# High Rise Building Construction Safety Risk Modelling in Addis Ababa

Abebe Bizualem

**A Thesis Submitted to the Department of Civil Engineering School of Civil Engineering and Architecture**

**Presented in Partial Fulfillment of the Requirement for the Degree of Master's in Civil engineering (Specialization in Construction Engineering and Management)**

**Office of Graduate Studies**

**Adama Science and Technology University**

**Adama, Ethiopia**

**September 2022**

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# DECLARATION

I hereby declare that this Master Thesis entitled "High Rise Building Construction Onsite Safety Risk Modelling in Addis Ababa" is my original work. That is, it has not been submitted for the award of any academic degree, diploma or certificate in any other university. All sources of materials that are used for this thesis have been duly acknowledged through citation.

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# RECOMMENDATION

I, the advisor of this thesis, hereby certify that I have read the revised version of the thesis entitled "High Rise Building Construction Onsite Safety Risk Modelling in Addis Ababa" prepared under my guidance by Abebe Bizualem submitted in partial fulfillment of the requirements for the degree of Mater's of Science in Construction Engineering and Management.

Therefore, I recommend the submission of revised version of the thesis to the department following the applicable procedures.

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# ABSTRACT

*With an increase in number of high-rise buildings in Addis Ababa, safety issues are becoming a main concern as construction of high-rise buildings is more risk prone than conventional buildings. Safety risks related to the construction of high-rise buildings has not been identified and prioritized along with the determination of which construction phase is risky. Moreover, there has been a lack of research that separately studies foreign contractors' held and local contractors' held construction sites. Past studies have been focusing on evaluating and/or assessing the existing safety practices of contractors. They failed to identify and prioritize the most important safety risks and which construction phase is more likely exposed to these safety risks and compare it between local and foreign contractor held construction sites. The aim of the study is to prioritize safety risks and determine the most risky construction phase using Analytical Network Process (ANP) modeling technique and compare the result between local and foreign contractors held sites in Addis Ababa. The results show that in case of local contractors; Sub-structure phase is the most risky phase and falling from height, falling objects, slips, trips, and falls, and trench failure/excavation accident are the top four most important safety risk factors. In case of foreign contractors, super-structure is determined to be the most risky phase and falling objects, falling from height, slips, trips and falls, and trench failure/excavation accident are the top four most important safety risks. These shows that much of safety related risks happen most likely during sub-structure phase in local contractors' case and in case of foreign contractors it is super-structure phase that is most likely exposed to safety related risks. Moreover, new safety risks that are prevalent in Ethiopian context have been identified from literature, i.e., caught in between/compressed by equipment or objects, repetitive motion, and manual handling are identified in this thesis. The results can be used by safety managers and/or their team to focus on these safety risks and these construction phases to minimize them to a certain degree to better manage safety before any loss or damage had happened.*

*Key words: safety risks, high-rise buildings, ANP modeling, local and foreign contractors.*

# APPROVAL PAGE

I, the advisors of the thesis entitled "High Rise Building Construction Onsite Safety Risk Modelling in Addis Ababa" and developed by Abebe Bizualem hereby certify that the recommendation and suggestions made by the board of examiners are appropriately incorporated into the final version of the thesis.

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We, the undersigned, members of the Board of Examiners of the thesis by Abebe Bizualem have read and evaluated the thesis entitled "High Rise Building Construction Onsite Safety Risk Modelling in Addis Ababa" and examined the candidate during open defense. This is, therefore, to certify that the thesis is accepted for partial fulfillment of the requirement of the degree of Master of Science in Construction Engineering and Management.

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Final approval and acceptance of the thesis is contingent upon submission of its final copy to the Office of Postgraduate Studies (OPGS) through the Department Graduate Council (DGC) and School Graduate Committee (SGC).

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| Office of Postgraduate Studies, Dean | Signature | Date |

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I would like to thank my family, brothers and sisters, for their continuous support. My mommy Eneye for your advices and Daddy for you moral support, you will live with me forever. I would also like to thank Adama Science and Technology University for the opportunity to extend my education and knowledge in this field and I would really like to thank my Advisor Dr Fikreyesus Demeke for his remarkable comments and follow ups throughout the conducting of this thesis. I would also like to extend my deepest appreciation to Addis Ababa city Construction Permit and Control Authority for their kind and humble services. Thank you all individuals who directly and indirectly help this study to become a reality.

