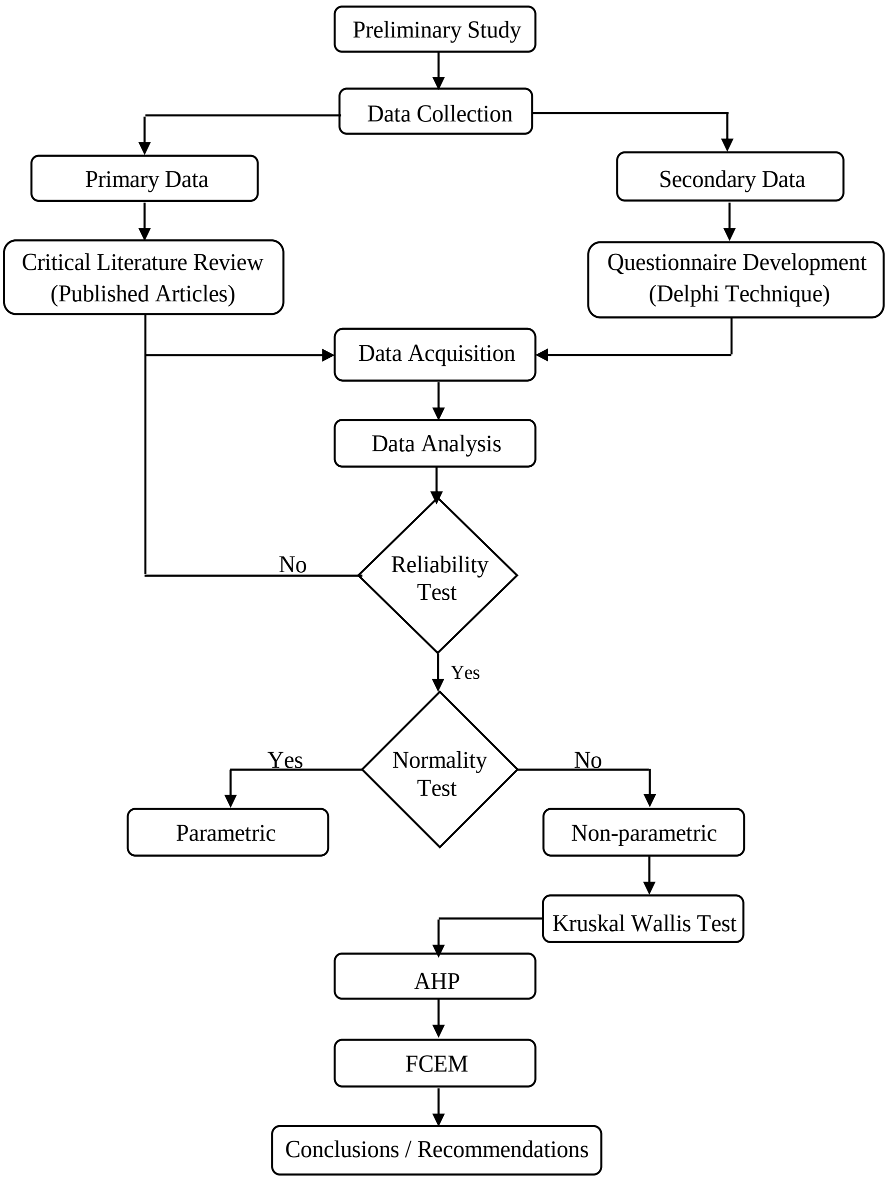


FIGURE 3.1: Flow chart of research methodology described in this chapter

### 3.2.1 Preliminary Study

Comprehensive literature review and a preliminary research work were conducted. Firstly, to gain knowledge about health and safety responsibilities and roles of construction workers, stakeholders and management team in the construction industry. Secondly, on the basis of literature review analysis, problem statement was established and the research goals were set.

### 3.2.2 Data Collection

Data collection is the stage in a research in which an appropriate and essential data are collected from the field in conjunction with goals and aims of the study. Two key origins have been used for this research work, first one is primary data and the other is secondary data.

#### 3.2.2.1 Primary Data

The strategies used in the gathering of primary data contain questionnaire and considerations with the goal of determining risk factors concerning the health and safety of the workers at construction sites.

#### 3.2.2.2 Secondary Data

From the outset of this thesis, a literature review was created so that the research issues could be thoroughly understood. Secondary data was collected by scholarly literature, journals publications and conference proceedings.

### 3.2.3 Literature Review

Critical literature review was performed to find out the risk factors that affect health and safety of the workers during construction at site. Data related to Pakistan's construction industry was collected by direct approach and online from public and government organizations. After gathering the relevant research articles, publications, journals and other relevant publications, the health and safety risk factors were identified. These factors were scrutinized and further categorized into groups.

### 3.2.4 Questionnaire Development

The Delphi technique proceeds by the following steps which is shown in figure 3.2.

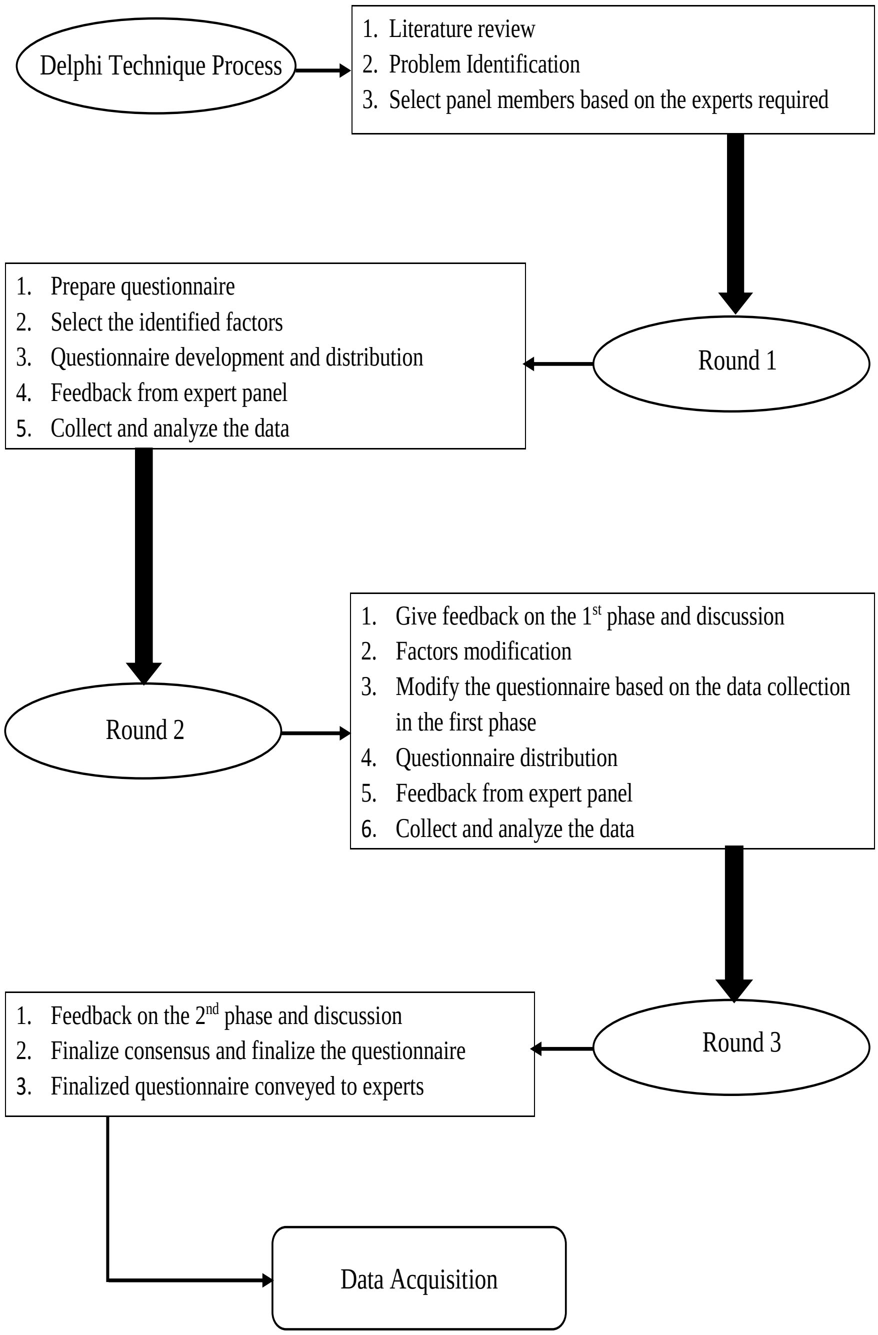


FIGURE 3.2: Delphi technique process

Delphi method was performed in the development of a questionnaire survey for the acquisition of the data after literature review analysis. Delphi method is a formal technique or process for communication, initially developed as a comprehensive and prediction method based on a panel of professionals, researchers and expert. Delphi method and focus group conversations are typically implemented for feedback [87]. Usually, nominal group technique and Delphi method are being used for feedback but Delphi technique offers conversations, indirect communications along with a detectable written input that makes the procedure more extensive, simplify and effective than other techniques [88].

In this field study, a number of professionals of the industry were involved to give their beneficial feedbacks for the identification of important factors and development of questionnaire. Identified factors were short-listed based upon the industry professional's collected feedbacks to be included in the questionnaire for further data gathering, table 3.1:

Table 3.1: Industry professional's background

| Sr.No | Designation | Experience | Category | Sector |
|---|---|---|---|---|
| 1 | Assistant Professor (CEM) | 10 - 15 years | Academia (9 years of field experience) | Private |
| 2 | Project Director | 15 - 20 years | Consultant | Private |
| 3 | Assistant Professor | 15 - 20 years | Academia (15 years of field experience) | Public |
| 4 | Assistant Engineer | 10 - 15 years | Contractor | Private |
| 5 | Director services | 5 years | Contractor | Private |
| 6 | Chief Engineer | More than 20 | Consultant | Public |
| 7 | Design Engineer | 10 - 15 years | Contractor | Private |
| 8 | Project Manager | 5 - 10 years | Contractor | Private |

Developed list of factors is short-listed after detailed discussion with experts and collecting the feedbacks from the industry professionals. These factors have been used to establish the questionnaire and presented in Appendix 1. Developed list of factors for the current study is presented in table 3.2.

TABLE 3.2: Short-list factors

| **Identified Factors** | **Inclusion Status** | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | Total |
| Workers poor attitude to safety instructions | ✓ | ✓ | | ✓ | ✓ | ✓ | ✓ | ✓ | 7 |
| Lack of wearing personal safety dress | | ✓ | ✓ | | ✓ | ✓ | ✓ | ✓ | 6 |
| Poor maintenance of equipment | ✓ | ✓ | ✓‘ | ✓ | ✓ | ✓ | ✓ | ✓ | 8 |
| Exposure to high level of noise | ✓ | ✓ | ✓ | ✓ | | ✓ | ✓ | ✓ | 6 |
| Inadequate monitoring system | ✓ | ✓ | | | | ✓ | ✓ | | 4 |
| Caught in between object and machinery | | ✓ | ✓ | ✓ | | | ✓ | ✓ | 5 |
| Collapse of scaffold | ✓ | ✓ | | ✓ | | | ✓ | | 4 |
| Fall from height | | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | 7 |
| Manual lifting of heavy weights | ✓ | ✓ | ✓ | | ✓ | | | ✓ | 5 |
| Absence of guard around the cutter | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | 8 |
| Improper communication | ✓ | ✓ | | ✓ | ✓ | ✓ | | ✓ | 6 |
| Workers falls on the steel bars | | | ✓ | | ✓ | | ✓ | | 3 |
| Musculoskeletal and respiratory disease | ✓ | | | ✓ | | ✓ | ✓ | ✓ | 5 |

| **Identified Factors** | **Inclusion Status** | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | Total |
| Ladders not properly placed | | ✓ | | | | ✓ | | | 2 |
| Waste materials littered on construction site | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | 8 |
| Inappropriate lifting | ✓ | ✓ | ✓ | | ✓ | | ✓ | ✓ | 6 |
| Took unsafe position | | ✓ | | ✓ | ✓ | | | ✓ | 4 |
| Lay steel bars against procedure | ✓ | | | ✓ | | ✓ | ✓ | ✓ | 5 |
| Using faulty machinery or tools | | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | 7 |
| Repairing machinery or tools while in use | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | | 7 |
| Use machine without safety devices | ✓ | ✓ | ✓ | | | ✓ | ✓ | | 5 |
| Working with insufficient sleep | | ✓ | | ✓ | ✓ | | ✓ | | 4 |
| Tiredness of workers | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | 8 |
| Carelessness and negligence | ✓ | ✓ | ✓ | | ✓ | | ✓ | | 5 |
| Improper supervision | | ✓ | ✓ | ✓ | | | ✓ | ✓ | 5 |
| Operated machine at unsafe speed | ✓ | | | | | ✓ | | | 2 |
| Insufficient guard rails | ✓ | | | ✓ | ✓ | ✓ | | ✓ | 5 |
| Chemical impairment | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | 8 |
| Defective working tools | | | ✓ | ✓ | ✓ | | | | 3 |
| Failing in guiding co-workers | | ✓ | ✓ | | ✓ | ✓ | | | 4 |

| **Identified Factors** | **Inclusion Status** | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | Total |
| Absence of caution sign within dangerous areas | | ✓ | ✓ | | ✓ | | ✓ | | 4 |
| Poor site management | ✓ | ✓ | | ✓ | | ✓ | ✓ | ✓ | 6 |
| Shortage of procurement planning | | ✓ | ✓ | ✓ | | | | ✓ | 4 |
| Site congestion | ✓ | | | | ✓ | | ✓ | | 3 |
| Flying materials | | ✓ | | | ✓ | ✓ | ✓ | ✓ | 5 |
| Insufficient safety training | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | 8 |
| Lighting arrangements | ✓ | ✓ | | ✓ | ✓ | ✓ | ✓ | | 6 |
| Worksite environment | | ✓ | ✓ | ✓ | | | | ✓ | 4 |
| Coordination with subcontractors | ✓ | | | ✓ | ✓ | ✓ | ✓ | | 5 |
| Poor communication between involved parties | | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | 7 |
| Lack of stakeholder's commitment | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | 8 |
| Inadequate policy formation | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | | 7 |
| Poor economic policies | ✓ | ✓ | ✓ | ✓ | | | | ✓ | 5 |
| Slow decision making | | ✓ | | ✓ | | | ✓ | ✓ | 4 |
| Weather conditions | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | 8 |
| Efficiency of work | ✓ | ✓ | ✓ | | ✓ | ✓ | ✓ | ✓ | 7 |
| Payment delays due to client poor financial management | | | ✓ | | | | | ✓ | 2 |
| Undocumented change orders | ✓ | | | | ✓ | ✓ | ✓ | ✓ | 4 |

| **Identified Factors** | **Inclusion Status** | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | Total |
| Improvements in drawings at construction stage | | ✓ | ✓ | ✓ | | | ✓ | ✓ | 5 |
| Acts of God | | ✓ | | ✓ | | | | ✓ | 3 |
| Pandemic and viral situations | | | ✓ | ✓ | | | | | 2 |
| Impact on mental health | ✓ | ✓ | ✓ | | | ✓ | | ✓ | 5 |
| Leadership role in crisis management | ✓ | ✓ | | | ✓ | ✓ | | ✓ | 5 |
| Resources management by organization | | ✓ | ✓ | ✓ | ✓ | | | | 4 |
| Social counselling of workers | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | 8 |
| Frequent contact with people | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | 8 |
| Stress and anxiety | | ✓ | ✓ | ✓ | ✓ | | ✓ | ✓ | 6 |

#### 3.2.4.1 Likert Scale

Likert scale was used to gauge the responses. The following corresponding criteria were implemented, shown in table 3.3 [89].

TABLE 3.3: Feedback's Scale, [89]

| **Sr.No** | **Description** | **Score Range** |
|---|---|---|
| 1 | Very Low | 1 |
| 2 | Low | 2 |
| 3 | Moderate | 3 |

| Sr.No | Description | Score Range |
|---|---|---|
| 4 | High | 4 |
| 5 | Very High | 5 |

### 3.2.5 Data Acquisition

A survey was undertaken after the development of questionnaire. The developed questionnaire was sent to the professionals, site managers and key personnels for their feedback in various private and public organizations of the Pakistan.

## 3.3 Data Analysis

Collected data was analyzed using statistical package for social sciences (SPSS) after collecting the data from the construction industry's professionals. The collected data was examined as detailed below:

### 3.3.1 Data Analysis Tool

SPSS means "Statistical Package for the Social Sciences" which was introduced for the first time in 1968. SPSS is a commonly used application for mathematical research of social sciences. This mathematical tool is very easy to use and accessible and numerous arithmetical experiments could be performed with this tool. This mathematical tool tackles with both comparative and correlational arithmetical experiments for both the parametric and non-parametric procedure [90]. It was really necessary to observe the distribution pattern of the results after the analysis of reliability. The SPSS can gather statistics from a record and then use it to produce the reports, graphs, charts, descriptive figures and complicated arithmetical analysis [91]. SPSS is able to interpret the data and understand the data in depth and resolve complicated problems in research. With updated statistical methods, SPSS can easily comprehend substantial and complicated data sets [92].

### 3.3.2 Reliability Test

The reliability test is one of the fundamental tests conducted to verify the reliability of the results. Reliability test ensures that the statistics are stable and accurate. Cronbach's alpha is a valuable analysis which is used to assess the reliability and the internal accuracy of any data collection [93]. Cronbach's alpha is strictly for reliability analysis. Its value above 0.7 is deemed appropriate and acceptable and it reveals that data collected can be accurately evaluated for further study [94]. Cronbach's alpha data sets are normally used in statistical studies [95], as seen in table 3.4, [96].

TABLE 3.4: Ranging Scale of Cronbach's Alpha, [96]

| **Internal Consistency** | **Cronbach's Alpha** |
|---|---|
| Excellent | $\alpha \geq 0.9$ |
| Good | $0.9 > \alpha \geq 0.8$ |
| Acceptable | $0.8 > \alpha \geq 0.7$ |
| Questionable | $0.7 > \alpha \geq 0.6$ |
| Poor | $0.6 > \alpha \geq 0.5$ |
| Unacceptable | $0.5 > \alpha$ |

### 3.3.3 Normality Test

Shapiro-Wilk's W-test (1965) is a well-established and effective test of normality. The normality test often referred to as the Shapiro-Wilk test used to determine whether the obtained data is normal or not. If data is normally distributed (parametric data), then the significance value should be greater than 0.05 and the value less than 0.05 means that the distribution pattern of the data is not normal (non-parametric data) [97].

### 3.3.4 Parametric and Non-parametric

When conducting the statistical analysis, the options between parametric and non-parametric tests happens when the obtained data does not satisfy the test hypothesis. The parametric test works well for a constant and typically distributed pattern and spread of each group is different in other words data is linear. While non-parametric tests are used when data measured in ordinal and ranked scale, follows no particular distribution and demonstrate a non-linear behavior [98]. Parametric test manifest that data distribution is normal while non parametric test manifest that data distribution is not normal [99]. Kim and Park [100], have confirmed that non-parametric test is used where data does not observe as normal distributed. The test rejects the normality hypothesis if the p-value is smaller or equal to 0.05. The normality evaluation hypothesis is as follows:

- H0: The data follows a normal distribution if p-value > alpha level.
- H1: The data does not follow a normal distribution if p-value < alpha level.

#### 3.3.4.1 Kruskal Wallis Test

The Kruskal-Wallis test (Kruskal and Wallis 1952, 1953) is the nonparametric test used for checking whether the sample data obtained from a single distribution or not. The Kruskal-Wallis test is effectively generalized for more than two samples from Wilcoxon and Mann Whitney two test samples. There are no assumptions about normality in the Kruskal-Wallis test [99]. The smallest score in the Kruskal Wallis test receives a rank of 1 and the second one smallest score receives second rank and so on. Kruskal Wallis test is suggested for non-parametric data analysis while one-way ANOVA is preferred for parametric data for better results [101].

Kruskal-Wallis test is suitable as a general non-parametric test for the comparison of more than two independent samples. It can be used to test if samples come from the same distribution. If the significance value is greater than 0.05, it means that all the respondents have the same perception. The null and alternative hypotheses for the Kruskal Wallis test are as follows, [102]:

- Null Hypothesis $H_o$: p > alpha level retains medians are equal (same perception).
- Alternative Hypothesis $H_1$: p < alpha level reject at least one median, all medians are not equal (variation in perception).