Table of Contents

# LIST OF TABLES

# LIST OF FIGURES

# LIST OF ACRONYMS

MCDM………………… Multi-Criteria Decision Making

MoUDC………………...Ministry of Urban Development and Construction

GDP…………………….Gross Domestic Product

CDM……………………Construction Design and Management

OSHA…………………..Occupational Safety and Health Association

ILO……………………...International Labor Organization

PMI……………………..Project Management Institute

PMBOK………………...Project Management Body of Knowledge

WBS……………………Work Breakdown Structure

RBS……………………..Risk Breakdown Structure

SMART…………………Simple Multi-attribute Rating Technique

ELECTRE………………Elimination Et Choix Traduisant la Realite

PROMETHEE………….Preference Ranking Organization Method for Enrichment Evaluation

DEMATEL……………..Decision Making Trial and Evaluation Laboratory

ANP…………………….Analytic Network Process

AHP…………………….Analytical Hierarchical Process

# CHAPTER ONE

# INTRODUCTION

## 1.1. Background of the study

Globally, the construction industry has a remarkable influence on economic growth. A country will achieve its social development, industrialization, freight transportation, sustainable development, and urbanization goals if the construction industry produces adequate buildings and infrastructures (Wesam Salah Aloul etal 2021). Despite its great use, the construction industry has the greatest risk of injury of any major industries in the world (Lehtola et al., 2008). According to the International Labor Organization (ILO), over 270 million occupational accidents occur each year, resulting in two million deaths (ILO, 2016) which costs the world's economy 4% of its gross domestic product (GDP) (USD 1.25 trillion). Occupational injuries can have both direct costs, such as hospital and diagnostic payments, as well as indirect costs on families and society (Tadesse and Israel, 2016). Occupational injuries can cost employers a lot of money, put a strain on healthcare providers, and have a negative impact on the long-term health and socioeconomic status of injured workers. According to studies (Zemachu Ashuro et al., 2019; Muizz O.Sanni et al., 2019; Fantahun Berhanu et al., 2019; Tewodros Bekele Tolera, 2016; Mesafint Molla et al., 2013), illnesses, traumatic injuries, and fatalities are more common among construction workers than in other industries. The risk of death in the construction industry is five times that of manufacturing, while the risk of serious injury is two and a half times that of manufacturing (Sawacha et al., 1999).

Though the construction industry typically makes up to 11% of the GDP in developing countries (Giang and Pheng, 2010), Construction accident is much worse in developing countries and sub-Sahara Africa and it is escalating even worse (Patrick Manu et al., 2018). And since Ethiopia is one of those developing countries the construction industry is one of fastest growing industries and a great contributor to Ethiopia's economy. It contributes a total GDP of Birr 8,185,747,000 at an average annual growth rate of 12.43% (MoUDC, 2019). But just like the rest of the world Ethiopian construction industry also suffers great amount of injuries and accidents of workers. According to Hanna Mersha et al (2017), injuries at construction site were reported to be 68.9% were injured in more than one way, 36.2% cuts and 26.6% abrasions, 46.1 % sharp instrument injuries, 37.3 % fall accidents, 8.9 % and injuries caused by falling, splinting, or splashing objects.

The majority, 86.7 %, were absent from work for 7 days or less (Hanna Mersha et al., 2017,). These staggering research results shows how serious onsite injuries can happen at a great scale.

One of the reasons that makes the construction industry so risk prone is that it involves diversified working parties. Every construction site necessitates the use of machinery in order to create, adapt, and maintain a safe and productive working environment because they move resources in and around construction projects, as well as perform some tasks that humans cannot do efficiently or at all. Of course, the majority of the machinery is determined by the type of construction and the scope of the project. Heavy machinery is dangerous and must be handled professionally, with appropriate safety precautions in place. These machineries include diggers, loaders and movers, transporters and lifters. Improper handling of these heavy machineries or collision of them will result in devastating accident both in the machineries and peoples around. Due to this diversification of human labors, and equipment the construction site suffers many fatal accidents that are not common in other industries. In both developed and developing countries, occupational injuries have been identified as one of the most significant crippling factors contributing to disabilities and life-threatening situations (Majori et al, 2002). The construction industry has a high level of occupational risk, as well as a high rate of occupational accidents, occupational diseases, and absenteeism. Construction workers are more vulnerable to mechanical, biological, chemical, and ergonomic hazards. Workplace injuries and fatalities in the construction industry have also been linked to high financial costs. Because of outdoor activities, work-at-height, intricate on-site plant machinery and equipment operation, and worker attitudes and behaviors toward safety, construction is always risky (Choudhry and Fang, 2007). And with lack of space and high migration rate into the capital Addis Ababa, high-rise buildings help to solve housing problems the city is currently facing. It also helps to build the image of the city. But high-rise building comes with high risk both in safety and other risk related areas because the more sophisticated a task is the more difficult more risky it becomes. The construction industry is prone to risk more than other industries, with high-rise buildings and skyscrapers added the safety risk goes even higher than common conventional buildings which can’t be categorized under high-rise building.

Since the study is focused on high-rise building construction, it is a necessity to incorporate foreign contractors as they play a huge role in building high-rise projects in Ethiopia including the tallest building in east Africa i.e. commercial bank of Ethiopia headquarters (Girma Geremew 2018, Fasil

Argaw 2017). According to Girma Geremew there is a difference in implementing safety practice between foreign and local contractors (Girma Geremew, 2018). This study wants to push safety management further by identifying and prioritizing safety risks and determining which phase is risky and which safety risk is important and compare the result between locals and foreign contractors. The comparison is done to determine by how much do both local and foreign contractors suffer each safety risk and provide a quantitative data for those who want to compare their safety risk rankings. This allows both local and foreign contractors that are participating in high-rise construction which safety risks are the most important ones and focus on them to minimize overall loss or damage before it happen and to focus on that phase which is more likely exposed to these safety risks than others.

Risk affects all undertakings, regardless of how thoroughly planned they are. The future cannot be anticipated with absolute confidence, but a framework or a model can be created to help deal with any unpleasant surprises that may arise during the course of a project. Risk modeling helps in the identification, analysis, and mitigation of risks to be well prepared to deal with them if they arise.

This thesis models (prioritizes) safety risks using ANP modeling technique that determines which safety risk is more important than others, and which construction phase among substructure, superstructure, and finishing works is more risky than others in high-rise buildings in Addis Ababa and compare the results between local and foreign held high-rise building construction sites.

## 1.2. Statement of the problem

The ILO estimates show that about 2.3million workers suffer from work related injuries globally every year. Which corresponds to 6,000 deaths every single year. The construction industry again had the highest number of fatalities of all industries in 2019 with 1,061 worker deaths (ILO, 2019). This is a 5.3% increase over the 1,008 fatal injuries in 2018. It's the highest total since 2007 when the industry recorded 1,204 fatal work injuries. The construction industry represented 21.6% of all private industry worker deaths in 2019 (ILO, 2019). Occupational injuries and accidents are dramatically increasing in Africa with the construction sector leading in 57% of all injury reports (Mitiku Bonsa et al., 2021). When it comes to Ethiopia, the construction industry had a 15% growth and contributed 72.5% of industrial output, showing its dominant position in the construction of roads, dams, and residential homes (NBE, 2019). Nearly 6.5 million people work at approximately 252,000 construction sites across the nation on any day (OSHA, 2005).

Most of the construction industry employees were less educated, none or semiskilled, untrained, and inexperienced with the tools and the hazards associated with the construction which can increase the risk of work-related injuries. The risk of construction workers is not decreasing as expected rather it is escalating to a degree that levels the construction industry as the most risky of all industries both globally and nationally (Amanual Tsegaye 2022).

In order to solve this problem, researches has been done so far both globally and nationally mainly by focusing on evaluating, assessing, and investigating safety practices from occupational health perspective only (Zemachu Ashuro et al., 2019; Muizz O.Sanni et al., 2019; Fantahun Berhanu et al., 2019; Tewodros Bekele Tolera 2016; Mesafint Molla et al., 2013; Hanish Verma and Neha Verma 2017; Geremew Tarekegn 2020). So far, site safety is considered to be increased by just employing more and more safety practices and packages, i.e. without considering safety risks identification and proper prioritization/modeling to minimize important ones, but this way of managing safety of workers has not been so effective (Hallowel et al., 2007). Risks associated with safety of workers has to be identified, assessed, and prioritized in order to properly manage and mitigate them and select safety programs and packages that enables to prevent those important ones and significantly decrease loss. In order to do so, the most important safety risks were not identified and prioritized along with determination of which construction phase is risky, thus enabling which safety risk factor and which construction phase to focus on to minimize overall safety risk of workers. There is lack of researches in identifying, measuring, and modeling safety risks of high-rise building constructions in Ethiopia. And since there are foreign contractors that have a huge role in construction of high-rise buildings in Ethiopia and their safety practice is different from those of local contractors, this prioritization of safety risks should include them. Most of the researches in Ethiopia are focused on safety practices of conventional (non-high-rise) buildings and they are not focused on prioritizing safety risks. Moreover, they do not make any distinction between foreign contractor held and local contractor held construction sites which will help expertise in safety management to compare the results and determine by how much each safety risk factors are prevalent or dominant in both local and foreign contractor held sites.