## 3.4 Framework Development Using AHP

The analytic hierarchy process was first introduced by Saaty (1980). AHP is an approach for resolving the complex and ambiguous issues. AHP is an important tool for dealing with complicated decision making that can help in determining and weighing criteria, assessing the data gathered and advancing the decision-making approach, [1]:

1. Develop a hierarchical framework using analytic hierarchy process (AHP).
2. Determine the relative importance index (RII).
3. Create the pair-wise matrix and evaluate the pair-wise comparisons
4. Assess consistency patterns

### 3.4.1 Develop a Hierarchical Framework

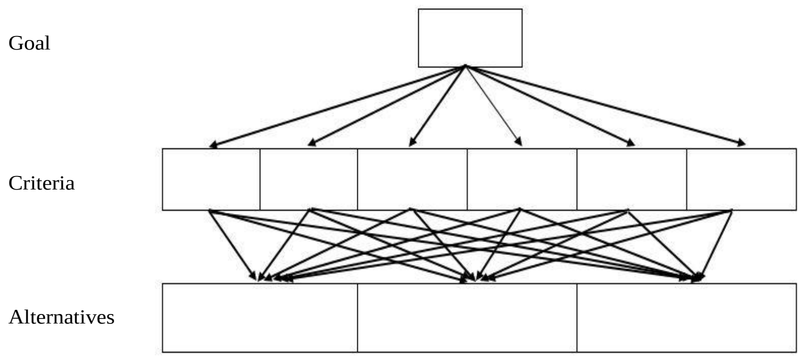


FIGURE 3.3: General structure of creating hierarchy, [103]

Figure 3.3 defines the hierarchical structure of AHP. The first step in the AHP is to construct the decision problem hierarchy. There is no specific rule that can be followed to construct a hierarchy. AHP enables the complex decision to be organized into a hierarchy and is structured to address the complicated problems at multiple hierarchy levels with a top priority as goal whereas medium levels are criteria and the lowest level as alternative [73]. In this research, according to overall goal and characteristics of multi criteria decision making problem, the complex determination of index weight is decomposed as hierarchical structure which include the goal layer, criteria layer and index layer [73], [103].

### 3.4.2 Determine Relative Importance Index

The methodology used in this research was to identify and rank the intensity level of the conclusions related to accidents and hazards, unsafe acts, unsafe conditions, management system and social groups and natural factor. By summarizing the data set values given by the respondents, the value of each factor was calculated. Hence, the intensity level selected by the respondents was then used to assess the relative importance index of each factor. In order to assess the ranks of all the factors, the 1 to 5 ranking scale was transformed into relative importance index for each factor [104]. The RII is measured using the equation (1), [62]:

$$RII = \Sigma W/A \times N \tag{1}$$

Σ W = Weightage given to each factor by respondents, ranges from 1 to 5 using Likert scale

A = Highest value for factors (which is 5 in Likert scale)

N = Total number of respondents

### 3.4.3 Evaluate Pair-wise Comparison

AHP constructs a pairwise comparison matrix (P) in order to determine the weights for the numerous criteria. The first step is to develop a pair-wise comparison matrix. It is necessary to compare each factor in pairs against a given criterion. Matrix (P) is a real (m x m) matrix where m is assumed to be evaluation criteria. Every value aij of the matrix (P) defines the importance of ith criterion in comparison to the jth criterion. If aij $>$ 1, it means ith criterion is more important than the jth criterion and if aij $<$ 1 then it means the ith criterion is less important than the jth criterion. If two criteria are of the same importance then it means aij is 1 [103]. Amin bakhsh et al. [1], revealed that Saaty proposes this scale for pair-wise comparison. Table 3.5 illustrates the numerical scale measurement. This numerical scale helps the decision maker to calculate the severity level of the judgments and to provide outcomes with a statistical framework for analysis.

Table 3.5: Scale of pair-wise comparison, [1]

| **Intensity of importance** | **Definition** | **Explanation** |
|---|---|---|
| 1 | Equal importance | Two elements contribute equally to the objective |
| 3 | Moderate importance of one over another | Experience and personal assessment strongly favor one activity over another |
| 5 | Essential of strong importance | Experience and personal assessment strongly favor one activity over another |
| 7 | Very strong importance | An element is strongly favored and its dominance demonstrated in practice |
| 9 | Extreme importance | The element favoring one activity over another is of the highest possible order of affirmation |
| 2, 4, 6, 8 | Intermediate values between two adjacent judgement | An assessment falls between two levels |

Kou et al. [103], proposed the following steps for the calculation of pairwise comparison matrix:

1. Pairwise comparison matrix $(P)$ for comparing criteria is constructed.

2. Each entry $\overline{\alpha}ij$ of the matrix $(P_{norm})$ is computed using equation (2).

$$\overline{\alpha}ij = \frac{\alpha ij}{\Sigma_{k=1}^{m} akj} \tag{2}$$

   $\alpha ij$= Entries of the matrix $(P)$

   $\Sigma_{k=1}^{m} akj$= Total sum score of each column of matrix $(P)$

   $\overline{\alpha}ij$=Entries of the normalized matrix $(P)$

3. The values obtained are normalized, i.e. each element is divided by the sum obtained to evaluate the weights of the criteria using equation (3).

$$W = \frac{\Sigma_{k=1}^{m} \overline{\alpha}ik}{n} \tag{3}$$

   $\Sigma_{k=1}^{m} \overline{\alpha}ik$= Total sum score of each row of normalized matrix $(P_{norm})$
   $n$= Number of items

4. Eigen values $(\lambda max)$ are calculated using equation (4).

$$\Sigma_{k=1}^{m} akj \times W \tag{4}$$

   $\Sigma_{k=1}^{m} akj$= Total sum score of each column of matrix $(P)$
   $W$= Criteria weight

### 3.4.4 Assess the Consistency Patterns

Analytic Hierarchy Process (AHP) is useful to verify the decisions given in each hierarchy. An inconsistency ratio of approximately 10% or less is commonly considered appropriate but the specific situations may warrant the approval or acceptance of a higher value (Saaty, 2012). A validation parameter in AHP is the $\lambda$

max value. $\lambda$ max as a testimonial index is used to assess the statistics figures by evaluating the consistency ratio (CR) of the calculated factors in order to verify whether the pairwise comparison matrix determine a totally consistent evaluation. In conjunction with these steps, the consistency index and consistency ratio are calculated [105], [106]:

1. Compute the consistency index for each matrix of order $n$ using equation (5):

$$CI = \frac{(\lambda max - n)}{(n-1)} \tag{5}$$

   $CI$= Consistency Index

   $\lambda max$= Largest eigen value

   $n$= Total number of factors

2. The consistency ratio is then calculated using equation (6):

$$CR = \frac{CI}{RI} \tag{6}$$

   $CR$= Consistency Ratio

   $RI$= Random Index

Table 3.6 manifests the random consistency index scores introduced by Thomas Saaty. As stated by Saaty (2012) the acceptable range of consistency ratio (CR) varies depending on the matrix size i.e. 0.05 for (3x3) matrix, 0.08 for (4x4) matrix and 0.1 for all bigger matrices, n $\geq$ 5. If the consistency ratio (CR) score is equal to or lower than that value, it means that the analysis within the matrix is acceptable or suggests a good level of consistency in the comparative decisions expressed in that matrix, [107].

Table 3.6: Random consistency index, [107]

| **N** | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **RI** | 0.00 | 0.00 | 0.58 | 0.90 | 1.12 | 1.24 | 1.32 | 1.41 | 1.45 | 1.49 | 1.51 | 1.48 | 1.56 | 1.57 | 1.58 |

## 3.5 Framework Evaluation Method

AHP and evaluation methods are amalgamated to determine the level of risks of the construction industry [108]. During the risk assessment process, numerous factors that influencing the risk level have a strong fuzzy unreliability and cannot be quantitatively evaluated. Hence, it is complicated or impossible to determine the level of risks by a single defined management criterion. Zadeh suggested in 1965, the idea of fuzzy sets and establish the groundwork for applying FCEM in risk management to overcome this fuzzy complexity challenge [109]. The evaluation method uses the synthesis theory of fuzzy relations to measure variables that have no clear boundaries. It extensively identifies the goal from the context of different factors [108]. Fuzzy comprehensive evaluation method (FCEM) is based on the principle of membership grade in fuzzy mathematics. In conjunction with the experts grading methodology, FCEM focus thoroughly on the assessment parameters and can deliver assessment outcomes similar to the actual situation. Based upon FCE's fundamental theory [110], [111], evaluation process proceeds as follows:

1. Establish factor set $U = (u1, u2, \ldots\ldots., un)$ and decision set $V = (v1, v2, \ldots \ldots., vn)$. U indicates factors; $(j = (1, 2, 3, \ldots\ldots.n))$ and V indicates very low, low, moderate, high and very high-risk scale $(i = (1, 2, 3, 4, 5))$.
2. Establish fuzzy relation matrix $R$.

Table 3.7: Membership and set grades

| | |
|---|---|
| Fuzzy set grade | $U = (u1, u2, \ldots\ldots., un)$ |
| Decision / Review set grade | $V = (v1, v2, \ldots\ldots., vn)$ |
| Membership grade | Rij=n/N |

$n$ = Frequency of the respondents of each sub factor

$N$ = Total number of the respondents

### 3.5.1 First Level Fuzzy Comprehensive Evaluation Matrix

Fuzzy comprehensive evaluation is the fuzzy composition method whose lines contain index weight vectors and membership vectors [108]. To determine the membership matrix Bi, multiplied the local weight of all the sub-criteria which was determined by the analytic hierarchy process (AHP) with each factor of the fuzzy relation matrix "R". Calculate membership matrix Bi which is known as first level comprehensive evaluation matrix using equation (7), [110].

$$Bi = W\ell \times R \tag{7}$$

$W\ell$= Local weight

$R$= Fuzzy relation matrix

### 3.5.2 Second Level Fuzzy Comprehensive Evaluation Matrix

Similar to the first-level fuzzy comprehensive evaluation, the matrix of second level fuzzy comprehensive evaluation contains all the assessment results of the first-class fuzzy comprehensive evaluation matrix as shown below:

$$R' = \begin{array}{|c|}\hline Bi\text{-}1 \\ \hline Bi\text{-}2 \\ \hline Bi\text{-}3 \\ \hline Bi\text{-}4 \\ \hline Bi\text{-}5 \\ \hline\end{array}$$

To obtain second level fuzzy comprehensive evaluation matrix, multiplied the factor's local weight with evaluation index R'. The comprehensive evaluation matrix $Bi$ represents the evaluation index R' of each comment. Second level fuzzy comprehensive evaluation matrix could be calculated using equation (8), [112].

$$B = W \times R' \tag{8}$$

$W$ = Factor's weight

$R'$ = Evaluation index matrix which contains first level FCE assessment result

After obtaining the second level FCE matrix (B), observed that which factor belongs to the $bi0 = maxbi(1 \leq i \leq m)$ grade, according to the concept of maximum membership grade [73]. Table 3.8 describes the definition of different risk [113].

TABLE 3.8: Meaning of different risks, [113]

| **Types of risk** | **Meaning** |
|---|---|
| Very Low | The likelihood of project risk is lower and the chance of risk would cause a so much minimum loss. |
| Low | The likelihood of project risk is minimum and the chance of risk would cause a minimum loss. |
| Moderate | The likelihood of project risk is moderate and the chance of risk would cause a general loss. |
| High | The likelihood of project risk is substantial and the chance of risk would cause a great loss. |
| Very High | The likelihood of project risk is greater and the chance of risk would cause a greater loss. |

## 3.6 Health and Safety Framework Risk Evaluation

The health and safety related factor's impact was conducted through questionnaires. Each respondent had different experience. They selected score for all the identified factors. Ruo-xin et al. [114], stated that the comment set $V = (v1, v2, \ldots\ldots., v5)$ of the evaluation object generally based on the actual situation that can help project managers to analyze the project risk more efficiently.

To establish the comment set, take the mid value of each segment as the level argument. Li et al. [115], found that some composite methods have been proposed to obtain evaluation results including $M(\wedge, \vee)$, $M(\bullet, \vee)$, $M(\wedge, +)$ and so on. The $M(\wedge, \vee))$ model was first introduced by Zadeh and has been frequently used in fuzzy areas due to its simplicity and straightforward. It is essentially a kind of dominant factor.

- "$\wedge$""symbol represent small value choosing
- "$\vee$"symbol represent large value choosing

The value with a larger effect is chosen. It is inevitable to neglect some weights or memberships with less important role. But it can provide useful information for managers and help them get a more comprehensive picture of HSE performance. The aim of risk evaluation is not only to get a precise result but a comprehensive also. Comprehensive evaluation comment set was developed by using $M(\wedge, \vee)$ model. After developing the comment set $V = (v1, v2, \ldots\ldots, v5)$ using centesimal system, multiply the $R'$ matrix and $B$ matrix of the second level comprehensive evaluation matrix with comment set $V$ of each indicator in criteria layer. To find out the health and safety framework risk evaluation, centesimal values of each indicator in criteria layer has evaluated using equation (9), [114].

$$C = R' \times V \tag{9}$$

C = Risk assessment result of the entire index object

$R'$= Evaluation index matrix which contains first level fuzzy comprehensive evaluation assessment result

$V$= Cumulative factor

## 3.7 Summary

The research methodology for this research work has been detailed in this chapter. It has been explained how to resolve the problems in existing construction risk management and how to assess the risk grade level as well as health and safety risk evaluation for building construction project. Risk factors that affect the health and safety of the workers were identified based on the literature review. Delphi methodology was used to check the identified factors by expert feedback whether these factors had an effect on the health and safety of the workers in the field project. A questionnaire survey was conducted to assess the impact of identified risk factors in order to rank the factors based on their importance. Firstly, different tests were applied to ensure the reliability of the data and to assess the nature of the data and perception level of the respondents. Multi criteria decision making technique (MCDM), analytic hierarchy process (AHP) was discussed in this chapter, which would evaluate the severity level of the final matrix judgements and the consistency of the matrix and evaluated local weight of the factors will be used in the fuzzy comprehensive evaluation method (FCEM). At the end, the combination of quantitative and qualitative approach AHP-FCE method was discussed which would evaluate the risk level of the project and would assess the health and safety framework risk evaluation for building construction projects.

# Chapter 4

# Results and Discussions

## 4.1 Introduction

This chapter reports collected data from construction industry participants and also reports an overview related to the health and safety framework of construction projects and its analysis using methodological tools and variables affecting the enforcement of health and safety policies at construction sites. The presentations have been rendered using tables and charts. The key objective of this study was to determine the status of occupational health and safety level of the workers for construction projects in Pakistan. The introduction, results, interpretation and conclusion of the thesis are based on the one hundred and seven copies of questionnaire returned as below under the numerous headings. Detailed results have been presented in this chapter.

## 4.2 Response Rate

139 questionnaires were distributed and out of 139 questionnaires, 107 questionnaires were recieved back. This represents the 77% response rate which is deemed to be very strong to make conclusions for a study. If the population size is unspecified any sample size greater than 96 can be considered as reasonable and

appropriate [116]. According to Ashley and Boyd [117], 50% response rate is satisfactory, 60% good and above 70% rated really good. According to this statement, the 77% response rate was very good.

## 4.3 Demographic Characteristics of the Respondents

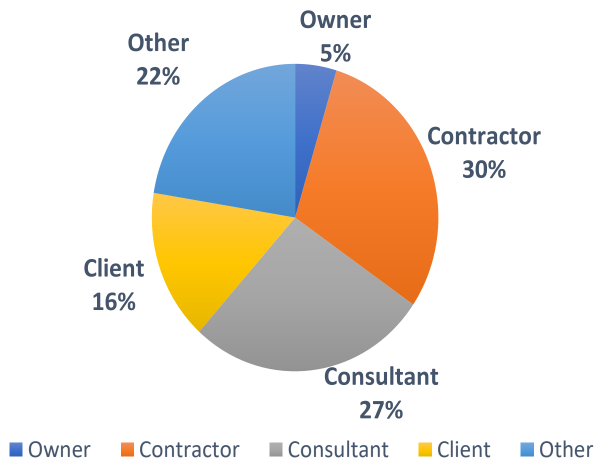


FIGURE 4.1: Types of organization

Figure 4.1 reveals that the respondents who filled the questionnaire, 5% were from owner, 30% from contractors, 27% from consultants, 16% from clients and 22% from other. The demographic statistics data indicates that majority of individuals are professional who filled the questionnaire.

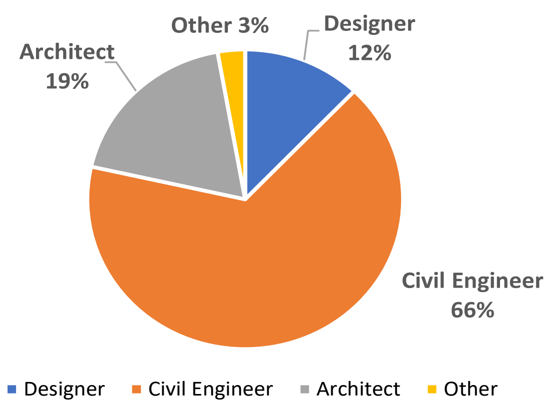


FIGURE 4.2: Profession of the respondents

Figure 4.2 indicates that the second major contribution was obtained from the civil engineers. The demographic response revealed that majority of individuals are professional civil engineers with a response rate of 66% and 12% were from designer, 19% from architect and 3% from others.

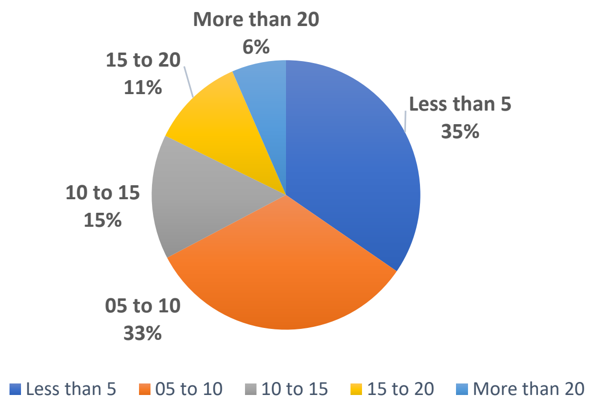


FIGURE 4.3: Working experience of respondents

The experience level plays an important role in enabling the professionals. Plenty of the respondents had experience of building construction projects. Figure 4.3 manifests that 35% respondents have an experience less than 5 years, 33% have 05 t0 10 years, 15% have 10 to 15 years, 11% have 15 to 20 years and 6% have an experience more than 20 years.

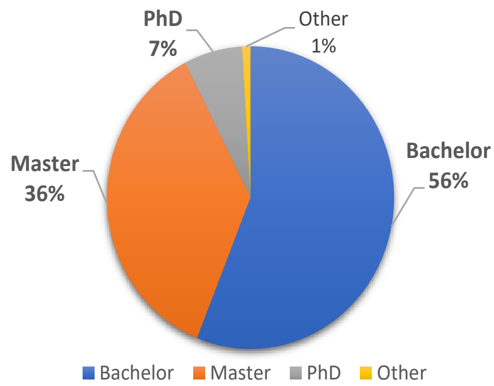


FIGURE 4.4: Respondents different educational qualification

The demographic response data presents respondents different educational qualification. Figure 4.4 shows that 56% of the respondents had done their bachelor, 36% had master degree, 7% had Ph.D. and only 1% had other educational qualification.

## 4.4 Reliability of the Research

Reliability is the concept used to assess the quality of research. It demonstrates how good a method or test measures something. Reliability is about the consistency of a measure [93].

### 4.4.1 Reliability of the Questionnaire:

To ensure the reliability of the questionnaire, Cronbach's alpha test was applied. Cronbach's alpha is the most common measure of internal consistency. It is most often used when there are several Likert questions in a survey or questionnaire that form a scale and wish to determine if the scale is reliable.

### 4.4.2 Reliability Analysis

The reliability test is one of the fundamental tests conducted to verify the reliability of the data. Reliability test is also known as Cronbach's alpha test. Cronbach's alpha test is a valuable analysis used to assess the reliability or internal consistency of any given data sets.

TABLE 4.1: Reliability value (Cronbach's alpha) of impact

| Case Summary | | | | Reliability Statistics | |
|---|---|---|---|---|---|
| | | Number | % | Cronbach's alpha | No of items |
| | Valid | 107 | 100 | .931 | 57 |
| Cases | Excluded | 0 | 0 | | |
| | Total | 107 | 100 | | |

a. Listwise deletion based on all variables in the procedure.

Statistics is used to assess the reliability test of inter item consistency. A higher value shows a strong relationship between the test items and a lower value shows a weaker relationship between test items. Reliability is acceptable if the alpha is within .70 and .99. If alpha value is greater than .70 it means the data is consistent for further analysis [96]. In our case study, Cronbach's alpha .931 is acquired which verify the consistency of data achieved. It means according to this statement; result of reliability analysis data is reliable and further analysis can be proceeded.