## 1.3 Objective of the study

### 1.3.1. General objective of the study

The general objective of the study is to develop high-rise building construction site safety risk model that determines the most important safety risk factor along with the most risky construction phase among substructure, superstructure and finishing phases.

### 1.3.2. Specific objectives of the study

- To identify safety risks at high-rise building construction sites in Addis Ababa.
- To determine the most important safety risk and the most risky construction phase in local contractors and foreign contractors held construction sites.
- To compare the results between local contractors and foreign contractors held construction sites and determine which one suffers more in each safety risk than others and by how much.

## 1.4. Research questions

The questions that gave rise to the conduct of this research are:-

1) What are construction onsite safety risks in high-rise buildings?
2) Which safety risk and which construction phase are the most important ones in local contractors and foreign contractors held construction sites?
3) Which safety risk and which construction phase is the most important among foreign and local contractors held sites and by how much do they suffer each safety risks?

## 1.5. Significance of the study

The research is focused on identifying major safety risk factors, and prioritize them to determine which of those risk factors are most important, and simultaneously determine which construction phase among substructure, superstructure and finishing is more risk prone. This enables safety managers to identify which safety risk factors to reduce or to focus on and which phase during the construction of the project should have high concern to safety risk than others. New safety risks has been introduced for prioritization. The result will provide an insight in making safety policies and provisions about specific safety risk factors than others. And since the study distinguishes between local contractor held and foreign contractor held sites, the final result helps both local and foreign contractors to determine which safety risk and construction phase is prominent in their respective sites and know by how much they share the same risk or the results will help those who wants to compare safety risks between local and foreign contractors in Addis Ababa. Determining which safety risk is important than others gives an insight in what safety practice or package better helps to decrease that risk, giving the safety management team an effective tool to select safety program that better address those important safety risks and reduce overall lose.

## 1.6. Scope and limitation of the study

The scope of the research is limited to active construction sites that are found in Addis Ababa, Ethiopia. The author choose Addis Ababa because most of high rise building projects in Ethiopia are found in the capital. The technical scope of the research is modeling safety risk factors on high rise building construction sites.

## 1.7. Organization of the paper

Chapter one: Introduction and Background of the study

This chapter gives an overall background about the research and states the problem and the objectives to be met after the completion of the study. It raises research questions and describes the significance of the study along with limitations and scope of this study.

Chapter two: Literature Review about the study

This chapter has two parts. The first part gives a theoretical literature review and the second one is an empirical review where past studies related to the topic of the study are reviewed.

Chapter three: Methodology of the study

In this chapter method of conducting the research, data collection, data analysis, population and sampling are discussed along with methods of checking validity and reliability of the results.

Chapter four: Result and Discussion of the study

This chapter contains the results of the study which is presented in tabular form and discusses these results.

Chapter five: Conclusion and Recommendation

This is the final chapter of the study where conclusions are drawn from result and discussion parts that meet the objectives set out in chapter one of this study. After drawing conclusions recommendations are made for future research.

# CHAPTER TWO

# LITERATURE REVIEW

## 2.1. Introduction

This chapter has two main parts. The first section presents the concept or the main ideas of different works of literature about safety risk modeling and risk management process generally. It deals with the relationship between safety risk, hazards, accidents, and also gives a clear overview about safety risk modeling and ANP modeling technique. The second part is an empirical review in which past studies are reviewed and presented that led to the study gap of this research.