## 4.5 Factor's Coding

Coding is a process of defining and detecting a connection between concepts. Coding is a means of indexing or categorizing the data in order to develop a framework of thematic ideas. This research comprises 5 health and safety risks factors. For the ease of risk evaluation coding C= (C1, C2, C3, C4, C5) are referred to each risk respectively and all the 5 health and safety risks factors contain 57 sub-factors and all of them is referred S= (S1, S2, S3, . . . . . . ., S57) respectively.

## 4.6 Normality Test

The normality test generally called as Shapiro-Wilk test was used to observe the distribution pattern of the gathered data in SPSS statistical tool to determine whether the gathered data belongs to the normally distributed or not [97], Kim and Park. [100], have confirmed that non-parametric test is used where data does not observe as normal distributed. The test rejects the normality hypothesis if the p-value is smaller or equal to 0.05. It was observed that the significance value for magnitude of impact of 0.000 were obtained, table 4.2.

Table 4.2: Results of Normality test (Shapiro Wilk test)

| **Sr.No** | **Description** | **Factors Code** | **Magnitude of impact** | | |
|---|---|---|---|---|---|
| | | | **Statistics** | **df** | **Sig.** |
| 1 | Poor attitude | S1 | 0.861 | 107 | 0 |
| 2 | Lack of safety dress | S2 | 0.793 | 107 | 0 |
| 3 | Poor maintenance | S3 | 0.867 | 107 | 0 |

| Sr.No | Description | Factors Code | Magnitude of impact | | |
|---|---|---|---|---|---|
| | | | Statistics | df | Sig. |
| 4 | High level of noise | S4 | 0.895 | 107 | 0 |
| 5 | Inadequate monitoring | S5 | 0.753 | 107 | 0 |
| 6 | Caught in between objects | S6 | 0.847 | 107 | 0 |
| 7 | Collapse of scaffold | S7 | 0.892 | 107 | 0 |
| 8 | Fall from height | S8 | 0.814 | 107 | 0 |
| 9 | Manual lifting of heavy weights | S9 | 0.772 | 107 | 0 |
| 10 | No guard around cutter | S10 | 0.897 | 107 | 0 |
| 11 | Improper communication | S11 | 0.843 | 107 | 0 |
| 12 | Workers fall on steel bars | S12 | 0.866 | 107 | 0 |
| 13 | Musculoskeletal disease | S13 | 0.87 | 107 | 0 |
| 14 | Ladders not properly placed | S14 | 0.856 | 107 | 0 |
| 15 | Waste material littered on site | S15 | 0.789 | 107 | 0 |
| 16 | Inappropriate lifting | S16 | 0.879 | 107 | 0 |
| 17 | Took unsafe position for work | S17 | 0.876 | 107 | 0 |
| 18 | Lay steel bars against procedures | S18 | 0.911 | 107 | 0 |
| 19 | Using faulty tools | S19 | 0.82 | 107 | 0 |

| Sr.No | Description | Factors Code | Magnitude of impact | | |
|---|---|---|---|---|---|
| | | | **Statistics** | **df** | **Sig.** |
| 20 | Repair tool while in use | S20 | 0.82 | 107 | 0 |
| 21 | No safety devices | S21 | 0.769 | 107 | 0 |
| 22 | Insufficient sleep | S22 | 0.897 | 107 | 0 |
| 23 | Tiredness | S23 | 0.794 | 107 | 0 |
| 24 | Carelessness and negligence | S24 | 0.733 | 107 | 0 |
| 25 | Improper supervision | S25 | 0.894 | 107 | 0 |
| 26 | Operated machine at high speed | S26 | 0.902 | 107 | 0 |
| 27 | Insufficient guard rails | S27 | 0.813 | 107 | 0 |
| 28 | Failing in guiding co-workers | S28 | 0.87 | 107 | 0 |
| 29 | Chemical impairment | S29 | 0.891 | 107 | 0 |
| 30 | Defective working tools | S30 | 0.908 | 107 | 0 |
| 31 | No caution signs | S31 | 0.888 | 107 | 0 |
| 32 | Poor site management | S32 | 0.838 | 107 | 0 |
| 33 | Lack of planning | S33 | 0.913 | 107 | 0 |
| 34 | Site congestion | S34 | 0.83 | 107 | 0 |
| 35 | Flying material | S35 | 0.909 | 107 | 0 |
| 36 | Insufficient safety training | S36 | 0.857 | 107 | 0 |
| 37 | Lighting arrangement | S37 | 0.917 | 107 | 0 |
| 38 | Worksite environment | S38 | 0.899 | 107 | 0 |
| 39 | Impact on mental health | S51 | 0.91 | 107 | 0 |

| Sr.No | Description | Factors Code | Magnitude of impact | | |
|---|---|---|---|---|---|
| | | | Statistics | df | Sig. |
| 40 | Poor communication | S40 | 0.904 | 107 | 0 |
| 41 | Lack of commitment | S41 | 0.907 | 107 | 0 |
| 42 | Inadequate policy | S42 | 0.9 | 107 | 0 |
| 43 | Poor economic policy | S43 | 0.906 | 107 | 0 |
| 44 | Slow decision making | S44 | 0.909 | 107 | 0 |
| 45 | Payment delays | S45 | 0.894 | 107 | 0 |
| 46 | Change order | S46 | 0.912 | 107 | 0 |
| 47 | Improvement in drawing | S47 | 0.916 | 107 | 0 |
| 48 | Weather condition | S48 | 0.865 | 107 | 0 |
| 49 | God's act | S49 | 0.832 | 107 | 0 |
| 50 | Pandemic | S50 | 0.909 | 107 | 0 |
| 51 | Coordination | S39 | 0.907 | 107 | 0 |
| 52 | Efficiency of work | S52 | 0.845 | 107 | 0 |
| 53 | Leadership role | S53 | 0.907 | 107 | 0 |
| 54 | Resource management | S54 | 0.84 | 107 | 0 |
| 55 | Social management | S55 | 0.908 | 107 | 0 |
| 56 | Frequent contact | S56 | 0.791 | 107 | 0 |
| 57 | Stress and anxiety | S57 | 0.877 | 107 | 0 |

Factors coding are essentially the short form of the questionnaire data with grouping numbers respectively. 139 questionnaires were distributed and 107 questionnaires were filled and returned.

Thus, after applying the normality test, the outcomes of the normality test (Shapiro Wilk test) is revealing that all the significance values are less than alpha level of 0.05 hence, rejecting the null hypothesis. So, it means that data does not belong to the normal distribution according to the normality's hypothesis. Data belongs to non-parametric data so further analysis will be performed by using non-parametric test.

## 4.7 Kruskal Wallis Test

After normality test it was necessary to verify the level of perception of the respondents. Normality's hypothesis had manifested that data relates to non-parametric data. Hence, the Kruskal Wallis test was then conducted to evaluate the level of perception of the respondents. Kruskal and Wallis [102], reported that this test investigated whether respondents have same or different perception regarding each identified factor.

If the p-value is smaller than 0.05, test rejects the hypothesis. Following table 4.3 shows the perception findings of the respondents.

TABLE 4.3: Results of Kruskal Wallis test

| Sr.No | Description | Factors Code | Magnitude of impact |
|---|---|---|---|
| | | | **Sig.** |
| 1 | Poor attitude | S1 | 0.193 |
| 2 | Lack of safety dress | S2 | 0.76 |
| 3 | Poor maintenance | S3 | **.028** |
| 4 | High level of noise | S4 | 0.204 |
| 5 | Inadequate monitoring | S5 | 0.751 |
| 6 | Caught in between objects | S6 | 0.109 |
| 7 | Collapse of scaffold | S7 | 0.054 |
| 8 | Fall from height | S8 | 0.266 |

| **Sr.No** | **Description** | **Factors Code** | **Magnitude of impact** |
|---|---|---|---|
| | | | **Sig.** |
| 9 | Manual lifting of heavy weights | S9 | 0.58 |
| 10 | No guard around cutter | S10 | 0.792 |
| 11 | Improper communication | S11 | 0.978 |
| 12 | Workers fall on steel bars | S12 | 0.615 |
| 13 | Musculoskeletal disease | S13 | 0.077 |
| 14 | Ladders not properly placed | S14 | 0.522 |
| 15 | Waste material littered on site | S15 | 0.832 |
| 16 | Inappropriate lifting | S16 | **.040** |
| 17 | Took unsafe position for work | S17 | 0.362 |
| 18 | Lay steel bars against procedures | S18 | 0.286 |
| 19 | Using faulty tools | S19 | 0.808 |
| 20 | Repair tool while in use | S20 | 0.288 |
| 21 | No safety devices | S21 | 0.565 |
| 22 | Insufficient sleep | S22 | 0.761 |
| 23 | Tiredness | S23 | 0.244 |
| 24 | Carelessness and negligence | S24 | 0.95 |

| Sr.No | Description | Factors Code | Magnitude of impact |
|---|---|---|---|
| | | | Sig. |
| 25 | Improper supervision | S25 | 0.841 |
| 26 | Operated machine at high speed | S26 | 0.108 |
| 27 | Insufficient guard rails | S27 | 0.428 |
| 28 | Failing in guiding co-workers | S28 | 0.809 |
| 29 | Chemical impairment | S29 | 0.227 |
| 30 | Defective working tools | S30 | 0.454 |
| 31 | No caution signs | S31 | 0.142 |
| 32 | Poor site management | S32 | 0.437 |
| 33 | Lack of planning | S33 | 0.362 |
| 34 | Site congestion | S34 | 0.676 |
| 35 | Flying material | S35 | 0.729 |
| 36 | Insufficient safety training | S36 | 0.494 |
| 37 | Lighting arrangement | S37 | 0.787 |
| 38 | Worksite environment | S38 | 0.069 |
| 39 | Impact on mental health | S51 | 0.132 |
| 40 | Poor communication | S40 | 0.381 |
| 41 | Lack of commitment | S41 | 0.373 |
| 42 | Inadequate policy | S42 | 0.196 |
| 43 | Poor economic policy | S43 | 0.093 |

| Sr.No | Description | Factors Code | Magnitude of impact |
|---|---|---|---|
| | | | **Sig.** |
| 44 | Slow decision making | S44 | 0.134 |
| 45 | Payment delays | S45 | 0.867 |
| 46 | Change order | S46 | .464 |
| 47 | Improvement in drawing | S47 | 0.216 |
| 48 | Weather condition | S48 | 0.196 |
| 49 | God's act | S49 | 0.058 |
| 50 | Pandemic | S50 | **.045** |
| 51 | Coordination | S39 | 0.998 |
| 52 | Efficiency of work | S52 | 0.757 |
| 53 | Leadership role | S53 | 0.844 |
| 54 | Resource management | S54 | 0.391 |
| 55 | Social management | S55 | 0.056 |
| 56 | Frequent contact with people | S56 | **.008** |
| 57 | Stress and anxiety | S57 | 0.25 |

The result of Kruskal Wallis test indicates the null hypothesis of the respondents (H0: $p >$ alpha level, medians are equal). It means that respondents have the same perception of impact level regarding most of the health and safety factors except for the few factors which have been outlined in the above result table. Kruskal-Wallis test is suitable as a general non-parametric test for the comparison of more than two independent samples. It can be used to test if samples come from the same distribution. If the significance value is greater than 0.05, it means that all the respondents have the same perception.

## 4.8 Framework Development Using AHP

Multi criteria decision approach is basically the analytic hierarchy process (AHP). The AHP approach for determining alternatives is relatively simple but technically effective multi criteria decision making approach. It helps decision makers to use a basic form of hierarchy in order to solve a complex issue and to analyze both quantitative data and qualitative data in a structured multi criteria decision making approach.

### 4.8.1 Health and Safety Hierarchical Framework

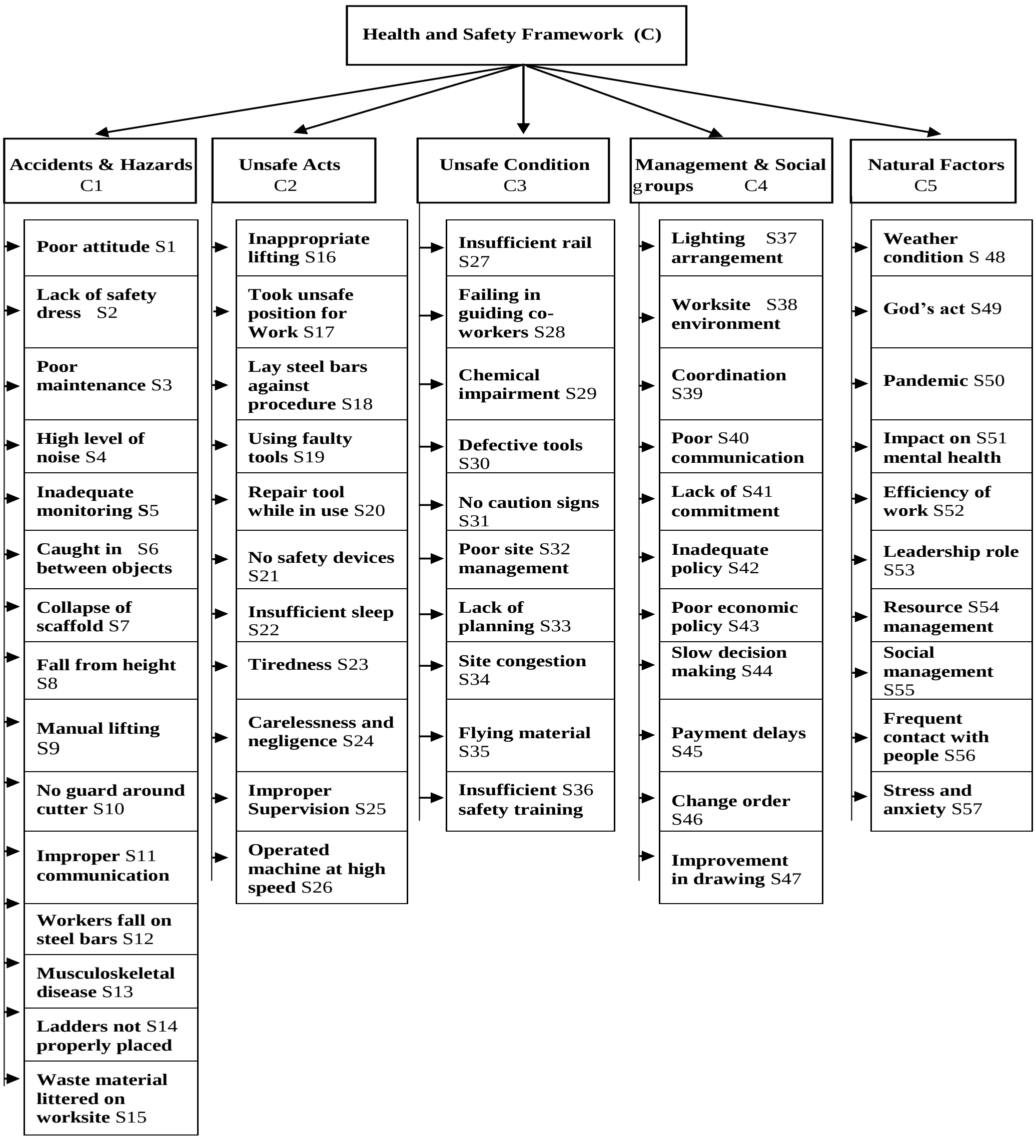


FIGURE 4.5: Hierarchical framework of risk evaluation

Figure 4.5 shows the hierarchical structure of the risk evaluation. Health and safety framework is constructed to address the complicated problems at multiple hierarchy levels that contains the goal layer, criteria layer and index layer. The health and safety risk management index framework named goal layer in this research which comprises 5 level of risk named criteria layer and the third level is sub-criteria named index layer which contains 57 risk factors related to the health and safety in construction industry. For the ease of risk evaluation coding $C = (C1, C2, C3, C4, C5)$ are referred to the criteria layer respectively accidents and hazards, unsafe acts, unsafe conditions, management system and social groups and natural factors and $S = (S1, S2, S3, \ldots\ldots., S57)$ are referred to the index layer.

### 4.8.2 Relative importance Index

The five-point Likert scale was used in questionnaire survey to gather data. It consists of 5 parts as mentioned above and these 5 parts have been further classified into 57 sub-factors. Firstly, the relative importance index (RII) values of each subfactor were assessed one by one and then RII of all the 5 factors were determined respectively by taking average of all the subfactors of each part in order to assess the impact level and ranks. Accidents and hazards ranking and RII values for health and safety framework are shown in table 4.4:

Table 4.4: Ranking of RII for accidents and hazards

| **Rank** | **Factors** | **RII** |
|---|---|---|
| 1 | Inadequate monitoring system | 0.824 |
| 2 | Waste material littered on construction site | 0.814 |
| 3 | Fall from height | 0.772 |
| 4 | Lack of wearing personal safety dress | 0.770 |
| 5 | Manual lifting of heavy weights | 0.766 |

| Rank | Factors | RII |
|---|---|---|
| 6 | Caught in between objects | 0.721 |
| 7 | Poor attitude to safety instructions | 0.718 |
| 8 | Improper communication | 0.694 |
| 9 | Ladders not properly placed | 0.683 |
| 10 | High level of noise | 0.680 |
| 11 | Musculoskeletal and respiratory disease | 0.671 |
| 12 | Poor maintenance of equipment | 0.667 |
| 13 | Collapse of scaffold | 0.658 |
| 14 | No guard around cutter | 0.656 |
| 15 | Workers falls on steel bars | 0.546 |

The first goal was to determine the level of accidents and hazards factors impact on building construction projects. From the findings of the table 4.4, it can be noted that the top five factors with high RII values inadequate monitoring system (0.824), waste material littered on construction site (0.814), fall from height (0.772), lack of wearing personal safety dress (0.770) and manual lifting of heavy weights (0.766) had high impact on accidents and hazards and the factors with low impact like workers falls on steel bars (0.546) were deemed negligible in the assessment of the impact on accidents and hazards in construction industry. Sub-factor with high relative importance index value means that factor has more impact level at the construction sites. It needs to be focused.

By summarizing the data set values given by the respondents, the value of each factor was calculated. Hence, the intensity level selected by the respondents was then used to assess the relative importance index of each factor. Table 4.5 displays the relative importance index values and ranks of the factors related to the section unsafe acts.

Table 4.5: Ranking of RII for unsafe acts

| Rank | Factors | RII |
|---|---|---|
| 1 | Use machine without safety devices | 0.804 |
| 2 | Carelessness and negligence | 0.782 |
| 3 | Working with insufficient sleep | 0.689 |
| 4 | Using faulty tools or machinery | 0.653 |
| 5 | Improper supervision | 0.651 |
| 6 | Operated machine at high speed | 0.650 |
| 7 | Repair tool while in use | 0.639 |
| 8 | Inappropriate lifting | 0.600 |
| 9 | Took unsafe position for work | 0.578 |
| 10 | Lay steel bars against procedure | 0.572 |
| 11 | Tiredness of workers | 0.449 |

The second goal was to determine the level of unsafe acts factors impact on construction projects. From the findings of the table 4.5, it can be noted that the top five factors with high RII values are use machine without safety devices (0.804), carelessness and negligence (0.782), working with insufficient sleep (0.689), using faulty tools or machinery (0.653), improper supervision (0.651) have high impact on unsafe acts and the factors with low impact tiredness of workers (0.449) and more were deemed negligible in the assessment of the impact on unsafe acts in construction industry. Factors with high relative importance index values are most remarkably among all factors because of their high impact level at the construction projects. They need to be focused. By summarizing the data set values given by the respondents, the value of each factor was calculated. Hence, the intensity level selected by the respondents was then used to assess the relative importance index of each factor. Table 4.6 illustrates the relative importance index values (RII) and ranks of the unsafe conditions related factors.

Table 4.6: Ranking of RII for unsafe conditions

| Rank | Factors | RII |
|---|---|---|
| 1 | Site congestion | 0.772 |
| 2 | Poor site management | 0.748 |
| 3 | Insufficient guard rails | 0.739 |
| 4 | Insufficient safety training | 0.728 |
| 5 | Absence of caution signs | 0.703 |
| 6 | shortage of procurement planning | 0.647 |
| 7 | Defective working tools | 0.634 |
| 8 | Chemical impairment | 0.623 |
| 9 | Failing in guiding co-workers | 0.615 |
| 10 | Flying materials | 0.612 |

Factors with high relative importance index values are most notably among all the factors because of their high impact level at the construction projects. They need to be focused.

Management system and social groups ranking all among all the relative importance index for health and safety framework are shown in table 4.7.

Table 4.7: Ranking of RII for management system and social groups

| Rank | Factors | RII |
|---|---|---|
| 1 | Payment delays | 0.656 |
| 2 | Lack of stakeholder's commitment | 0.655 |
| 3 | Poor communication | 0.642 |

| Rank | Factors | RII |
|---|---|---|
| 4 | Undocumented change order | 0.636 |
| 5 | Poor economic policies | 0.629 |
| 6 | Slow decision making by stakeholders | 0.626 |
| 7 | Coordination with subcontractors | 0.621 |
| 8 | Improvement in drawings while working | 0.620 |
| 9 | Worksite environment | 0.609 |
| 10 | Lighting arrangement | 0.603 |
| 11 | Inadequate policy formation | 0.584 |

Payment delays factor with (0.656) RII value in the section management system and social group is clearly at the top. Table 4.7 indicates that the factors which have high RII values need to be focused early and more. Among the factors such as lack of stakeholder's commitment (0.655) and poor communications (0.642), stakeholder's commitment at the second number in rank so firstly it needs to be effective and efficient and then communication gap between workers and managers to be improved and so on.

Natural Factors ranking of relative importance index for health and safety framework are display in table 4.8.

Table 4.8: Ranking of RII for Natural Factors

| Rank | Factors | RII |
|---|---|---|
| 1 | Stress and anxiety | 0.743 |
| 2 | Leadership role in crisis management | 0.658 |
| 3 | Pandemic (Covid-19, Influenza, etc.) | 0.643 |
| 4 | Impact on mental health | 0.638 |

| Rank | Factors | RII |
|---|---|---|
| 5 | Resource management | 0.619 |
| 6 | Social counseling of workers | 0.604 |
| 7 | Weather conditions | 0.556 |
| 8 | God's act | 0.546 |
| 9 | Efficiency of work | 0.510 |
| 10 | Frequent contact with people | 0.466 |

The fifth and the final goal was to determine the impact of natural factors on building construction projects. From the findings of the table 4.8, it can be observed that the top five factors with high RII values stress and anxiety (0.743), leadership role in crisis management (0.658), pandemic (Covid-19, influenza, etc.) (0.643), impact on mental health (0.638) and resource management (0.619) had high impact on construction projects. Most of these factors such as weather condition, pandemic etc. are the God's acts that the stakeholders or organization do not have jurisdiction over while appropriate plans need to be set to resolve these issues.After developing the set of each sub-criteria for health and safety, relative importance index of 5 criterion were obtained, table 4.9.

Table 4.9: RII values for health and safety factors

| Sr.No | Factors | RII | Rank |
|---|---|---|---|
| 1 | Accidents and Hazards | 0.709 | 1 |
| 2 | Unsafe acts | 0.643 | 5 |
| 3 | Unsafe conditions | 0.682 | 3 |
| 4 | Management system and social groups | 0.625 | 7 |
| 5 | Natural factors | 0.598 | 9 |

This study managed to observe that accidents and hazards related factors were extremely impactful on the construction projects with a cumulative relative importance index (0.709) and was clearly highest in the ranking, unsafe acts was ranked as the third most causes of unsafe acts with a cumulative relative importance index (0.643), unsafe conditions had second level in rank with (0.682) RII value, management system and social groups had fourth rank with (0.625) RII value and the natural factor had a fifth and final rank with (0.598) RII value. The ranking of the factors according to their RII values means that the first goal is to develop the pairwise comparison matrix to evaluate the local weight of each criterion.

### 4.8.3 Pair-wise Comparison Matrix

After attaining the (RII) values of all the factors and sub-factors, established the pair-wise comparison matrix by using the Saaty's scale for pair-wise comparison matrix and obtained the local weight of each factor and sub-factor. The local weight of all the factor and subfactors are shown in table 4.10:

Table 4.10: Local weight of health and safety factors and sub-factors

| **Factors** | **Weight** | **Indicator** | **Local weight** |
|---|---|---|---|
| Accidents and Hazards (C1) | 0.150 | S1 | 0.061 |
| | | S2 | 0.057 |
| | | S3 | 0.076 |
| | | S4 | 0.073 |
| | | S5 | 0.055 |
| | | S6 | 0.059 |
| | | S7 | 0.08 |
| | | S8 | 0.055 |

| **Factors** | **Weight** | **Indicator** | **Local weight** |
|---|---|---|---|
| | | S9 | 0.058 |
| | | S10 | 0.081 |
| | | S11 | 0.063 |
| | | S12 | 0.09 |
| | | S13 | 0.072 |
| | | S14 | 0.066 |
| | | S15 | 0.055 |
| Unsafe Acts (C2) | 0.191 | S16 | 0.099 |
| | | S17 | 0.107 |
| | | S18 | 0.118 |
| | | S19 | 0.074 |
| | | S20 | 0.09 |
| | | S21 | 0.073 |
| | | S22 | 0.081 |
| | | S23 | 0.13 |
| | | S24 | 0.073 |
| | | S25 | 0.075 |
| | | S26 | 0.08 |
| Unsafe Conditions (C3) | 0.168 | S27 | 0.084 |
| | | S28 | 0.125 |
| | | S29 | 0.114 |
| | | S30 | 0.104 |
| | | S31 | 0.093 |

| Factors | Weight | Indicator | Local weight |
|---|---|---|---|
| | | S32 | 0.092 |
| | | S33 | 0.096 |
| | | S34 | 0.077 |
| | | S35 | 0.132 |
| | | S36 | 0.083 |
| Management system | 0.226 | S37 | 0.122 |
| and social groups (C4) | | S38 | 0.112 |
| | | S39 | 0.095 |
| | | S40 | 0.069 |
| | | S41 | 0.064 |
| | | S42 | 0.133 |
| | | S43 | 0.081 |
| | | S44 | 0.087 |
| | | S45 | 0.06 |
| | | S46 | 0.075 |
| | | S47 | 0.103 |
| Natural Factors (C5) | 0.274 | S48 | 0.105 |
| | | S49 | 0.118 |
| | | S50 | 0.076 |
| | | S51 | 0.083 |
| | | S52 | 0.132 |
| | | S53 | 0.074 |
| | | S54 | 0.089 |

| Factors | Weight | Indicator | Local weight |
|---|---|---|---|
| | | S55 | 0.097 |
| | | S56 | 0.151 |
| | | S57 | 0.076 |

In table 4.10, each factor and sub-factor has different weights. It means that each factor and sub-factor has different level of impact at construction sites. Factor with maximum weight has high impact at construction site than other factors.

### 4.8.4 Consistency

It was important to check the consistency of pair-wise comparisons matrix after obtaining the local weights. The maximum eigenvalue of the comparison matrix was equal to the number of criteria. An inconsistency ratio of approximately 10% or less is commonly considered appropriate but the specific situations may warrant the approval or acceptance of a higher value. The computation for $\lambda$ max of all the criteria and index is shown in table 4.11.

TABLE 4.11: Computed maximum eigenvalues ($\lambda_{max}$)

| **Criteria** | **C** | **C-1** | **C-2** | **C-3** | **C-4** | **C-5** |
|---|---|---|---|---|---|---|
| $\lambda_{max}$ | 5.123 | 15.256 | 11.285 | 10.259 | 11.305 | 10.089 |

The maximum eigenvalue of the pair-wise comparison matrix was equal to the number of criterion relevant to two consistency tests respectively, first one was consistency index (CI) and second was consistency ratio (CR). The scores of consistency index and consistency ratio of all the factors are shown in table 4.12.

TABLE 4.12: Obtained result of consistency index and consistency ratio

| **Criteria** | **C** | **C-1** | **C-2** | **C-3** | **C-4** | **C-5** |
|---|---|---|---|---|---|---|
| **CI** | 0.0308 | 0.0182 | 0.0285 | 0.028 | 0.0305 | 0.001 |
| **CR** | $0.0275 < 0.1$ | $0.0115 < 0.1$ | $0.0189 < 0.1$ | $0.0187 < 0.1$ | $0.020 < 0.1$ | $0.00006 < 0.1$ |

Table 4.12 indicates the consistency index and consistency ratio of all the factors. Consistency index values for accidents and hazards (0.0182), unsafe acts (0.0285), unsafe conditions (0.028), management system and social groups (0.0305) and natural factors (0.001) have been calculated to assess the consistency ratio of all the identified factors. As stated by Saaty,[105], the acceptable range of consistency ratio (CR) is 0.01 for all bigger matrices than (4x4) matrix. If the consistency ratio (CR) score is equal to or lower than that value, it means that the analysis within the matrix is acceptable. According to this statement, in this research the consistency ratio value is less than 0.1 for all the factors such as accidents and hazards (0.0115) unsafe acts (0.0189), unsafe conditions (0.0187), management system and social groups (0.020) and natural factors (0.00006). It means that the evaluated values are acceptable and further process can be proceeded.

## 4.9 Framework Evaluation Method

Fuzzy comprehensive evaluation method (FCEM) is based on the membership degree theory in fuzzy mathematics. Before developing the first level fuzzy relation matrix R, established the factor set "u" and decision or evaluation grade "v".

### 4.9.1 First Level Fuzzy Comprehensive Evaluation Matrix

In first level comprehensive evaluation matrix, frequency-based method (very low, low, moderate, high and very high) and the membership grade (Rij = n / N) was used to develop the first level fuzzy relation matrix R. Fuzzy comprehensive evaluation method (FCEM) is based on the principle of membership grade in fuzzy mathematics. In conjunction with the experts grading methodology, FCEM focus thoroughly on the assessment parameters and can deliver assessment outcomes similar to the actual situation. To determine the membership matrix Bi, multiplied the local weight of all the sub-criteria which was determined by the analytic hierarchy process (AHP) with each factor of the fuzzy relation matrix "R". Table 4.13 shows the fuzzy relation matrix.

Table 4.13: Fuzzy relation matrix (R-1)

| **Accidents & Hazards** | **Very Low** | **Low** | **Moderate** | **High** | **Very High** | **Probability** |
|---|---|---|---|---|---|---|
| 1 | 0.047 | 0.037 | 0.346 | 0.421 | 0.15 | 1 |
| 2 | 0.075 | 0.112 | 0.065 | 0.383 | 0.364 | 1 |
| 3 | 0.019 | 0.103 | 0.458 | 0.364 | 0.056 | 1 |
| 4 | 0.028 | 0.112 | 0.421 | 0.308 | 0.131 | 1 |
| 5 | 0.028 | 0.065 | 0.047 | 0.477 | 0.383 | 1 |
| 6 | 0.037 | 0.121 | 0.383 | 0.112 | 0.346 | 1 |
| 7 | 0.047 | 0.121 | 0.421 | 0.318 | 0.093 | 1 |
| 8 | 0.065 | 0.084 | 0.121 | 0.383 | 0.346 | 1 |
| 9 | 0.075 | 0.112 | 0.028 | 0.477 | 0.308 | 1 |
| 10 | 0.065 | 0.112 | 0.439 | 0.243 | 0.14 | 1 |
| 11 | 0.037 | 0.047 | 0.402 | 0.439 | 0.075 | 1 |
| 12 | 0.103 | 0.318 | 0.43 | 0.047 | 0.103 | 1 |
| 13 | 0.056 | 0.065 | 0.439 | 0.346 | 0.093 | 1 |
| 14 | 0.019 | 0.065 | 0.477 | 0.364 | 0.075 | 1 |
| 15 | 0.019 | 0.065 | 0.243 | 0.178 | 0.495 | 1 |

This first level fuzzy relation matrix (R-1) has been developed by the membership grade function in order to assess the probability of the accidents and hazards factors and to create the first level fuzzy comprehensive evaluation matrix. In this case, the probability is equal to 1, it means that the further process can be proceeded. Rest of the factors $R = (R1, R2. \ldots ..., R5)$ also have been calculated by this method. After obtaining the first level fuzzy relation matrix $(R)$, all the first level fuzzy relation matrix, $(R - 1)$ was multiplied by the local weight of index layer of the accidents and hazards, $(R-2)$ was multiplied by the local weight of index layer of the unsafe acts, $(R-3)$ was multiplied by the local weight of index layer of the unsafe conditions, $(R-4)$ was multiplied by the local weight of index layer of the management system and social groups and $(R-5)$ was multiplied with the local weight of index layer of the natural factors respectively which were determined by analytic hierarchy process (AHP) to obtain the first level fuzzy comprehensive evaluation matrix $(Bi)$. Fuzzy comprehensive evaluation method (FCEM) is based on the principle of membership grade in fuzzy mathematics. Following tables 4.14 to 4.18 show the First level fuzzy comprehensive evaluation matrix $(Bi)$.

TABLE 4.14: First level fuzzy comprehensive evaluation matrix $(Bi-1)$

| **Accidents & Hazards** | **Very Low** | **Low** | **Moderate** | **High** | **Very High** |
|---|---|---|---|---|---|
| 1 | 0.003 | 0.002 | 0.021 | 0.026 | 0.009 |
| 2 | 0.004 | 0.006 | 0.004 | 0.022 | 0.021 |
| 3 | 0.001 | 0.008 | 0.035 | 0.028 | 0.004 |
| 4 | 0.002 | 0.008 | 0.031 | 0.023 | 0.01 |
| 5 | 0.002 | 0.004 | 0.003 | 0.026 | 0.021 |
| 6 | 0.002 | 0.007 | 0.022 | 0.007 | 0.02 |
| 7 | 0.004 | 0.01 | 0.034 | 0.025 | 0.007 |
| 8 | 0.004 | 0.005 | 0.007 | 0.021 | 0.019 |
| 9 | 0.004 | 0.007 | 0.002 | 0.028 | 0.018 |
| 10 | 0.005 | 0.009 | 0.036 | 0.02 | 0.011 |
| 11 | 0.002 | 0.003 | 0.025 | 0.028 | 0.005 |
| 12 | 0.009 | 0.028 | 0.038 | 0.004 | 0.009 |
| 13 | 0.004 | 0.005 | 0.032 | 0.025 | 0.007 |

| Accidents & Hazards | Very Low | Low | Moderate | High | Very High |
|---|---|---|---|---|---|
| 14 | 0.001 | 0.004 | 0.031 | 0.024 | 0.005 |
| 15 | 0.001 | 0.004 | 0.013 | 0.01 | 0.027 |
| $Bi - 1$ | **0.049** | **0.109** | **0.333** | **0.315** | **0.315** |

Comprehensive evaluation matrix ($Bi - 1$) of accidents and hazards was constructed in order to obtain the sum-up values according to their Liker scale very low (0.049), low (0.109), moderate (0.333), high (0.315) and very high (0.194) of each section of the factors named criteria layer. Similarly, all the comprehensive evaluation matrixes of all the factors ($Bi - 1$) to ($Bi - 5$) were obtained.

TABLE 4.15: First level fuzzy comprehensive evaluation matrix ($Bi - 2$)

| Unsafe acts | Very Low | Low | Moderate | High | Very High |
|---|---|---|---|---|---|
| 1 | 0.007 | 0.011 | 0.044 | 0.033 | 0.006 |
| 2 | 0.003 | 0.033 | 0.049 | 0.017 | 0.005 |
| 3 | 0.014 | 0.029 | 0.045 | 0.019 | 0.011 |
| 4 | 0.006 | 0.006 | 0.027 | 0.033 | 0.002 |
| 5 | 0.008 | 0.031 | 0.006 | 0.041 | 0.003 |
| 6 | 0.004 | 0.003 | 0.007 | 0.032 | 0.026 |
| 7 | 0.003 | 0.01 | 0.027 | 0.031 | 0.011 |
| 8 | 0.039 | 0.058 | 0.006 | 0.016 | 0.011 |
| 9 | 0.008 | 0.003 | 0.002 | 0.036 | 0.025 |
| 10 | 0.007 | 0.008 | 0.026 | 0.026 | 0.008 |
| 11 | 0.01 | 0.01 | 0.025 | 0.022 | 0.013 |

| Unsafe acts | Very Low | Low | Moderate | High | Very High |
|---|---|---|---|---|---|
| $Bi-2$ | **0.109** | **0.202** | **0.263** | **0.305** | **0.121** |

Comprehensive evaluation matrix ($Bi-2$) of unsafe acts was created in order to obtain the sum-up values according to their Liker scale very low (0.109), low (0.202), moderate (0.263), high (0.305) and very high (0.121).

TABLE 4.16: First level fuzzy comprehensive evaluation matrix ($Bi-3$)

| Unsafe acts | Very Low | Low | Moderate | High | Very High |
|---|---|---|---|---|---|
| 1 | 0.009 | 0.01 | 0.007 | 0.027 | 0.03 |
| 2 | 0.009 | 0.015 | 0.065 | 0.027 | 0.008 |
| 3 | 0.012 | 0.024 | 0.026 | 0.044 | 0.009 |
| 4 | 0.009 | 0.018 | 0.035 | 0.033 | 0.01 |
| 5 | 0.007 | 0.009 | 0.024 | 0.033 | 0.019 |
| 6 | 0.009 | 0.007 | 0.017 | 0.027 | 0.033 |
| 7 | 0.005 | 0.019 | 0.032 | 0.029 | 0.012 |
| 8 | 0.004 | 0.009 | 0.01 | 0.025 | 0.029 |
| 9 | 0.007 | 0.031 | 0.053 | 0.028 | 0.012 |
| 10 | 0.008 | 0.009 | 0.015 | 0.025 | 0.026 |
| $Bi-3$ | **0.079** | **0.152** | **0.284** | **0.298** | **0.187** |

Fuzzy comprehensive evaluation method (FCEM) is based on the principle of membership grade in fuzzy mathematics. Comprehensive evaluation matrix ($Bi-3$) of unsafe conditions was created in order to obtain the sum-up values according to their Liker scale very low (0.079), low (0.152), moderate (0.284), high (0.298) and very high (0.187).

Table 4.17: First level fuzzy comprehensive evaluation matrix ($Bi-4$)

| **Management system and social groups** | **Very Low** | **Low** | **Moderate** | **High** | **Very High** |
|---|---|---|---|---|---|
| 1 | 0.013 | 0.026 | 0.042 | 0.029 | 0.013 |
| 2 | 0.004 | 0.029 | 0.042 | 0.03 | 0.006 |
| 3 | 0.007 | 0.016 | 0.041 | 0.022 | 0.009 |
| 4 | 0.004 | 0.011 | 0.027 | 0.021 | 0.006 |
| 5 | 0.003 | 0.013 | 0.022 | 0.021 | 0.006 |
| 6 | 0.011 | 0.044 | 0.032 | 0.037 | 0.009 |
| 7 | 0.008 | 0.015 | 0.022 | 0.027 | 0.008 |
| 8 | 0.006 | 0.023 | 0.027 | 0.018 | 0.014 |
| 9 | 0.006 | 0.014 | 0.012 | 0.014 | 0.014 |
| 10 | 0.006 | 0.015 | 0.021 | 0.023 | 0.009 |
| 11 | 0.01 | 0.023 | 0.032 | 0.024 | 0.014 |
| $Bi-4$ | **0.077** | **0.229** | **0.319** | **0.267** | **0.108** |

Comprehensive evaluation matrix ($Bi-4$) of management system and social groups was developed in order to obtain the sum-up values according to their Liker scale very low (0.077), low (0.229), moderate (0.319), high (0.267) and very high (0.108).

Table 4.18: First level fuzzy comprehensive evaluation matrix ($Bi-5$)

| **Natural factors** | **Very Low** | **Low** | **Moderate** | **High** | **Very High** |
|---|---|---|---|---|---|
| 1 | 0.009 | 0.047 | 0.016 | 0.026 | 0.008 |
| 2 | 0.037 | 0.025 | 0.013 | 0.015 | 0.026 |

| **Natural factors** | **Very Low** | **Low** | **Moderate** | **High** | **Very High** |
|---|---|---|---|---|---|
| 3 | 0.007 | 0.013 | 0.026 | 0.016 | 0.013 |
| 4 | 0.008 | 0.015 | 0.022 | 0.025 | 0.012 |
| 5 | 0.039 | 0.015 | 0.058 | 0.005 | 0.015 |
| 6 | 0.006 | 0.01 | 0.026 | 0.021 | 0.011 |
| 7 | 0.003 | 0.038 | 0.008 | 0.028 | 0.013 |
| 8 | 0.009 | 0.023 | 0.029 | 0.03 | 0.006 |
| 9 | 0.066 | 0.03 | 0.007 | 0.035 | 0.013 |
| 10 | 0.003 | 0.008 | 0.017 | 0.029 | 0.019 |
| $Bi-5$ | **0.189** | **0.223** | **0.222** | **0.230** | **0.136** |

Comprehensive evaluation matrix ($Bi-5$) of natural factors was developed in order to obtain the sum-up values according to their Liker scale very low (0.189), low (0.223), moderate (0.222), high (0.230) and very high (0.136).