## 2.2. The Construction industry

Construction transforms a wide range of resources into social, economic, and environmental infrastructures. It is one of the most powerful industries on a global and national scale. It also has a significant workforce. The construction industry is estimated that it employs over 220 million people, or about 7% of the total global workforce (ILO 2019). All countries' GDP is boosted by the construction industry (Wesam Salah et al., 2021). Like all other nations on the globe, Ethiopia's construction industry is one of the major drivers of economic growth. Massive government investment in infrastructure and residential construction projects is propelling the country to the top of the continent's economic rankings. Construction accounts for 50% of total amount of Ethiopia's industry, according to the National Bank of Ethiopia (NBE 2021). Moreover, the industry is quickly developing, and according to NBE data, the construction industry gained 37% growth in 2013/14 (NBE 2021). The construction industry grew by 6.6 percent, accounting for 72.2% of total industrial output, with roads, trains, dams, and residential housing building all contributing significantly (NBE 2021). Rapid urbanization has created a great need for improved infrastructural systems. The country has one of the most robust construction industries in Africa and the conditions are ideal for a construction boom across the country. The Ethiopian government is quite interested in modernizing and creating new infrastructure links, residential complexes, and so on. Indeed, the nation's Second Growth and Transformation Plan prioritizes development in these regions i.e. construction sector (GTP II Growth and Transformation Plan II) (ITE builds and interior report 2019). These data shows that the construction industry in Ethiopia is transforming to building high-rise buildings to meet its goals and serve the need of its peoples (ITE builds and interior report 2019).

## 2.3. Definition and use of high-rise buildings

A building is a structure with an enclosed surface that has walls, floors, a roof, and usually doors and windows. Buildings can be classified into different categories depending different criteria. But, depending on height, buildings can be classified into 6 categories (He Sijia etal 2019). The first classification is as low-rise buildings which have 1-3 floors and a maximum height of 9meters, buildings that have floor number from 4-6 and height of 9-21meters are labeled as multi-story building, buildings that have a floor number of 7-9 and height limit of 21-30metres are labeled as middle-rise-buildings, buildings with a floor number 10-16 and height of 30-50metres are labeled as small high-rise buildings, buildings with a floor number of 17-40 and a height of 50-100metres are labeled as high-rise buildings, and finally buildings with floor number of greater than 40 and height of 100metres are labeled as ultra-high-rise buildings (skyscrapers) (He Sijia et al 2019). Although there is no internationally agreed definition for high-rise buildings, it can be defined as a multi-story structure in which occupants are dependent on elevator for circulation within the structure (Challinger D 2008). However, a high rise building can be defined as follows:

- Any structure that has a direct and serious impact on evacuation during fire hazard can be labeled high-rise building (The International Conference on Fire Safety in High-Rise Buildings). (Wikipedia Encyclopedia, High-rise. March 5, 2022).
- Buildings that have seven stories and above are sometimes called high-rise and sometimes linear height of the building is used to determine whether high-rise or not (Hall Jr JR 2005).
- Buildings that extends above maximum reach of firefighting equipment is generally classified as high-rise. The height above which it is considered high-rise is between 75 feet (23m) and 100feet (30m) (Knoke ME) or about seven to ten stories (depending on the slab-to-slab distance between floors).
- EMPORIS defines high-rise building as buildings whose height is between 35meters to 100metres and a minimum of 12 floors (EMPORIS 2022).

The exact height at which a building is considered a high-rise is determined by the fire protection and building code of the country, region, state, or city in which the building is found. If the building exceeds a specified height, fires that are dangerous in such facilities must be fought by firefighters from inside the building rather than from the outside using fire hoses and ladders. For practicality and convenience, these multi-story structures use elevators as vertical transport systems, and most even use escalators to move people from floor to floor (High-rise security and fire life safety 2009).

Developing countries have not yet be able to have a definition for a high-rise building but generally their height limit for high-rise buildings is much less than developed countries (Imaah and Napoleon Ono 2019). In Ethiopia, there is no specific definition of high-rise buildings and their specification. But according to Ethiopian Standards Agency or ESA building spatial design in 2015, a building is considered to be high-rise when buildings having occupied floors located more than 25m above the lowest level of fire department vehicle access (Compulsory Ethiopian standards 1st edition 2015). And the new regulation for building height classifies building heights based on building height zones.

AACPPO 2017 classifies buildings by height zones as follows:

Building height zone 1 is when buildings have a minimum height of 75m and puts no maximum limit

Building height zone 2 is when the maximum building height of 70m

Building height zone 3 is when the maximum building height of 35m

Building height zone 4 is when the maximum Building height is 35m but the floor area ratio is different from zone 3.

Among all these different definitions this research employs the definition given by EMPORIS because it complies with our building height zone 4. So this research considers high-rise building as buildings having 35metres or 12 floors and above and below 100metres or 40 floors (Zone 4 and above).

High–rise buildings projects investment signifies a country’s economic power and is a sign of advantage to the country. So many countries have been looking forward to achieving their progress by encouraging the preparation of comprehensive plans to establish high-rise investment projects to advance their economic power and prestige, cities like Hong Kong, Malaysia, UAE, Qatar, and others (Akram Farouk 2011).