### 4.9.2 Second Level Fuzzy Comprehensive Evaluation Matrix

To obtain second level fuzzy comprehensive evaluation matrix, multiplied the factor's local weight with evaluation index R‘. The comprehensive evaluation matrix $Bi$ represents the evaluation index R‘ of each comment. The evaluation method uses the synthesis theory of fuzzy relations to measure variables that have no clear boundaries. It extensively identifies the goal from the context of different factors. After obtaining first level fuzzy comprehensive evaluation matrix accidents and hazards ($Bi-1$), unsafe acts ($Bi-2$), unsafe condition ($Bi-3$), management system and social groups (Bi-4) and natural factors ($Bi-5$), second level fuzzy relation matrix ($R'$) was developed which is shown in table 4.19.

TABLE 4.19: Second level fuzzy relation matrix named ($R'$)

| Criteria index | Very Low | Low | Moderate | High | Very High |
|---|---|---|---|---|---|
| Accidents and Hazards | 0.049 | 0.109 | 0.333 | 0.315 | 0.194 |
| Unsafe Acts | 0.109 | 0.202 | 0.263 | 0.305 | 0.121 |
| Unsafe Conditions | 0.079 | 0.152 | 0.284 | 0.298 | 0.187 |
| Management system | 0.077 | 0.229 | 0.319 | 0.267 | 0.108 |
| Natural Factors | 0.189 | 0.223 | 0.222 | 0.230 | 0.136 |

To obtain the second level fuzzy comprehensive evaluation matrix B, second level fuzzy relation matrix ($R'$) was multiplied with the local weight of the factors in criteria layer which were determined by AHP. Table 4.20 shows the comprehensive evaluation matrix (B).

TABLE 4.20: Second level fuzzy comprehensive evaluation matrix (B)

| Criteria index | Very Low | Low | Moderate | High | Very High |
|---|---|---|---|---|---|
| Accidents and Hazards | 0.007 | 0.016 | 0.050 | 0.047 | 0.029 |
| Unsafe Acts | 0.021 | 0.039 | 0.050 | 0.058 | 0.023 |
| Unsafe Conditions | 0.013 | 0.026 | 0.048 | 0.050 | 0.041 |
| Management system | 0.017 | 0.052 | 0.072 | 0.060 | 0.024 |
| Natural Factors | 0.052 | 0.061 | 0.061 | 0.063 | 0.037 |

| Criteria index | Very Low | Low | Moderate | High | Very High |
|---|---|---|---|---|---|
| **B** | **0.111** | **0.193** | **0.281** | **0.279** | **0.145** |

After obtaining the second level fuzzy comprehensive evaluation matrix (B), risk grade level of the project can be assessed. So, by using maximum membership garde bi0 = max bi ($1 \leq i \leq m$), it can be observed that maximum value in matrix (B) is 0.281 which indicates that project risk is moderate and risk occurrence would produce general loss. Thus, to ensure the successful completion of the construction projects, it is an important to implement certain precise risk management techniques or steps.

## 4.10 Health and Safety Framework Risk Evaluation

Based on the methodology and framework of health and safety performance evaluation stated previously, an assessment system is designed to conduct the process. In this case, evaluation results are divided into five levels qualitatively. According to evaluation result classifications, the evaluation set of health and safety performance can be described as $V = (v1, v2, v3, v4, v5)$. where these five levels represent the five possible evaluation classifications very poor, poor, moderate, high and very high. After establishing the risk evaluation set, corresponding parameters evaluation grades were determined $V = (10, 30, 55, 85, 95)$ and then centesimal value of each factors in criteria layer and the health and safety framework in goal layer have been calculated by the multiplication of corresponding parameters evaluation grades "$V$" and the second level fuzzy comprehensive evaluation matrix ($R'$), table 4.19.

C-1 = (0.049 x 10) + (0.109 x 30) + (0.333 x 55) + (0.315 x 85) + (0.194 x 95)
**C-1 = 67.237**

C-2 = (0.109 x 10) + (0.202 x 30) + (0.263 x 55) + (0.305 x 85) + (0.121 x 95)

**C-2 = 59.035**

C-3 = (0.079 x 10) + (0.152 x 30) + (0.284 x 55) + (0.298 x 85) + (0.187 x 95)

**C-3 = 64.065**

C-4 = (0.077 x 10) + (0.229 x 30) + (0.319 x 55) + (0.267 x 85) + (0.108 x 95)

**C-4 = 58.162**

C-5 = (0.109 x 10) + (0.202 x 30) + (0.263 x 55) + (0.305 x 85) + (0.121 x 95)

**C-5 = 53.282**

Similarly, the centesimal value of risk evaluation of health and safety framework (C) in the construction industry was also calculated to assess the severe effect of the factors in criteria layer.

C = (0.111 x 10) + (0.193 x 30) + (0.281 x 55) + (0.279 x 85) + (0.145 x 95) **C = 59.845**

Centesimal values of each factor in criteria layer and centesimal value of goal represented by (C) are shown in figure 4.6.

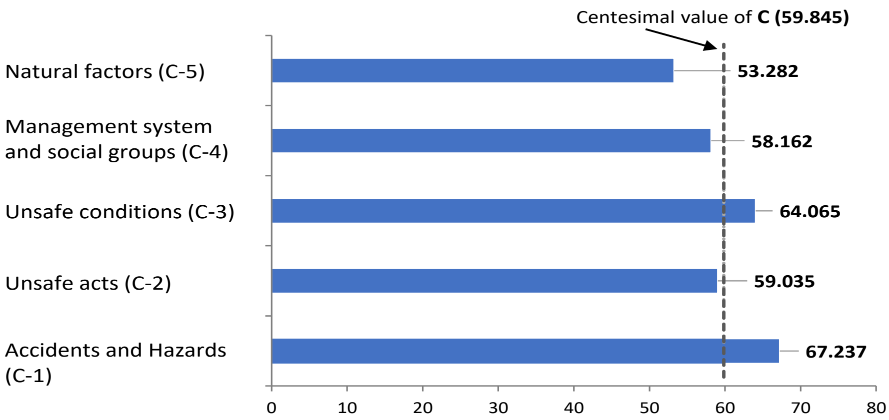


FIGURE 4.6: Centesimal values of each factor

Figure 4.6 shows the centesimal values of all the factors in criteria layer and the value of goal layer.

C-1 > C-3 > C > C-2 > C-4 > C-5

The centesimal value of C-1 is greater than all the factors in criteria layer and then C-3 is greater than C, C-2, C-4 and C-5 respectively. The centesimal values of unsafe acts "C-2" (59.035), management system and social groups "C-4" (58.162) and natural factors "C-5" (53.282) are lower than the centesimal value of the goal layer (59.845). It means unsafe acts, management system and social groups and natural factors had less impact on health and safety, while the centesimal values of accidents and hazards (67.237) and unsafe conditions (64.065) are larger than the target value in goal layer (59.845) represented by "C". It means accidents and hazards and unsafe conditions had high impact on health and safety in building construction projects. So, the factors in criteria layer accidents and hazards "C-1" and unsafe conditions "C-3" should be paid more attention in the health and safety framework for building construction projects in Pakistan.

## 4.11 Summary

The results and discussion have been detailed in this chapter. The response rate and demographic characteristic of the respondents were summarized. Three tests for statistical data reliability test, normality test and non-parametric Kruskal Wallis test was applied in this research work to obtain and assess the reliability level, nature and perception level of the respondents respectively. All the identified factors were referred with the code for the ease of understanding. In this chapter, health and safety problem in construction industry was structured as a hierarchy in the analytic hierarchy process to assess the weight of each factor to solve the major problem. Risk assessment was impossible only with quantitative approach because risk assessment is the combination of quantitative and qualitative evaluation. So, by using AHP-FCE method project risk grade level was evaluated. This helped to achieve the framework for a pre-empitive risk management strategy.

# Chapter 5

# Conclusions and Recommendations

This chapter deals with the conclusions and recommendations based on the data analysis as well as suggests the directions for future research.

## 5.1 Conclusion of the Study

The main objective of this research work was limited to the development of health and safety framework keeping in view the concerns and problems in construction industry of Pakistan. Risk factors were further categorized to find out the potential impact of health and safety problems in construction industry of Pakistan. A detailed Delphi technique was applied to shortlist the identified factors. 107 filled questionnaires were received back, which was acceptable as supported by Osborn [116]. Conclusions are summarized as below:

1. The statistic of reliability analysis impact data was 0.931, means values greater than 0.7. This result justified that the impact data was reliable.

2. As per Kruskal-Wallis test, according to the respondent's,poor maintenance of equipment (0.028), inappropriate lifting of heavy weight (0.040), pandemic

and viral situation (e.g. Covid-19, influenza, dengue, fever) (0.045), frequent contact with people (0.008) have no significant impact.

3. Based upon the frequency data, RII values of all the 57 sub-factors in index layer and their 5 main factors in criteria layer were calculated one by one.

4. Relative importance index values of the 5 main factors accidents and hazards (0.709), unsafe acts (0.643), unsafe conditions (0.682), management system and social groups (0.625) and natural factors (0.598) were calculated.

5. Local weights of all 57 sub-factors and their 5 factors were calculated. Local weight of the 5 factors in criteria layer were accidents and hazards (0.150), unsafe acts (0.191), unsafe conditions (0.168), management system and social groups (0.226) and natural factors (0.274) were calculated.

The pair-wise comparison matrix was created to evaluate the local weight of the factors. The consistency of the data collected and analyzed through the AHP was very good overall. Consistency ratio (CR) is less than 0.1 for all factors. It means, it indicates a good level of consistency in comparative judgments represented in the matrix.

1. Consistency index (CI) values of the 5 main factors accidents and hazards (0.0182), unsafe acts (0.0285), unsafe conditions (0.028), management system and social groups (0.0305) and natural factors (0.001) were calculated.

2. Consistency ratio (CR) of all the main factors accidents and hazards (0.0115), unsafe acts (0.0189), unsafe condition (0.0187), management system and social groups (0.020) and natural factors (0.00006) were calculated.

AHP was used to determine the factors weights in criteria layer and index layer while FCE method was used to evaluate the project risk.

- In case of $Bi$, the sum-up values of each factor in index layer C1 to C5 according to Likert scale very poor, poor, moderate, high and very high were 0.049, 0.109, 0.333, 0.315, 0.194 for accidents and hazards, 0.109, 0.202, 0.263, 0.305, 0.121 for unsafe acts, 0.079, 0.152, 0.284, 0.298, 0.187 for unsafe conditions, 0.077, 0.229, 0.319, 0.267, 0.108 for management system and social groups and 0.189, 0.223, 0.222, 0.230, 0.136 for natural factors were determined, named second level fuzzy relation matrix ($R'$).

Second level fuzzy comprehensive evaluation matrix (B) was constructed to identify the grade level of the factors for the occurrence probability.

- In case of matrix B, the likelihood of the occurrence for health and safety framework was observed moderate (0.281). It means risk occurrence would produce general loss.

An overall matrix, first and second level fuzzy relation and fuzzy comprehensive evaluation matrix on the basis of identified health and safety risk factors for risk evaluation was formulated and the risk evaluation result were;

- Accidents and hazards related factors and unsafe condition related factors had greater impact (67.237) and (64.065) than their threshold value (59.845) on health and safety in building construction projects. That need to be focused properly.
- Rest of three factors unsafe acts, management system and social groups and natural factors had less impact (59.035), (58.162) and (53.282) on health and safety building construction projects respectively.

The overall results of this research work helped in better understanding of significant impact related to health and safety risk factors in construction industry. All the identified factors in this research are significantly occurring and have significant impact. The study has achieved a mile stone in development of health and safety framework in construction industry that will help the project managers to analyze the project risk more efficiently. Based upon these analysis, proper remedial measures would be possible for incorporation at planning and strategy level to improve and manage these barriers.

## 5.2 Recommendations

The study has helped to gain an in-depth view of health and safety concerns. It has achieved a milestone to address such issues by developing a proper framework. Based upon the study, it is recommended that;

- The current study was limited to building construction projects, a further study can be progressed for environmental health and safety.
- This framework is developed by analytic hierarchy process (AHP). However, other multi criteria decision making models like analytic network process (ANP), game theory approach and deep learning applications may also be adopted. A comprehensive analysis of such applications would lead to more in-depth and effective achievement of such framework.
- The local construction industry lacks implementation the health and safety rules and regulation with the fears of financial aspects. The current work has prioritized the adoption strategies based upon their concerns. It is recommended that policy makers in this area of research shall enforce such research models to achieve the fundamental concerns.
- Highest percentage of accidents and hazards and unsafe conditions were caused by unsafe acts of the workers. No systematic effort has been made to assess the accidents and hazards and unsafe conditions related factors through the use of multivariate statistical analysis. However, it is recommended, factors that may lead to accidents and hazards and unsafe conditions should be known more and require in-depth understanding to achieve the fundamental concerns.
- Research should be undertaken to evaluate the cost, benefits and effectiveness of occupational health and safety training programs.

# Bibliography


[1] S. Aminbakhsh, M. Gunduz, and R. Sonmez, "Safety risk assessment using analytic hierarchy process (ahp) during planning and budgeting of construction projects," *Journal of safety research*, vol. 46, pp. 99–105, 2013.

[2] A. Pinto, I. L. Nunes, and R. A. Ribeiro, "Occupational risk assessment in construction industry–overview and reflection," *Safety science*, vol. 49, no. 5, pp. 616–624, 2011.

[3] A. Raheem and J. Hinze, "Understanding the safety culture of construction companies in pakistan by analyzing safety policy manuals," in *Proceedings of the International Conference on Safety, Construction Engineering and Project Management, Islamabad, August 19*, vol. 21, 2013.

[4] A. Darko, A. P. C. Chan, E. E. Ameyaw, E. K. Owusu, E. Pärn, and D. J. Edwards, "Review of application of analytic hierarchy process (ahp) in construction," *International Journal of Construction Management*, vol. 19, no. 5, pp. 436–452, 2019.

[5] E. S. Bakhoum and D. C. Brown, "A hybrid approach using ahp–topsis–entropy methods for sustainable ranking of structural materials," *International Journal of Sustainable Engineering*, vol. 6, no. 3, pp. 212–224, 2013.

[6] X. Wang and H. K. Chan, "A hierarchical fuzzy topsis approach to assess improvement areas when implementing green supply chain initiatives," *International Journal of Production Research*, vol. 51, no. 10, pp. 3117–3130, 2013.

[7] C. Wu and K. Chau, "Rainfall–runoff modeling using artificial neural network coupled with singular spectrum analysis," *Journal of Hydrology*, vol. 399, no. 3-4, pp. 394–409, 2011.

[8] H. Lingard, "Occupational health and safety in the construction industry," *Construction management and economics*, vol. 31, no. 6, pp. 505–514, 2013.

[9] A. A. Raheem and R. R. Issa, "Safety implementation framework for pakistani construction industry," *Safety science*, vol. 82, pp. 301–314, 2016.

[10] I. Ahmed, M. Z. Shaukat, A. Usman, M. M. Nawaz, and M. S. Nazir, "Occupational health and safety issues in the informal economic segment of pakistan: a survey of construction sites," *International journal of occupational safety and ergonomics*, vol. 24, no. 2, pp. 240–250, 2018.

[11] "Pbs, pakistan statistical book," pp. 251–258, 2019.

[12] "Pbs, compendium on gender statistics of pakistan," Ph.D. dissertation.

[13] H. Zahoor, A. P. Chan, W. P. Utama, and R. Gao, "A research framework for investigating the relationship between safety climate and safety performance in the construction of multi-storey buildings in pakistan," *Procedia engineering*, vol. 118, pp. 581–589, 2015.

[14] R. M. Choudhry, B. Tariq, and H. F. Gabriel, "Insvestigation of fall protection practices in the construction industry of pakistan," *Achieving Sustainable Construction Health and Safety*, 2014.

[15] A. H. Memon, M. A. Soomro, N. A. Memon, and M. N. Abassi, "Factors causing health and safety hazards in construction projects in pakistan," *Mehran University Research Journal of Engineering and Technology*, vol. 36, no. 3, pp. 559–568, 2017.

[16] H. Zahoor, A. P. Chan, R. Masood, R. M. Choudhry, A. A. Javed, and W. P. Utama, "Occupational safety and health performance in the pakistani construction industry: stakeholders' perspective," *International Journal of Construction Management*, vol. 16, no. 3, pp. 209–219, 2016.

[17] Y. Khosravi, H. Asilian-Mahabadi, E. Hajizadeh, N. Hassanzadeh-Rangi, H. Bastani, and A. H. Behzadan, "Factors influencing unsafe behaviors and accidents on construction sites: a review," *International journal of occupational safety and ergonomics*, vol. 20, no. 1, pp. 111–125, 2014.

[18] S. A. Memon, M. Zain, D. Zhang, S. K. U. Rehman, M. Usman, and D. Lee, "Emerging trends in the growth of structural systems for tall buildings," *Journal of Structural Integrity and Maintenance*, vol. 5, no. 3, pp. 155–170, 2020.

[19] H. Zahoor, A. P. Chan, R. Gao, and W. P. Utama, "The factors contributing to construction accidents in pakistan," *Engineering, construction and architectural management*, vol. 24(3), 463-485, 2017.

[20] J.-M. Kim, K. Son, S.-G. Yum, and S. Ahn, "Analyzing the risk of safety accidents: The relative risks of migrant workers in construction industry," *Sustainability*, vol. 12, no. 13, p. 5430, 2020.

[21] Y. Le, M. Shan, A. P. Chan, and Y. Hu, "Overview of corruption research in construction," *Journal of management in engineering*, vol. 30, no. 4, p. 02514001, 2014.

[22] M. Irfan, H. Zahoor, M. Abbas, and Y. Ali, "Determinants of labor productivity for building projects in pakistan," *Journal of Construction Engineering, Management & Innovation*, vol. 3, no. 2, pp. 85–100, 2020.

[23] A. Maqsoom and C. Charoenngam, "Motives and competitive assets of pakistani international construction contracting firms," *Journal of Financial Management of Property and Construction*, vol.19(2), pp.138-151, 2014.

[24] J. B. H. Yap and W. K. Lee, "Analysing the underlying factors affecting safety performance in building construction," *Production Planning & Control*, vol. 31, no. 13, pp. 1061–1076, 2020.

[25] S. N. Longinos, Y. M. Qadri, and M. Parlaktuna, "Health and safety conditions in four major industrial sectors of pakistan from 2010 to 2015," *Int J Pet Petrochem Eng*, vol. 3, no. 4, pp. 102–110, 2017.

[26] D. Fang and H. Wu, "Development of a safety culture interaction (sci) model for construction projects," *Safety science*, vol. 57, pp. 138–149, 2013.

[27] M. W. Khan, Y. Ali, F. De Felice, and A. Petrillo, "Occupational health and safety in construction industry in pakistan using modified-sira method," *Safety science*, vol. 118, pp. 109–118, 2019.

[28] N. Mostafa. and M. Memon, "Occupational health and safety training: knowledge, attitude and practice among technical education students," *Egyptian Journal of Occupational Medicine*, vol. 38, no. 2, pp. 153–165, 2014.

[29] A. Munir, M. A. Ashraf, A. Nasir, O. Hensel, and M. Iqbal, "Ergonomics and occupational health in sugar industry of pakistan," *Pak J of Life and Soc Sci*, vol. 10, pp. 74–9, 2012.

[30] G. I. Idoro, "Effect of mechanisation on occupational health and safety performance in the nigerian construction industry," *Journal of Construction in Developing countries*, vol. 16, no. 2, pp. 27–45, 2011.

[31] A. J.-P. Tixier, M. R. Hallowell, B. Rajagopalan, and D. Bowman, "Automated content analysis for construction safety: A natural language processing system to extract precursors and outcomes from unstructured injury reports," *Automation in Construction*, vol. 62, pp. 45–56, 2016.

[32] M. M. Asad, F. Sherwani, and Z. H. Khand, "Risk factors for construction workforce safety towards sustainability," *International Journal of Sustainable Construction Engineering and Technology*, vol. 11, no. 2, pp. 219–224, 2020.

[33] L. S. Robson, H. Lee, B. C. Amick III, V. Landsman, P. M. Smith, and C. A. Mustard, "Preventing fall-from-height injuries in construction: Effectiveness of a regulatory training standard," *Journal of Safety Research*, vol. 74, pp. 271–278, 2020.

[34] M. Jafari, M. Gharari, M. Ghafari, L. Omidi, S. Kalantari, and G. Asadolah-Fardi, "The influence of safety training on safety climate factors in a construction site," *International journal of occupational hygiene*, vol. 6, no. 2, pp. 81–87, 2014.

[35] A. Nawaz, X. Su, Q. M. U. Din, M. I. Khalid, M. Bilal, and S. A. R. Shah, "Identification of the h&s (health and safety factors) involved in infrastructure projects in developing countries-a sequential mixed method approach of olmt-project," *International journal of environmental research and public health*, vol. 17, no. 2, p. 635, 2020.

[36] C. D. Reese and J. V. Eidson, *Handbook of OSHA construction safety and health.* Crc Press, 2nd Editon, pp.952, 2006.

[37] Z. Anwar, A. Mustafa, and M. Ali, "Appraisal of process safety management practices in refining sector of pakistan," *Process Safety and Environmental Protection*, vol. 128, pp. 36–40, 2019.

[38] P. A. Michaud, *Accident prevention and OSHA compliance.* CRC Press, 1st Editoin, pp.315-320, 2017.

[39] H. Lingard and R. Wakefield, *Integrating work health and safety into construction project management.* Wiley Online Library, 289-306, 2019.

[40] S. L. Sauter, L. R. Murphy, and J. J. Hurrell, "Prevention of work-related psychological disorders: A national strategy proposed by the national institute for occupational safety and health (niosh)." *American Psychologist*, vol. 45, no. 10, p. 1146, 1990.

[41] I. Ahmad, A. Sattar, and A. Nawaz, "Occupational health and safety in industries in developing world." *Gomal Journal of Medical Sciences*, vol. 14, no. 4, 2016.

[42] G. M. Stave and P. H. Wald, *Physical and biological hazards of the workplace.* John Wiley & Sons, 3rd Editon, 2016.

[43] M. I. Qaisrani, N. Baig, T. Rathore, and F. Yousuf, "Occupational health hazards of livestock workers in pakistan," *Pakistan Journal of Public Health*, vol. 8, no. 1, pp. 52–57, 2018.

[44] M. Ishtiaq, R. Nawaz, K. U. Khan, H. U. Khan, S. Zakir, G. Sarwar, and N. Jehan, "Prevalance of pneumoconiosis among coal miners of cherat, district nowshera-pakistan," *Journal of Postgraduate Medical Institute (Peshawar-Pakistan)*, vol. 28, no. 2, 2014.

[45] G. Santin, B. Geoffroy, L. Bénézet, P. Delézire, J. Chatelot, R. Sitta, J. Bouyer, A. Gueguen, and S.-A. C. Group, "In an occupational health surveillance study, auxiliary data from administrative health and occupational databases effectively corrected for nonresponse," *Journal of clinical epidemiology*, vol. 67, no. 6, pp. 722–730, 2014.

[46] M. Abbas, "Trend of occupational injuries/diseases in pakistan: Index value analysis of injured employed persons from 2001–02 to 2012–13," *Safety and health at work*, vol. 6, no. 3, pp. 218–226, 2015.

[47] J. S. Boschman, H. F. van der Molen, J. K. Sluiter, and M. H. Frings-Dresen, "Musculoskeletal disorders among construction workers: a one-year follow-up study," *BMC musculoskeletal disorders*, vol. 13, no. 1, p. 196, 2012.

[48] K.-T. Rim and C.-H. Lim, "Biologically hazardous agents at work and efforts to protect workers' health: a review of recent reports," *Safety and health at work*, vol. 5, no. 2, pp. 43–52, 2014.

[49] M. M. Manana, C. C. Van Waveren, and K.-Y. Chan, "Does regulation have an impact on project success?: an empirical study in the construction industry in south africa," African Journal of Buisness Managment, vol.6(6), pp.2116-2125, 2012.

[50] H. Danso, "Building houses with locally available materials in ghana: benefits and problems," *International Journal of Science and Technology*, vol. 2, no. 2, pp. 225–231, 2013.

[51] W. Farid, N. I. Kureshi, S. Babar, and S. Mahmood, "Critical risk factors of construction industry of pakistan for improving project outcome," *Mehran University Research Journal of Engineering and Technology*, vol. 39, no. 1, pp. 71–80, 2020.

[52] S. Liaqat, A. Fatima, M. Riaz, and A. Rehman, "Assessment and development of framework of building maintenance management practices in construction industry of pakistan. 2nd international conference on sustainable development in civil engineering, muet, pakistan, 2019."

[53] W. Waheed and L. M. Khodeir, "Health and safety considerations in mega construction projects," *The Academic Research Community publication*, vol. 4, no. 1, pp. 44–57, 2020.

[54] M. Islam, T. Nazifa, H. Priyanka, A. Ahmed, and S. Shahid, "Identifying factors and mitigation measures of safety practices for sustainable building construction," in *IOP Conference Series: Earth and Environmental Science*, vol. 294, no. 1. IOP Publishing, pp. 012 041, 2019.

[55] A. H. A. Sheikh, M. Ikram, R. M. Ahmad, H. Qadeer, and M. Nawaz, "Evaluation of key factors influencing process quality during construction projects in pakistan," *Grey Systems: Theory and Application*, vol. 9(3), pp.321-335, 2019.

[56] H. Asadi, D. Yu, and J. H. Mott, "Risk factors for musculoskeletal injuries in airline maintenance, repair & overhaul," *International Journal of Industrial Ergonomics*, vol. 70, pp. 107–115, 2019.

[57] M. Ijaz, S. R. Ahmad, M. Akram, W. U. Khan, N. A. Yasin, and F. A. Nadeem, "Quantitative and qualitative assessment of musculoskeletal disorders and socioeconomic issues of workers of brick industry in pakistan," *International Journal of Industrial Ergonomics*, vol. 76, p. 102933, 2020.

[58] L. Vassie and W. Lucas, "An assessment of health and safety management within working groups in the uk manufacturing sector," *Journal of Safety Research*, vol. 32, no. 4, pp. 479–490, 2001.

[59] M. Khokhar, W. Iqbal, Y. Hou, M. Abbas, and A. Fatima, "Assessing supply chain performance from the perspective of pakistan's manufacturing industry through social sustainability," *Processes*, vol. 8, no. 9, p. 1064, 2020.

[60] S. Zaid Alkilani, J. Jupp, A. Sawhney *et al.*, "Issues of construction health and safety in developing countries: a case of jordan," *Australasian Journal of Construction Economics and Building*, vol. 13, no. 3, p. 141, 2013.

[61] P. K. Ray, R. Parida, and E. Saha, "Status survey of occupational risk factors of manual material handling tasks at a construction site in india," *Procedia Manufacturing*, vol. 3, pp. 6579–6586, 2015.

[62] A. Kamal, M. Abas, D. Khan, and R. W. Azfar, "Risk factors influencing the building projects in pakistan: from perspective of contractors, clients and consultants," *International Journal of Construction Management*, pp. 1–17, 2019.

[63] R. T. Adebiyi, O. Babalola, G. Amuda-yusuf, S. A. Rasheed, and T. O. Olowa, "Effect of knowledge and compliance of health and safety information on construction sites workers' safety in nigeria," *Journal homepage: http://iieta. org/journals/ijsse*, vol. 10, no. 2, pp. 269–277, 2020.

[64] G. Ashebir, C. Nie, Y. Chen, and E. Yirsaw, "Determinants of health and safety management in construction industry; the case of hengyang city, china," in *IOP Conference Series: Earth and Environmental Science*, vol. 526, no. 1. IOP Publishing, pp. 012 195, 2020.

[65] I. Ahmed, A. Usman, M. S. Nazir, and M. Z. Shaukat, "Safety practices in informal industrial segment of pakistan," *Safety Science*, vol. 110, pp. 83–91, 2018.

[66] T. Umar and C. Egbu, "Heat stress, a hidden cause of accidents in construction," in *Proceedings of the Institution of Civil Engineers–Municipal Engineer*, vol. 173, no. 1, pp. 49–60, 2020.

[67] N. H. Abas, "The analysis of struck-by accidents at construction sites in johor," *International Journal of Integrated Engineering*, vol. 12, no. 4, pp. 266–275, 2020.

[68] M. K. A. El Rahim, "Analysis and evaluation of health and safety solutions in a construction site," *International Journal of Advanced Engineering, Sciences and Applications*, vol. 1, no. 4, pp. 29–33, 2020.

[69] M. Amiri, A. Ardeshir, and M. H. F. Zarandi, "Fuzzy probabilistic expert system for occupational hazard assessment in construction," *Safety science*, vol. 93, pp. 16–28, 2017.

[70] S. M. Zin and F. Ismail, "Employers' behavioural safety compliance factors toward occupational, safety and health improvement in the construction industry," *Procedia-Social and Behavioral Sciences*, vol. 36, pp. 742–751, 2012.

[71] M. Abas, S. B. Khattak, T. Habib, and U. Nadir, "Assessment of critical risk and success factors in construction supply chain: a case of pakistan," *International Journal of Construction Management*, pp. 1–9, 2020.

[72] K. I. Wali and M. M. Mahdi, "Identification and management of major risk factors in construction of healthcare centers projects," *Engineering and Technology Journal*, vol. 38, no. 1A, pp. 65–73, 2020.

[73] H. Zhao and S. Guo, "Risk evaluation on uhv power transmission construction project based on ahp and fce method," *Mathematical Problems in Engineering*, vol. pp.1-14, 2014.

[74] P. Guide, "Guide: to the project management body of knowledge." project management institute," 3rd Edition, pp.403, 2004.

[75] M. Bouzon, K. Govindan, C. M. T. Rodriguez, and L. M. Campos, "Identification and analysis of reverse logistics barriers using fuzzy delphi method and ahp," *Resources, Conservation and Recycling*, vol. 108, pp. 182–197, 2016.

[76] M. Waris, S. Panigrahi, A. Mengal, M. I. Soomro, N. H. Mirjat, M. Ullah, Z. S. Azlan, and A. Khan, "An application of analytic hierarchy process (ahp) for sustainable procurement of construction equipment: Multicriteria-based decision framework for malaysia," *Mathematical Problems in Engineering*, vol. 2019, pp.1-20, 2019.

[77] K. Govindan, M. Kaliyan, D. Kannan, and A. N. Haq, "Barriers analysis for green supply chain management implementation in indian industries using analytic hierarchy process," *International Journal of Production Economics*, vol. 147, pp. 555–568, 2014.

[78] D. Sabaei, J. Erkoyuncu, and R. Roy, "A review of multi-criteria decision making methods for enhanced maintenance delivery," *Procedia CIRP*, vol. 37, pp. 30–35, 2015.

[79] N. Khalil, S. N. Kamaruzzaman, and M. R. Baharum, "Ranking the indicators of building performance and the users' risk via analytical hierarchy process (ahp): Case of malaysia," *Ecological Indicators*, vol. 71, pp. 567–576, 2016.

[80] H. Pouresfandyani and S. Najiazarpour, "Providing the developmental model of a comprehensive system of prioritizing occupational risks using analytical hierarchy process (ahp) technique in the management of integrated health, safety and environment (case study of oil industrial contractors)," *Modern Applied Science*, vol. 13, no. 6, 2019.

[81] G. Raviv, A. Shapira, and B. Fishbain, "Ahp-based analysis of the risk potential of safety incidents: Case study of cranes in the construction industry," *Safety science*, vol. 91, pp. 298–309, 2017.

[82] A. Badri, S. Nadeau, and A. Gbodossou, "Proposal of a risk-factor-based analytical approach for integrating occupational health and safety into project risk evaluation," *Accident Analysis & Prevention*, vol. 48, pp. 223–234, 2012.

[83] D. Jato-Espino, E. Castillo-Lopez, J. Rodriguez-Hernandez, and J. C. Canteras-Jordana, "A review of application of multi-criteria decision making

methods in construction," *Automation in Construction*, vol. 45, pp. 151–162, 2014.

[84] Y. Zhang, R. Wang, P. Huang, X. Wang, and S. Wang, "Risk evaluation of large-scale seawater desalination projects based on an integrated fuzzy comprehensive evaluation and analytic hierarchy process method," *Desalination*, vol. 478, p. 114286, 2020.

[85] D. Zhang, S. Yang, Z. Wang, C. Yang, and Y. Chen, "Assessment of ecological environment impact in highway construction activities with improved group ahp-fce approach in china," *Environmental Monitoring and Assessment*, vol. 192, no. 7, pp. 1–18, 2020.

[86] X. Zhang, S. Huang, S. Yang, R. Tu, and L. Jin, "Safety assessment in road construction work system based on group ahp-pca," *Mathematical Problems in Engineering*, vol. pp. 1-12, 2020.

[87] M. I. Yousuf, "Using expertsopinions through delphi technique," *Practical assessment, research, and evaluation*, vol. 12, no. 1, p. 4, 2007.

[88] N. Mukherjee, J. Huge, W. J. Sutherland, J. McNeill, M. Van Opstal, F. Dahdouh-Guebas, and N. Koedam, "The delphi technique in ecology and biological conservation: applications and guidelines," *Methods in Ecology and Evolution*, vol. 6, no. 9, pp. 1097–1109, 2015.

[89] I. Kandasamy, W. V. Kandasamy, J. M. Obbineni, and F. Smarandache, "Indeterminate likert scale: feedback based on neutrosophy, its distance measures and clustering algorithm," *Soft Computing*, vol. 24, no. 10, pp. 7459–7468, 2020.

[90] M. H. A. Ong and F. Puteh, "Quantitative data analysis: Choosing between spss, pls, and amos in social science research," *International Interdisciplinary Journal of Scientific Research*, vol. 3, no. 1, pp. 14–25, 2017.

[91] C. Ozgur, M. Kleckner, and Y. Li, "Selection of statistical software for solving big data problems: A guide for businesses, students, and universities," *SAGE Open*, vol. 5, no. 2, pp. 1–12, 2015.

[92] U. B. Baizyldayeva, R. Uskenbayeva, and S. Amanzholova, “Decision making procedure: applications of ibm spss cluster analysis and decision tree,” *World Applied Sciences Journal*, vol. 21, no. 8, pp. 1207–1212, 2013.

[93] D. A. Abowitz and T. M. Toole, “Mixed method research: Fundamental issues of design, validity, and reliability in construction research,” *Journal of construction engineering and management*, vol. 136, no. 1, pp. 108–116, 2010.

[94] A. M. J. T. C. Haupt, “Major construction risk factors considered by general contractors in qatar,” *Journal of Engineering, Design and Technology*, vol. 13, no. 1, pp. 165–194, 2015.

[95] M. M. Mohamad, N. L. Sulaiman, L. C. Sern, and K. M. Salleh, “Measuring the validity and reliability of research instruments,” *Procedia-Social and Behavioral Sciences*, vol. 204, pp. 164–171, 2015.

[96] S. Jain and V. Angural, “Use of cronbach’s alpha in dental research,” *Medico Research Chronicles*, vol. 4, no. 03, pp. 285–291, 2017.

[97] N. M. Razali, Y. B. Wah *et al.*, “Power comparisons of shapiro-wilk, kolmogorov-smirnov, lilliefors and anderson-darling tests,” *Journal of statistical modeling and analytics*, vol. 2, no. 1, pp. 21–33, 2011.

[98] B. Derrick, P. White, and D. Toher, “Parametric and non-parametric tests for the comparison of two samples which both include paired and unpaired observations,” *Journal of Modern Applied Statistical Methods*, vol. 18, no. 1, p. 9, 2020.

[99] E. Ostertagova, O. Ostertag, and J. Kováč, “Methodology and application of the kruskal-wallis test,” in *Applied Mechanics and Materials*, vol. 611, pp. 115–120, 2014.

[100] T. K. Kim and J. H. Park, “More about the basic assumptions of t-test: normality and sample size,” *Korean journal of anesthesiology*, vol. 72, no. 4, p. 331, 2019.

[101] T. V. Hecke, "Power study of anova versus kruskal-wallis test," *Journal of Statistics and Management Systems*, vol. 15, no. 2-3, pp. 241–247, 2012.

[102] W. H. Kruskal and W. A. Wallis, "Use of ranks in one-criterion variance analysis," *Journal of the American statistical Association*, vol. 47, no. 260, pp. 583–621, 1952.

[103] G.Kou., D.Ergu., Y.Peng, and Y.Shi, "Data processing for the ahp/anp," Springer, 1st Edition, pp.138-141, 2013.

[104] S. S. Hosseinian, Z. J. Torghabeh, and A. Ressang, "Relative importance of factors affecting construction hazards in the design phase," in *Applied Mechanics and Materials*, vol. 330. Trans Tech Publ, 2013, pp. 862–866.

[105] T. L. Saaty and L. G. Vargas, *Models:, methods, concepts & applications of the analytic hierarchy process.* Springer US, 2nd Edition, pp. 341-346, 2012.

[106] M. Brunelli, *"Introduction to the analytic hierarchy process".* Springer, 1st Edition, pp. 83, 2015.

[107] L. F. A. M. Gomes and R. M. d. Andrade, "Performance evaluation in assets management with the ahp," *Pesquisa Operacional*, vol. 32, no. 1, pp. 31–54, 2012.

[108] Y. Li, Z. Sun, L. Han, and N. Mei, "Fuzzy comprehensive evaluation method for energy management systems based on an internet of things," *IEEE Access*, vol. 5, pp. 21 312–21 322, 2017.

[109] L. Bai, Y. Li, Q. Du, and Y. Xu, "A fuzzy comprehensive evaluation model for sustainability risk evaluation of ppp projects," *Sustainability*, vol. 9, no. 10, p. 1890, 2017.

[110] X. Yu, C. Mu, and D. Zhang, "Assessment of land reclamation benefits in mining areas using fuzzy comprehensive evaluation," *Sustainability*, vol. 12, no. 5, p. 2015, 2020.

[111] Y. Li-gen and L. Xiu-ming, "Fuzzy comprehensive evaluation of work safety capacity for construction enterprises based on rough set," in *2010 International Conference on E-Business and E-Government*. IEEE, pp. 2704–2707, 2010.

[112] L. Cui, "Applying fuzzy comprehensive evaluation method to evaluate quality in crisis and emergency management," *Communications in Statistics-Theory and Methods*, vol. 41, no. 21, pp. 3942–3959, 2012.

[113] H. Zhao and N. Li, "Risk evaluation of a uhv power transmission construction project based on a cloud model and fce method for sustainability," *Sustainability*, vol. 7, no. 3, pp. 2885–2914, 2015.

[114] Z. Ruo-xin, X.-j. Cui, S.-j. Gong, H.-k. Ren, and K. Chen, "Model for cloud computing security assessment based on ahp and fce," in *2014 9th International Conference on Computer Science & Education*. IEEE, pp. 197–204, 2014.

[115] W. Li, W. Liang, L. Zhang, and Q. Tang, "Performance assessment system of health, safety and environment based on experts' weights and fuzzy comprehensive evaluation," *Journal of Loss Prevention in the Process Industries*, vol. 35, pp. 95–103, 2015.

[116] C. E. Osborn, *Essentials of statistics in health information technology*. Jones & Bartlett Publishers, 2008.

[117] P. Ashley and B. W. Boyd, "Quantitative and qualitative approaches to research in environmental management," *Australasian Journal of environmental management*, vol. 13, no. 2, pp. 70–78, 2006.

# Appendix A

Department of Civil Engineering

**Health and Safety Framework Using Analytic Hierarchy Process for Building Construction Projects in Pakistan**

(QUESTIONNAIRE)

Workplace health and safety is a multidisciplinary area also known as Occupational Health and Safety (OH&S) that is related to the health, welfare, and safety of people at worksite. Construction industry is one of the riskiest industry in the world. Construction projects experience continuous risks which could be a reason of various accidents and large number of deaths. Safety control is looking forward to taking account of all risks and accidents which can probably be predicted that put project workers at hazard. Therefore, developing plans for hazards or accidents identification for health and safety framework at construction sites are essential. Although, health and safety framework at construction sites are the vital factors, however, the level of implementation for any organization depends upon the economic constraints and organizational structure. The efficient risk management directly effects the project execution, project completion and project budget. The aim of this work is to evaluation and devise pre-emptive strategies of health and safety adopted measures by using analytic hierarchy process for buildings construction projects in consideration with economic sustainability concerns.

As you will agree that the feedback from the industry professionals remains the key to a successful implementation of health and safety framework. Being industry professionals, please answer the questions for identified concerns that you face at the construction projects. Keeping in view, the financial and organization variables within your organization. This would enable us to strategies occupational health and safety (OHS) guidelines and achieve vital feedback to develop a framework for the prioritized variables. Your kind cooperation is highly requested.