A country's progress is achieved through economic, urban, and planning progress; they are the most important reasons that encourage technological progress by seeking the use of the latest materials & systems (Jiaqi Qu et al 2021). All these elements help to attract sources of capital to the country. With the end of the twentieth century, many countries began to achieve progress through the preparation of comprehensive plans to establish high-rise building investment projects with the development of many standards and principles to ensure the success of these schemes. Most of the Arabic Gulf countries, Malaysia and Hong Kong started such steps in order to promote the country at various levels (Akram Farouk 2011).

High-rise buildings have always fascinated the minds of people since the start of their construction in ancient times. The construction of such buildings began in ancient times for defensive purposes or religious purposes (roman temples, pharaonic, churches…). But in the modern era construction of such project began in the eighties of the nineteenth century for the purpose of either residential or administrative, then it became to meet the requirements of hotels & other touristic needs as well (High-rise security and fire life safety 2009).

### 2.3.1. The development of high rise buildings

The city of Rome was the site of a large number of hurriedly constructed apartment buildings during the sharp rise of the Roman Empire under the reigns of Julius and Augustus Caesar, many of which were erected to considerable heights. Cities looked very different more than 150 years ago than they do today. People and their businesses were rarely housed in structures taller than a flagpole. Aside from monuments, temples, and town halls; and cathedrals (adorned with domes, spires, or towers) that "towered above all else in a city or town; they were visible from miles away," urban landscapes tended to be flat and homogeneous in pattern. High-rise buildings started in ancient Rome with their four-storey wooden residential buildings. The construction material and method advanced and continued to be constructed by rich laymen. Then residential buildings were constructed using bricks and other locally available materials such as mud from various types of soil. The modern story of high-rise buildings is considered to be started in North America in the ninetieth century, the monadnock building (in Chicago) 1891 was constructed out of sixteen storey using the bearing walls construction system. And with the advancement of the construction methods, buildings continued to increase in height till they reached the height of 60 storey's in the year 1913 with the construction of the Woolworth building in New York. After that tall buildings become common and now Burj Khalifa in the United Arab Emirates is the tallest building on earth with a height of 828m.

Ethiopia has a long story of constructing buildings, either castles, temples, or worshiping places. Its history dates back to the Axumite period when multi-story buildings were designed and shown at Axum obelisks. Then the period of Zagwe brought many wonderful palaces and churches including Lalibela's 11 rock-hewn churches. After this period building techniques and methods were changed to building 3 to 4 storey buildings like king's castle in Gonder and G+2 castle in Jimma aba Jifar. After these times contemporary buildings were seen in the current capital city Addis Ababa in the late 1800s and have been advancing since then. Now Addis Ababa is home to more than 23 high-rise buildings under construction, and 19 or more finished ones (Yonatan Taddese 2020). Many of these high-rise buildings were built by foreign contractors showing that their role in construction of high-rise buildings in Ethiopia is high (Girma Geremew 2018).

Reasons for taking the trend of constructing high rise buildings:

There are many reasons to establish high rise building investment projects, among them:

- The rapid growth of population in urban communities, and therefore the constant pressure of the limited land area affected the evolution of a building.
- Expensive land prices.
- Restriction of random expansion in major cities adjacent to agricultural land. − The high cost of setting up infrastructure for new cities.
- Expression of progress and civilization. And there are many other factors, for example, the city of Rio de Janeiro & Hong Kong, had other specific reasons such as terrain conditions or the lack of land areas like the United Arab Emirates and others. (Akram Farouk et al 2011).

## 2.4. Construction site definition

A construction site is a location or parcel of land where construction is taking place. The terms 'building site' and 'construction site' are frequently interchanged, though 'building site' usually refers to the construction of buildings (and sometimes, more specifically, housing), whereas 'construction site' can refer to any type of work, such as road construction, sewer construction, landscaping, and so on. A construction site is any place where construction work is being carried out or to which employees have access to, but does not places where other works are being undertaken (CDM Regulations 2015). It can also be defined as a place at which construction work is undertaken and any other area in the vicinity where a plant or other material used or to be used in connection with the construction work is located or kept during the construction work. It does not include a place where elements are manufactured 'off-site' or where construction material is stored as stock for sale or hire." (Law insider dictionary).