## Part-01: Demographic Data

1. **Type of Organization**

- Owner
- Contractor
- Consultant
- Client
- Other: _______

2. **Profession**

- Designer
- Contractor
- Civil Engineer
- Architect
- Other: _________

3. **Gender**

- Male
- Female

4. **Working Experience (Years)**

- Less than 5
- 5-10
- 10-15
- 15-20
- More than 20

5. **Educational Qualification**

- Bachelor
- Master
- PhD
- Other: ____

## Part-02: Health and Safety Concerns

This section focuses on the assessment of health and safety factors in term of impact. Keeping in view, the financial and organization variables within your organization. The impact is the measure of extremity of such factors on project objective (Health and Safety) with a scale i.e. very low = 1, Low = 2, Moderate = 3, High = 4 and very high = 5. keeping in view the above criteria. What do you think, what will be the impact of identified factors? Please mark one box for impact level.

### 1. Accidents and Hazards:

These are the kinds and likely causes of accidents and injuries on construction sites. On a scale of 1-5 indicate the likelihood of accident. Please mark one box for impact level.

| **Sr. No** | **Factors** | **Impact** | | | | |
|---|---|---|---|---|---|---|
| | | Very low | Low | Moderate | High | Very high |
| 1 | Workers poor attitude to safety instructions | | | | | |
| 2 | Lack of wearing personal safety dress | | | | | |
| 3 | Poor maintenance of equipment | | | | | |
| 4 | Exposure to high level of noise | | | | | |
| 5 | Inadequate monitoring system | | | | | |
| 6 | Caught in between object and machinery | | | | | |
| 7 | Collapse of scaffold | | | | | |
| 8 | Fall from height | | | | | |
| 9 | Manual lifting of heavy weights | | | | | |
| 10 | Absence of guard around the cutter | | | | | |
| 11 | Improper communication | | | | | |
| 12 | Workers falls on the steel bars | | | | | |
| 13 | Musculoskeletal and respiratory disease | | | | | |
| 14 | Ladders not properly placed | | | | | |
| 15 | Waste materials littered on construction site | | | | | |

### 2. Unsafe Acts:

| Sr. No | Factors | Impact | | | | |
|---|---|---|---|---|---|---|
| | | Very low | Low | Moderate | High | Very high |
| 1 | Inappropriate lifting | | | | | |
| 2 | Took unsafe position or posture to do work | | | | | |
| 3 | Lay steel bars against procedure | | | | | |
| 4 | Using faulty machinery or tools | | | | | |
| 5 | Repairing machinery or tools while in use | | | | | |
| 6 | Use machine without safety devices | | | | | |
| 7 | Working with insufficient sleep | | | | | |
| 8 | Tiredness of workers | | | | | |
| 9 | Carelessness and negligence | | | | | |
| 10 | Improper supervision | | | | | |
| 11 | Operated machine at unsafe speed | | | | | |

### 3. Unsafe Conditions:

| Sr. No | Factor | Impact | | | | |
|---|---|---|---|---|---|---|
| | | Very low | Low | Moderate | High | Very high |
| 1 | Insufficient guard rails | | | | | |
| 2 | Failing in guiding co-workers | | | | | |
| 3 | Chemical impairment | | | | | |
| 4 | Defective working tools | | | | | |
| 5 | Absence of caution sign within dangerous areas | | | | | |
| 6 | Poor site management | | | | | |
| 7 | Shortage of procurement planning | | | | | |
| 8 | Site congestion | | | | | |
| 9 | Flying materials | | | | | |
| 10 | Insufficient safety training | | | | | |

## Part-03: External Health and Safety Concerns

Stakeholders are not just the parties who involved at first hand in project construction, any person or entity which can directly or indirectly play its role for fulfillment of project targets are also stakeholders. These contributing factors will have possibility of occurrence and impact on or during project construction.

What do you think that what will be the impact of factors detailed in groups? Please mark one box for impact level.

## 1. Management System and Social Groups:

| Sr. No | Factors | Impact | | | | |
|---|---|---|---|---|---|---|
| | | Very low | Low | Moderate | High | Very high |
| 1 | Lighting arrangements | | | | | |
| 2 | Worksite environment | | | | | |
| 3 | Coordination with subcontractors | | | | | |
| 4 | Poor communication between involved parties | | | | | |
| 5 | Lack of stakeholder's commitment | | | | | |
| 6 | Inadequate policy formation | | | | | |
| 7 | Poor economic policies | | | | | |
| 8 | Slow decision making by stakeholders | | | | | |
| 9 | Payment delays due to client poor financial management | | | | | |
| 10 | Undocumented change orders | | | | | |
| 11 | Improvements in drawings at construction stage | | | | | |

## 2. Natural Factors:

| Sr. No | Factors | Impact | | | | |
|---|---|---|---|---|---|---|
| | | Very low | Low | Moderate | High | Very high |
| 1 | Weather conditions | | | | | |
| 2 | Acts of God | | | | | |
| 3 | Pandemic and viral situations (e.g Covid-19, Influenza, Dengue, Fever) | | | | | |
| 4 | Impact on mental health | | | | | |
| 5 | Efficiency of work | | | | | |
| 6 | Leadership role in crisis management | | | | | |
| 7 | Resources management by organization | | | | | |
| 8 | Social counselling of workers | | | | | |
| 9 | Frequent contact with people | | | | | |
| 10 | Stress and anxiety | | | | | |

# Appendix B

## 1. Relative Importance Index

| Frequency of "5" responses | Frequency of "4" responses | Frequency of "3" responses | Frequency of "2" responses | Frequency of "1" responses | Total respondents (N) | Weighted total | RII |
|---|---|---|---|---|---|---|---|
| 16 | 45 | 37 | 4 | 5 | 107 | 384 | 0.718 |
| 39 | 41 | 7 | 12 | 8 | 107 | 412 | 0.770 |
| 6 | 39 | 49 | 11 | 2 | 107 | 357 | 0.667 |
| 14 | 33 | 45 | 12 | 3 | 107 | 364 | 0.680 |
| 41 | 51 | 5 | 7 | 3 | 107 | 441 | 0.824 |
| 37 | 12 | 41 | 13 | 4 | 107 | 386 | 0.721 |
| 10 | 34 | 45 | 13 | 5 | 107 | 352 | 0.658 |
| 37 | 41 | 13 | 9 | 7 | 107 | 413 | 0.772 |
| 33 | 51 | 3 | 12 | 8 | 107 | 410 | 0.766 |
| 15 | 26 | 47 | 12 | 7 | 107 | 351 | 0.656 |
| 8 | 47 | 43 | 5 | 4 | 107 | 371 | 0.694 |
| 11 | 5 | 46 | 34 | 11 | 107 | 292 | 0.546 |
| 10 | 37 | 47 | 7 | 6 | 107 | 359 | 0.671 |
| 8 | 39 | 51 | 7 | 2 | 107 | 365 | 0.683 |
| 53 | 19 | 26 | 7 | 2 | 107 | 435 | 0.814 |
| **Average** | | | | | | | **0.709** |

| Frequency of "5" responses | Frequency of "4" responses | Frequency of "3" responses | Frequency of "2" responses | Frequency of "1" responses | Total respondents (N) | Weighted total | RII |
|---|---|---|---|---|---|---|---|
| 6 | 35 | 47 | 12 | 7 | 107 | 342 | 0.639 |
| 5 | 17 | 49 | 33 | 3 | 107 | 309 | 0.578 |
| 10 | 17 | 41 | 26 | 13 | 107 | 306 | 0.572 |
| 3 | 48 | 39 | 8 | 9 | 107 | 349 | 0.653 |
| 4 | 49 | 7 | 37 | 10 | 107 | 321 | 0.600 |
| 39 | 47 | 11 | 4 | 6 | 107 | 430 | 0.804 |
| 14 | 41 | 35 | 13 | 4 | 107 | 369 | 0.689 |
| 9 | 13 | 5 | 48 | 32 | 107 | 240 | 0.449 |
| 36 | 52 | 3 | 5 | 11 | 107 | 418 | 0.782 |
| 11 | 37 | 37 | 12 | 10 | 107 | 348 | 0.651 |
| 18 | 30 | 33 | 13 | 13 | 107 | 348 | 0.650 |
| **Average** | | | | | | | **0.643** |

| Frequency of "5" responses | Frequency of "4" responses | Frequency of "3" responses | Frequency of "2" responses | Frequency of "1" responses | Total respondents (N) | Weighted total | RII |
|---|---|---|---|---|---|---|---|
| 38 | 35 | 9 | 13 | 12 | 107 | 395 | 0.739 |
| 7 | 23 | 56 | 13 | 8 | 107 | 329 | 0.615 |
| 8 | 41 | 24 | 23 | 11 | 107 | 333 | 0.623 |
| 10 | 34 | 36 | 18 | 9 | 107 | 339 | 0.634 |
| 22 | 38 | 28 | 11 | 8 | 107 | 376 | 0.703 |
| 38 | 31 | 20 | 8 | 10 | 107 | 400 | 0.748 |
| 13 | 32 | 35 | 21 | 6 | 107 | 346 | 0.647 |
| 40 | 35 | 14 | 13 | 5 | 107 | 413 | 0.772 |
| 10 | 23 | 43 | 25 | 6 | 107 | 327 | 0.612 |
| 34 | 32 | 19 | 12 | 10 | 107 | 389 | 0.728 |
| **Average** | | | | | | | **0.682** |

| Frequency of "5" responses | Frequency of "4" responses | Frequency of "3" responses | Frequency of "2" responses | Frequency of "1" responses | Total respondents (N) | Weighted total | RII |
|---|---|---|---|---|---|---|---|
| 11 | 25 | 37 | 23 | 11 | 107 | 323 | 0.604 |
| 6 | 29 | 40 | 28 | 4 | 107 | 326 | 0.609 |
| 10 | 25 | 46 | 18 | 8 | 107 | 332 | 0.621 |
| 9 | 33 | 42 | 17 | 6 | 107 | 343 | 0.641 |
| 10 | 35 | 36 | 21 | 5 | 107 | 345 | 0.645 |
| 7 | 30 | 26 | 35 | 9 | 107 | 312 | 0.583 |
| 11 | 36 | 29 | 20 | 11 | 107 | 337 | 0.630 |
| 17 | 22 | 33 | 28 | 7 | 107 | 335 | 0.626 |
| 25 | 25 | 22 | 25 | 10 | 107 | 351 | 0.656 |
| 13 | 33 | 30 | 22 | 9 | 107 | 340 | 0.636 |
| 15 | 25 | 33 | 24 | 10 | 107 | 332 | 0.621 |
| **Average** | | | | | | | **0.625** |

| Frequency of "5" responses | Frequency of "4" responses | Frequency of "3" responses | Frequency of "2" responses | Frequency of "1" responses | Total respondents (N) | Weighted total | RII |
|---|---|---|---|---|---|---|---|
| 8 | 26 | 16 | 48 | 9 | 107 | 297 | 0.556 |
| 24 | 14 | 12 | 23 | 34 | 107 | 292 | 0.546 |
| 19 | 23 | 37 | 18 | 10 | 107 | 344 | 0.643 |
| 15 | 32 | 29 | 20 | 11 | 107 | 341 | 0.638 |
| 12 | 4 | 47 | 12 | 32 | 107 | 273 | 0.510 |
| 16 | 31 | 37 | 14 | 9 | 107 | 352 | 0.658 |
| 15 | 33 | 10 | 45 | 4 | 107 | 331 | 0.619 |
| 7 | 33 | 32 | 25 | 10 | 107 | 323 | 0.604 |
| 9 | 25 | 5 | 21 | 47 | 107 | 249 | 0.466 |
| 27 | 41 | 24 | 11 | 4 | 107 | 397 | 0.743 |
| **Average** | | | | | | | **0.598** |

## 2. Pairwise Comparison Matrix

| | A & H | UA | UC | MS | NF |
|---|---|---|---|---|---|
| A & H | 1.000 | 0.709 | 0.709 | 0.709 | 0.709 |
| UA | 1.410 | 1.000 | 1.467 | 0.642 | 0.642 |
| UC | 1.410 | 0.682 | 1.000 | 0.682 | 0.682 |
| MS | 1.410 | 1.556 | 1.466 | 1.000 | 0.625 |
| NF | 1.410 | 1.556 | 1.466 | 1.600 | 1.000 |
| **Sum** | **6.640** | **5.503** | **6.108** | **4.633** | **3.658** |

| | A & H | UA | UC | MS | NF | **Weight** |
|---|---|---|---|---|---|---|
| A & H | 0.15 | 0.129 | 0.116 | 0.159 | 0.194 | **0.150** |
| UA | 0.212 | 0.182 | 0.24 | 0.143 | 0.176 | **0.191** |
| UC | 0.212 | 0.124 | 0.164 | 0.153 | 0.187 | **0.168** |
| MS | 0.212 | 0.283 | 0.24 | 0.224 | 0.17 | **0.226** |
| NF | 0.212 | 0.283 | 0.24 | 0.359 | 0.274 | **0.274** |
| Weight | 0.998 | 1.001 | 1 | 1.038 | 1.001 | |

| **Weight** | **Sum** | **Ans** |
|---|---|---|
| 0.150 | 6.640 | 0.996 |
| 0.191 | 5.503 | 1.051 |
| 0.168 | 6.108 | 1.026 |
| 0.226 | 4.633 | 1.047 |
| 0.274 | 3.658 | 1.002 |
| | **$\lambda_{max}$** | **5.123** |
| | **CI** | **0.0308** |
| | **CR** | **0.0275** |

| | WPA | LWP | PME | EHL | IMS | CBO | COS | FFH | MLH | AGA | IC | WFS | MRD | LNP | WML |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| WPA | 1.000 | 1.299 | 0.718 | 0.718 | 1.214 | 1.387 | 0.718 | 1.296 | 1.289 | 0.718 | 0.718 | 0.718 | 0.718 | 0.718 | 1.220 |
| LWP | 0.770 | 1.000 | 0.770 | 0.770 | 1.214 | 0.770 | 0.770 | 1.296 | 0.770 | 0.770 | 0.770 | 0.770 | 0.770 | 0.770 | 1.220 |
| PME | 1.393 | 1.299 | 1.000 | 1.470 | 1.214 | 1.387 | 0.667 | 1.296 | 1.289 | 0.667 | 1.442 | 0.667 | 1.490 | 1.465 | 1.220 |
| EHL | 1.393 | 1.299 | 0.680 | 1.000 | 1.214 | 1.387 | 0.680 | 1.296 | 1.289 | 1.525 | 1.442 | 0.680 | 0.680 | 1.465 | 1.220 |
| IMS | 0.824 | 0.824 | 0.824 | 0.824 | 1.000 | 0.824 | 0.824 | 0.824 | 0.824 | 0.824 | 0.824 | 0.824 | 0.824 | 0.824 | 0.824 |
| CBO | 0.721 | 1.299 | 0.721 | 0.721 | 1.214 | 1.000 | 0.721 | 1.296 | 1.289 | 0.721 | 0.721 | 0.721 | 0.721 | 0.721 | 1.220 |
| COS | 1.393 | 1.299 | 1.490 | 1.470 | 1.214 | 1.387 | 1.000 | 1.296 | 1.289 | 0.658 | 1.442 | 0.658 | 1.490 | 1.465 | 1.220 |
| FFH | 0.772 | 0.772 | 0.772 | 0.772 | 1.214 | 0.772 | 0.772 | 1.000 | 0.772 | 0.772 | 0.772 | 0.772 | 0.772 | 0.772 | 1.220 |
| MLH | 0.776 | 1.299 | 0.766 | 0.766 | 1.214 | 0.766 | 0.766 | 1.296 | 1.000 | 0.766 | 0.766 | 0.766 | 0.766 | 0.766 | 1.220 |
| AGA | 1.393 | 1.299 | 1.490 | 0.656 | 1.214 | 1.387 | 1.510 | 1.296 | 1.289 | 1.000 | 1.442 | 0.656 | 1.490 | 1.465 | 1.220 |
| IC | 1.393 | 1.299 | 0.693 | 0.693 | 1.214 | 1.387 | 0.693 | 1.296 | 1.289 | 0.693 | 1.000 | 0.693 | 0.693 | 0.693 | 1.220 |
| WFS | 1.393 | 1.299 | 1.490 | 1.470 | 1.214 | 1.387 | 1.510 | 1.296 | 1.289 | 1.525 | 1.442 | 1.000 | 1.490 | 1.465 | 1.220 |
| MRD | 1.393 | 1.299 | 0.671 | 1.470 | 1.214 | 1.387 | 0.671 | 1.296 | 1.289 | 0.671 | 1.442 | 0.671 | 1.000 | 1.465 | 1.220 |
| KNP | 1.393 | 1.299 | 0.682 | 0.682 | 1.214 | 1.387 | 0.682 | 1.296 | 1.289 | 0.682 | 1.442 | 0.682 | 0.682 | 1.000 | 1.220 |
| WML | 0.813 | 0.813 | 0.813 | 0.813 | 1.214 | 0.813 | 0.813 | 0.813 | 0.813 | 0.813 | 0.813 | 0.813 | 0.813 | 0.813 | 1.000 |
| **Sum** | 16.820 | 17.698 | 13.581 | 14.296 | 17.996 | 17.428 | 12.798 | 18.189 | 17.069 | 12.806 | 16.478 | 11.092 | 14.400 | 15.868 | 17.684 |

| | WPA | LWP | PME | EHL | IMS | CBO | COS | FFH | MLH | AGA | IC | WFS | MRD | LNP | WML | **Weight** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| WPA | 0.059 | 0.073 | 0.053 | 0.050 | 0.067 | 0.080 | 0.056 | 0.071 | 0.076 | 0.056 | 0.044 | 0.065 | 0.050 | 0.045 | 0.069 | **0.061** |
| LWP | 0.046 | 0.057 | 0.057 | 0.054 | 0.067 | 0.044 | 0.060 | 0.071 | 0.045 | 0.060 | 0.047 | 0.069 | 0.053 | 0.049 | 0.069 | **0.057** |
| PME | 0.083 | 0.073 | 0.074 | 0.103 | 0.067 | 0.080 | 0.052 | 0.071 | 0.076 | 0.052 | 0.088 | 0.060 | 0.103 | 0.092 | 0.069 | **0.076** |
| EHL | 0.083 | 0.073 | 0.050 | 0.070 | 0.067 | 0.080 | 0.053 | 0.071 | 0.076 | 0.119 | 0.088 | 0.061 | 0.047 | 0.092 | 0.069 | **0.073** |
| IMS | 0.049 | 0.047 | 0.061 | 0.058 | 0.056 | 0.047 | 0.064 | 0.045 | 0.048 | 0.064 | 0.050 | 0.074 | 0.057 | 0.052 | 0.047 | **0.055** |
| CBO | 0.043 | 0.073 | 0.053 | 0.050 | 0.067 | 0.057 | 0.056 | 0.071 | 0.076 | 0.056 | 0.044 | 0.065 | 0.050 | 0.045 | 0.069 | **0.059** |
| COS | 0.083 | 0.073 | 0.110 | 0.103 | 0.067 | 0.080 | 0.078 | 0.071 | 0.076 | 0.051 | 0.088 | 0.059 | 0.103 | 0.092 | 0.069 | **0.080** |
| FFH | 0.046 | 0.044 | 0.057 | 0.054 | 0.067 | 0.044 | 0.060 | 0.055 | 0.045 | 0.060 | 0.047 | 0.070 | 0.054 | 0.049 | 0.069 | **0.055** |
| MLH | 0.046 | 0.073 | 0.056 | 0.054 | 0.067 | 0.044 | 0.060 | 0.071 | 0.059 | 0.060 | 0.046 | 0.069 | 0.053 | 0.048 | 0.069 | **0.058** |
| AGA | 0.083 | 0.073 | 0.110 | 0.046 | 0.067 | 0.080 | 0.118 | 0.071 | 0.076 | 0.078 | 0.088 | 0.059 | 0.103 | 0.092 | 0.069 | **0.081** |
| IC | 0.083 | 0.073 | 0.051 | 0.049 | 0.067 | 0.080 | 0.054 | 0.071 | 0.076 | 0.054 | 0.061 | 0.063 | 0.048 | 0.044 | 0.069 | **0.063** |
| WFS | 0.083 | 0.073 | 0.110 | 0.103 | 0.067 | 0.080 | 0.118 | 0.071 | 0.076 | 0.119 | 0.088 | 0.090 | 0.103 | 0.092 | 0.069 | **0.090** |
| MRD | 0.083 | 0.073 | 0.049 | 0.103 | 0.067 | 0.080 | 0.052 | 0.071 | 0.076 | 0.052 | 0.088 | 0.060 | 0.069 | 0.092 | 0.069 | **0.072** |
| KNP | 0.083 | 0.073 | 0.050 | 0.048 | 0.067 | 0.080 | 0.053 | 0.071 | 0.076 | 0.053 | 0.088 | 0.062 | 0.047 | 0.063 | 0.069 | **0.066** |
| WML | 0.048 | 0.046 | 0.060 | 0.057 | 0.067 | 0.047 | 0.064 | 0.045 | 0.048 | 0.063 | 0.049 | 0.073 | 0.056 | 0.051 | 0.057 | **0.055** |
| **Sum** | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | |