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## 2.5. Prevalence of safety risk in construction

The construction industry is a large industry that needs the involvement of human labor, sophisticated machinery, and large equipment. A machine is an apparatus used for mechanical power and has several parts, each with a definite function, which together performs a particular task. Equipment is any necessary items required for a particular purpose. While machines can be autonomous i.e. they can be used without human intervention, humans use equipment to complete a certain task, and therefore, it needs humans' intervention. The hugeness and complexity of the industry bring more challenges in operating and working on construction sites. Hugeness can be defined in terms of size, the construction industry being a large industry. Complexity can be difficult to define because it can refer to a variety of different things. Complexity is defined as "the state or quality of being intricate or complex", whereas complexity is defined as "made up of many interconnected parts." (Oxford University 2019). It should be noted that the word complex is sometimes used interchangeably with complicated. The complex should only be used to describe something that has multiple parts, rather than something that is difficult to understand, analyze and to deal with. When discussing construction projects, the term "complexity" is frequently used. Construction projects, in general, are made up of many interconnected parts, and thus fit the Oxford university dictionary definition of complexity well. However, complexity can be defined in ways other than the simple definition provided thus far. It is a widely held belief that the construction process is one of the most complex and risky industries undertaken in today's world. The construction process is the most complex undertaking of any industry (Jose R. San Cristobal et al 2018) and the construction sector has faced significant difficulty in coping with the increasing complexity of major construction projects.

The construction industry is one of the most dynamic, risky, and challenging businesses (Mills, 2001). However, the industry has a very poor reputation for risk management, with many major projects failing to meet deadlines and cost targets (Nasser Alsaadi and Norhayatizakuan 2020). Construction projects are initiated in complex and dynamic environments (Patel Kishan and Rajiv Bhatt 2014), resulting in high uncertainty and risk, which is compounded by demanding time constraints. The scope of work defines how complex a project can be and high-rise buildings need much more personnel and equipment to be completed than conventional non-high-rise buildings. Cranes, hoisting equipment, large material stores, and other huge equipment which are promising in completing the demanded high-rise buildings pose a big threat to the safety of workers on site.

This makes the construction of high-rise buildings even more risk-prone than other buildings. Unfortunately, the construction industry is one of the world's most dangerous, with the highest accident rates. Construction has a 2.5-fold higher chance of having a serious accident than the manufacturing industry, and a five-fold higher chance of having a fatal accident. Around 30–40% of construction-related accidents are fatal on a global scale (Felipe Muñoz-La Rivera et al 2021).

## 2.6. Construction safety risks, hazards, and accidents

Since these words i.e. risk, hazard, and accident are being misused interchangeably and being misunderstood, the researcher found it compelling to discuss them in detail to eliminate any misconception about them and to clarify which of these terms is the main concern of the study. Risk and safety are closely related concepts. While risk is what we typically quantify and compare, safety is what we want to achieve. In the literatures, the notion of safety is predominately used as the sought state-of-affairs i.e. regulations and procedural documents are more focused on rules and procedures to enhance safety, but they lack direct and precise characterization of the concept of safety (Sabine Roeser et al 2012 1st edition). When the risk is low, safety is high, and conversely, when safety is low, risk is high. As stated by Sabine Roeser safety is a positive property, while risk is generally something negative. And if safety is to be increased risk must be considered first and manage it properly to minimize it. Minimizing risk is maximizing safety and enhancing safety is reducing risk. This relationship is better understood by the following diagram:-


Figure 2. 1 safety and risk relationship

Source of the figure is Avatar Management Services website. Understanding this relationship is vital in dealing with safety risk management. As the figure above, i.e. figure 2.1, shows safety and risk has inverse relationship. When risk decreases safety increases and vice versa. Having a safe behavior helps to minimize risk and in turn increase safety, this is where most researches about safety management are focused on, i.e., to help workers increase their perception about safety and create a safe behavior for workers which in turn helps to increase safety and decrease risk.

Construction safety risk management is an integral part of construction management. Safety risks exist due to the damage or impact of a hazardous situations. Where there is no hazard there will be no risk, (Cooke and Williams, 2004). But there are hazards everywhere on construction sites that can cause safety risks. Safety risk, within the context of occupational health, relates to an assessment of hazards that can lead to harm, injury, death, or illness of a worker in a determined workplace.

Generally, risk is a degree of uncertainty about the occurrence of an event (events). There may be different kinds of risks depending on what event is likely to happen during the course of a project, it may be a financial risk, time delay risk, cost overrun risk. But, safety risk within the context of occupational health, relates to an assessment of hazards that can lead to the harm, injury, death, or illness of a worker in a determined workplace.