| | IOL | TUP | LBA | UFM | RMI | UMWD | WIS | TF | CN | IS | OMUS |
|---|---|---|---|---|---|---|---|---|---|---|---|
| IOL | 1.000 | 0.639 | 0.639 | 1.533 | 1.667 | 1.245 | 1.440 | 0.639 | 1.270 | 1.536 | 1.538 |
| TUP | 1.565 | 1.000 | 0.578 | 1.533 | 1.667 | 1.245 | 1.440 | 0.578 | 1.270 | 1.536 | 1.538 |
| LBA | 1.565 | 1.732 | 1.000 | 1.533 | 1.667 | 1.245 | 1.440 | 0.572 | 1.270 | 1.536 | 1.538 |
| UFM | 0.652 | 0.652 | 0.652 | 1.000 | 0.652 | 1.245 | 1.440 | 0.652 | 1.270 | 0.652 | 0.652 |
| RMI | 0.600 | 0.600 | 0.600 | 1.533 | 1.000 | 1.245 | 1.440 | 0.600 | 1.270 | 1.536 | 1.538 |
| UM | 0.804 | 0.804 | 0.804 | 0.804 | 0.804 | 1.000 | 0.804 | 0.804 | 0.804 | 0.804 | 0.804 |
| WIS | 0.690 | 0.690 | 0.690 | 0.690 | 0.690 | 1.245 | 1.000 | 0.690 | 1.270 | 1.449 | 1.449 |
| ToF | 1.565 | 1.732 | 1.749 | 1.533 | 1.667 | 1.245 | 1.440 | 1.000 | 1.270 | 1.536 | 1.538 |
| C&N | 0.781 | 0.781 | 0.781 | 0.781 | 0.781 | 1.245 | 0.781 | 0.781 | 1.000 | 0.781 | 0.781 |
| IS | 0.651 | 0.651 | 0.651 | 1.533 | 0.651 | 1.245 | 0.690 | 0.651 | 1.270 | 1.000 | 0.651 |
| OMU | 0.650 | 0.650 | 0.650 | 1.533 | 0.650 | 1.245 | 0.690 | 0.650 | 1.270 | 1.536 | 1.000 |
| **Sum** | 10.524 | 9.932 | 8.794 | 14.006 | 11.897 | 13.450 | 12.604 | 7.617 | 13.234 | 13.902 | 13.027 |

| | IOL | TUP | LBA | UFM | RMI | UMW | WIS | TF | C&N | IS | OMU | **Weight** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| IOL | 0.095 | 0.064 | 0.073 | 0.109 | 0.140 | 0.093 | 0.114 | 0.084 | 0.096 | 0.110 | 0.118 | **0.099** |
| TUP | 0.149 | 0.101 | 0.066 | 0.109 | 0.140 | 0.093 | 0.114 | 0.076 | 0.096 | 0.110 | 0.118 | **0.107** |
| LBA | 0.149 | 0.174 | 0.114 | 0.109 | 0.140 | 0.093 | 0.114 | 0.075 | 0.096 | 0.110 | 0.118 | **0.118** |
| UFM | 0.062 | 0.066 | 0.074 | 0.071 | 0.055 | 0.093 | 0.114 | 0.086 | 0.096 | 0.047 | 0.050 | **0.074** |
| RMI | 0.057 | 0.060 | 0.068 | 0.109 | 0.084 | 0.093 | 0.114 | 0.079 | 0.096 | 0.110 | 0.118 | **0.090** |
| UMW | 0.076 | 0.081 | 0.091 | 0.057 | 0.068 | 0.074 | 0.064 | 0.106 | 0.061 | 0.058 | 0.062 | **0.073** |
| WIS | 0.066 | 0.069 | 0.078 | 0.049 | 0.058 | 0.093 | 0.079 | 0.091 | 0.096 | 0.104 | 0.111 | **0.081** |
| TF | 0.149 | 0.174 | 0.199 | 0.109 | 0.140 | 0.093 | 0.114 | 0.131 | 0.096 | 0.110 | 0.118 | **0.130** |
| CN | 0.074 | 0.079 | 0.089 | 0.056 | 0.066 | 0.093 | 0.062 | 0.103 | 0.076 | 0.056 | 0.060 | **0.073** |
| IS | 0.062 | 0.066 | 0.074 | 0.109 | 0.055 | 0.093 | 0.055 | 0.085 | 0.096 | 0.072 | 0.050 | **0.075** |
| OMU | 0.062 | 0.065 | 0.074 | 0.109 | 0.055 | 0.093 | 0.055 | 0.085 | 0.096 | 0.110 | 0.077 | **0.080** |
| **Sum** | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | |

| | IGR | FGW | CI | DWT | ACS | PSM | SPP | SC | FM | IST |
|---|---|---|---|---|---|---|---|---|---|---|
| IGR | 1.000 | 0.738 | 0.738 | 0.738 | 0.738 | 1.338 | 0.738 | 1.296 | 0.738 | 0.738 |
| FGW | 1.355 | 1.000 | 1.607 | 1.579 | 1.423 | 1.338 | 1.547 | 1.296 | 0.615 | 1.376 |
| CI | 1.355 | 0.622 | 1.000 | 1.579 | 1.423 | 1.338 | 1.547 | 1.296 | 0.622 | 1.376 |
| DWT | 1.355 | 0.634 | 0.634 | 1.000 | 1.423 | 1.338 | 1.547 | 1.296 | 0.634 | 1.376 |
| ACS | 1.355 | 0.703 | 0.703 | 0.703 | 1.000 | 1.338 | 0.703 | 1.296 | 0.703 | 1.376 |
| PSM | 0.748 | 0.748 | 0.748 | 0.748 | 0.748 | 1.000 | 0.748 | 1.296 | 1.338 | 1.338 |
| SPP | 1.355 | 0.647 | 0.647 | 0.647 | 1.423 | 1.338 | 1.000 | 1.296 | 0.647 | 1.376 |
| SC | 0.772 | 0.772 | 0.772 | 0.772 | 0.772 | 0.772 | 0.772 | 1.000 | 0.772 | 0.772 |
| FM | 1.355 | 1.627 | 1.607 | 1.579 | 1.423 | 0.748 | 1.547 | 1.296 | 1.000 | 1.376 |
| IST | 1.355 | 0.727 | 0.727 | 0.727 | 0.727 | 0.748 | 0.727 | 1.296 | 0.727 | 1.000 |
| **Sum** | 12.005 | 8.218 | 9.182 | 10.072 | 11.100 | 11.295 | 10.876 | 12.664 | 7.796 | 12.104 |

| | IGR | FGW | CI | DWT | ACS | PSM | SPP | SC | FM | IST | **Weight** |
|---|---|---|---|---|---|---|---|---|---|---|---|
| IGR | 0.083 | 0.090 | 0.080 | 0.073 | 0.067 | 0.118 | 0.068 | 0.102 | 0.095 | 0.061 | **0.084** |
| FGW | 0.113 | 0.122 | 0.175 | 0.157 | 0.128 | 0.118 | 0.142 | 0.102 | 0.079 | 0.114 | **0.125** |
| CI | 0.113 | 0.076 | 0.109 | 0.157 | 0.128 | 0.118 | 0.142 | 0.102 | 0.080 | 0.114 | **0.114** |
| DWT | 0.113 | 0.077 | 0.069 | 0.099 | 0.128 | 0.118 | 0.142 | 0.102 | 0.081 | 0.114 | **0.104** |
| ACS | 0.113 | 0.086 | 0.077 | 0.070 | 0.090 | 0.118 | 0.065 | 0.102 | 0.090 | 0.114 | **0.093** |
| PSM | 0.062 | 0.091 | 0.081 | 0.074 | 0.067 | 0.089 | 0.069 | 0.102 | 0.172 | 0.111 | **0.092** |
| SPP | 0.113 | 0.079 | 0.070 | 0.064 | 0.128 | 0.118 | 0.092 | 0.102 | 0.083 | 0.114 | **0.096** |
| SC | 0.064 | 0.094 | 0.084 | 0.077 | 0.070 | 0.068 | 0.071 | 0.079 | 0.099 | 0.064 | **0.077** |
| FM | 0.113 | 0.198 | 0.175 | 0.157 | 0.128 | 0.066 | 0.142 | 0.102 | 0.128 | 0.114 | **0.132** |
| IST | 0.113 | 0.088 | 0.079 | 0.072 | 0.066 | 0.066 | 0.067 | 0.102 | 0.093 | 0.083 | **0.083** |
| **Sum** | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | |

| | LA | WE | CWS | PC | LSC | IPF | PEP | SDMS | PD | UCO | IDCS |
|---|---|---|---|---|---|---|---|---|---|---|---|
| LA | 1.000 | 1.641 | 1.610 | 1.559 | 1.550 | 0.604 | 1.588 | 1.597 | 1.525 | 1.574 | 1.612 |
| WE | 0.609 | 1.000 | 1.610 | 1.559 | 1.550 | 0.609 | 1.588 | 1.597 | 1.525 | 1.574 | 1.612 |
| CWS | 0.621 | 0.621 | 1.000 | 1.559 | 1.550 | 0.621 | 1.588 | 1.597 | 1.525 | 1.574 | 0.621 |
| PC | 0.641 | 0.641 | 0.641 | 1.000 | 1.550 | 0.641 | 0.641 | 0.641 | 1.525 | 0.641 | 0.641 |
| LSC | 0.645 | 0.645 | 0.645 | 0.645 | 1.000 | 0.645 | 0.645 | 0.645 | 1.525 | 0.645 | 0.645 |
| IPF | 1.551 | 1.641 | 1.610 | 1.559 | 1.550 | 1.000 | 1.588 | 1.597 | 1.525 | 1.574 | 1.612 |
| PEP | 0.630 | 0.630 | 0.630 | 1.559 | 1.550 | 0.630 | 1.000 | 0.630 | 1.525 | 1.574 | 0.630 |
| SDM | 0.626 | 0.626 | 0.626 | 1.559 | 1.550 | 0.626 | 1.588 | 1.000 | 1.525 | 1.574 | 0.626 |
| PD | 0.656 | 0.656 | 0.656 | 0.656 | 0.656 | 0.656 | 0.656 | 0.656 | 1.000 | 0.656 | 0.656 |
| UCO | 0.636 | 0.636 | 0.636 | 1.559 | 1.550 | 0.636 | 0.636 | 0.636 | 1.525 | 1.000 | 0.636 |
| IDC | 0.621 | 0.621 | 1.610 | 1.559 | 1.550 | 0.621 | 1.588 | 1.597 | 1.525 | 1.574 | 1.000 |
| **Sum** | 8.235 | 9.357 | 11.275 | 14.773 | 15.606 | 7.288 | 13.106 | 12.192 | 16.250 | 13.960 | 10.291 |

| | LA | WE | CWS | PC | LSC | IPF | PEP | SDM | PD | UCO | IDC | **Weight** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| LA | 0.121 | 0.175 | 0.143 | 0.106 | 0.099 | 0.083 | 0.121 | 0.131 | 0.094 | 0.113 | 0.157 | **0.122** |
| WE | 0.074 | 0.107 | 0.143 | 0.106 | 0.099 | 0.084 | 0.121 | 0.131 | 0.094 | 0.113 | 0.157 | **0.112** |
| CWS | 0.075 | 0.066 | 0.089 | 0.106 | 0.099 | 0.085 | 0.121 | 0.131 | 0.094 | 0.113 | 0.060 | **0.095** |
| PC | 0.078 | 0.069 | 0.057 | 0.068 | 0.099 | 0.088 | 0.049 | 0.053 | 0.094 | 0.046 | 0.062 | **0.069** |
| LSC | 0.078 | 0.069 | 0.057 | 0.044 | 0.064 | 0.088 | 0.049 | 0.053 | 0.094 | 0.046 | 0.063 | **0.064** |
| IPF | 0.188 | 0.175 | 0.143 | 0.106 | 0.099 | 0.137 | 0.121 | 0.131 | 0.094 | 0.113 | 0.157 | **0.133** |
| PEP | 0.076 | 0.067 | 0.056 | 0.106 | 0.099 | 0.086 | 0.076 | 0.052 | 0.094 | 0.113 | 0.061 | **0.081** |
| SDM | 0.076 | 0.067 | 0.056 | 0.106 | 0.099 | 0.086 | 0.121 | 0.082 | 0.094 | 0.113 | 0.061 | **0.087** |
| PD | 0.080 | 0.070 | 0.058 | 0.044 | 0.042 | 0.090 | 0.050 | 0.054 | 0.062 | 0.047 | 0.064 | **0.060** |
| UCO | 0.077 | 0.068 | 0.056 | 0.106 | 0.099 | 0.087 | 0.048 | 0.052 | 0.094 | 0.072 | 0.062 | **0.075** |
| IDC | 0.075 | 0.066 | 0.143 | 0.106 | 0.099 | 0.085 | 0.121 | 0.131 | 0.094 | 0.113 | 0.097 | **0.103** |
| **Sum** | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | |

| | WC | AG | PVS | IMH | EW | LRC | RM | SCW | FC | SA |
|---|---|---|---|---|---|---|---|---|---|---|
| WC | 1.000 | 0.555 | 1.556 | 1.569 | 0.555 | 1.066 | 1.617 | 1.657 | 0.555 | 1.348 |
| AG | 1.802 | 1.000 | 1.556 | 1.569 | 0.546 | 1.066 | 1.617 | 1.657 | 0.546 | 1.348 |
| PVS | 0.643 | 0.643 | 1.000 | 0.643 | 0.643 | 1.066 | 0.643 | 0.643 | 0.643 | 1.348 |
| IMH | 0.637 | 0.637 | 1.556 | 1.000 | 0.637 | 1.066 | 0.637 | 0.637 | 0.637 | 1.348 |
| EW | 1.802 | 1.833 | 1.556 | 1.569 | 1.000 | 1.066 | 1.617 | 1.657 | 0.510 | 1.348 |
| LRC | 0.658 | 0.658 | 0.658 | 0.658 | 0.658 | 1.000 | 0.658 | 0.658 | 0.658 | 1.348 |
| RM | 0.619 | 0.619 | 1.556 | 1.569 | 0.619 | 1.066 | 1.000 | 0.619 | 0.619 | 1.348 |
| SCW | 0.604 | 0.604 | 1.556 | 1.569 | 0.604 | 1.066 | 1.617 | 1.000 | 0.604 | 1.348 |
| FC | 1.802 | 1.833 | 1.556 | 1.569 | 1.950 | 1.066 | 1.617 | 1.657 | 1.000 | 1.348 |
| SA | 0.742 | 0.742 | 0.742 | 0.742 | 0.742 | 0.742 | 0.742 | 0.742 | 0.742 | 1.000 |
| **Sum** | 10.309 | 9.124 | 13.292 | 12.457 | 7.954 | 10.270 | 11.765 | 10.927 | 6.514 | 13.132 |

| | WC | AG | PVS | IMH | EW | LRC | RM | SCW | FC | SA | **Weight** |
|---|---|---|---|---|---|---|---|---|---|---|---|
| WC | 0.097 | 0.061 | 0.117 | 0.126 | 0.070 | 0.104 | 0.137 | 0.152 | 0.085 | 0.103 | **0.105** |
| AG | 0.175 | 0.110 | 0.117 | 0.126 | 0.069 | 0.104 | 0.137 | 0.152 | 0.084 | 0.103 | **0.118** |
| PVS | 0.062 | 0.070 | 0.075 | 0.052 | 0.081 | 0.104 | 0.055 | 0.059 | 0.099 | 0.103 | **0.076** |
| IMH | 0.062 | 0.070 | 0.117 | 0.080 | 0.080 | 0.104 | 0.054 | 0.058 | 0.098 | 0.103 | **0.083** |
| EW | 0.175 | 0.201 | 0.117 | 0.126 | 0.126 | 0.104 | 0.137 | 0.152 | 0.078 | 0.103 | **0.132** |
| LRC | 0.064 | 0.072 | 0.049 | 0.053 | 0.083 | 0.097 | 0.056 | 0.060 | 0.101 | 0.103 | **0.074** |
| RM | 0.060 | 0.068 | 0.117 | 0.126 | 0.078 | 0.104 | 0.085 | 0.057 | 0.095 | 0.103 | **0.089** |
| SCW | 0.059 | 0.066 | 0.117 | 0.126 | 0.076 | 0.104 | 0.137 | 0.092 | 0.093 | 0.103 | **0.097** |
| FC | 0.175 | 0.201 | 0.117 | 0.126 | 0.245 | 0.104 | 0.137 | 0.152 | 0.154 | 0.103 | **0.151** |
| SA | 0.072 | 0.081 | 0.056 | 0.060 | 0.093 | 0.072 | 0.063 | 0.068 | 0.114 | 0.076 | **0.076** |
| **Sum** | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | |

## 3. Consistency

| Weight | Sum | Ans |
|---|---|---|
| 0.061 | 16.820 | 1.026 |
| 0.057 | 17.698 | 1.002 |
| 0.076 | 13.581 | 1.035 |
| 0.073 | 14.296 | 1.048 |
| 0.055 | 17.996 | 0.983 |
| 0.059 | 17.428 | 1.020 |
| 0.080 | 12.798 | 1.026 |
| 0.055 | 18.189 | 0.995 |
| 0.058 | 17.069 | 0.997 |
| 0.081 | 12.806 | 1.036 |
| 0.063 | 16.478 | 1.035 |
| 0.090 | 11.092 | 0.993 |
| 0.072 | 14.400 | 1.043 |
| 0.066 | 15.868 | 1.039 |
| 0.055 | 17.684 | 0.980 |
| | **$\lambda_{max}$** | **15.256** |
| | **CI** | **0.0182** |
| | **CR** | **0.0115** |

| Weight | Sum | Ans |
|---|---|---|
| 0.099 | 10.524 | 1.042 |
| 0.107 | 9.932 | 1.058 |
| 0.118 | 8.794 | 1.034 |
| 0.074 | 14.006 | 1.036 |
| 0.090 | 11.897 | 1.070 |
| 0.073 | 13.450 | 0.975 |
| 0.081 | 12.604 | 1.025 |
| 0.130 | 7.617 | 0.993 |
| 0.073 | 13.234 | 0.966 |
| 0.075 | 13.902 | 1.043 |
| 0.080 | 13.027 | 1.044 |
| | **$\lambda_{max}$** | **11.285** |
| | **CI** | **0.0285** |
| | **CR** | **0.0189** |

| Weight | Sum | Ans |
|---|---|---|
| 0.084 | 12.005 | 1.006 |
| 0.125 | 8.218 | 1.027 |
| 0.114 | 9.182 | 1.046 |
| 0.104 | 10.072 | 1.052 |
| 0.093 | 11.100 | 1.032 |
| 0.092 | 11.295 | 1.037 |
| 0.096 | 10.876 | 1.048 |
| 0.077 | 12.664 | 0.975 |
| 0.132 | 7.796 | 1.032 |
| 0.083 | 12.104 | 1.004 |
| | **$\lambda_{max}$** | **10.259** |
| | **CI** | **0.028** |
| | **CR** | **0.0187** |

| Weight | Sum | Ans |
|---|---|---|
| 0.122 | 8.235 | 1.005 |
| 0.112 | 9.357 | 1.044 |
| 0.095 | 11.275 | 1.066 |
| 0.069 | 14.773 | 1.023 |
| 0.064 | 15.606 | 1.001 |
| 0.133 | 7.288 | 0.970 |
| 0.081 | 13.106 | 1.056 |
| 0.087 | 12.192 | 1.064 |
| 0.060 | 16.250 | 0.976 |
| 0.075 | 13.960 | 1.042 |
| 0.103 | 10.291 | 1.058 |
| | **$\lambda_{max}$** | **11.305** |
| | **CI** | **0.0305** |
| | **CR** | **0.020** |

| **Weight** | **Sum** | **Ans** |
|---|---|---|
| 0.105 | 10.309 | 1.084 |
| 0.118 | 9.124 | 1.072 |
| 0.076 | 13.292 | 1.009 |
| 0.083 | 12.457 | 1.029 |
| 0.132 | 7.954 | 1.049 |
| 0.074 | 10.270 | 0.758 |
| 0.089 | 11.765 | 1.049 |
| 0.097 | 10.927 | 1.062 |
| 0.151 | 6.514 | 0.986 |
| 0.076 | 13.132 | 0.992 |
| | $\lambda_{max}$ | **10.089** |
| | **CI** | **0.001** |
| | **CR** | **0.00006** |