Occupational safety and health is still an area of intense research and practical development (Sousa et al. 2015). Safety management is comprised of several management processes, and risk assessment is a key process among them. It is of great importance to facilitate the risk assessment process in the construction industry because occupational safety risk assessment is the core of safety practices (Pinto 2014) as well as a requirement in most safety-related legislations. Right measures can be known only by identifying hazards and prioritizing risks precisely and thoroughly. However, one should not expect risk assessment to avoid the hazards prevalent in a workplace in a short period of time. Rather, this can be achieved through a long-term continuous study; hence the underlying principle should be a persistent improvement.

Occupational safety and health (OSH) in construction is generally defined as a science of anticipation or prediction, recognition, evaluation, and control of hazards arising in or from the workplace that could impair the health and well-being of workers, taking into account the possible impact on the surrounding communities and the general environment (Takele Tadesse and Mengesha Admassu, 2006). It also has been defined by the International Labor Organization (ILO), 2005 as: “The prevention and maintenance of the highest degree of physical, mental and social well-being, the prevention of ill-health among workers caused by their working conditions, The protection of workers from factors adverse to their health in their employment, and the placing and maintaining workers in occupational environments adapted to their individual and psychological conditions.” (ILO, 2005). Safety means a state in which no danger causing an accident exists or a state of being free from risk. A high level of occupational health and safety contributes to the successful achievement of material and economic objectives and provides high quality and performance of work. Despite this, conditions in the work environment for many occupations and in many countries still involve a distinct and even severe hazard to health that reduces the well-being, working capacity, and even the life span of workers. According to (Mwombeki, 2005) safety is defined as the condition of being protected against any type of events (accidents) that could be considered non-desirable by controlling hazards to achieve an acceptable level of risk. Also, an accident is defined as some sudden and unexpected event taking place without the expectation that causes injury, damage, or death.

There is a misconception related to hazards, accidents and risk. Despite the fact that naturally occurring events have a profound effect on societies that dates back to the earliest human history, significant interest and research on natural hazards and disasters have been a fairly recent endeavor. Modern hazard analysis of hazards and risk is commenced in the 1930s by Gilbert White (Daren Gravley 2010). Since then it there have been some advancements in research regarding this topics. These three terms, i.e. hazard, accident and risk are different in terms of concept.

Understanding the relationship between Hazard – Risk – Accidents is very important in accident prevention in the workplace. While hazard is anything, situation, or condition which has the potential to cause harm to people, equipment, and the environment, risk is the probability that an incident will occur and the severity of the outcome. Risk is graded into low, medium, and high, and an accident is an unexpected and unwanted occurrence that could result in injury to persons, damage to equipment, materials or environment. The Occupational Safety and Health Administration OSHA 2021 defines hazard as “a potential or substantial property of a process, product or case that may cause damage or leave harmful health effects on people or damage things.” (OSHA, 2021).

This phenomenon is best described by U. Bong Udet (2018) using a figure 2.2as:-

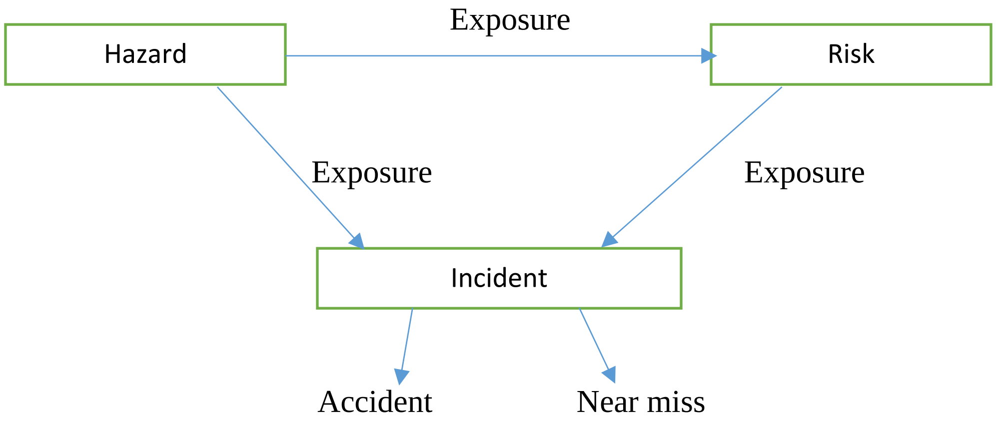


Figure 2. 2 Hazard, Accident, and Risk relationship

As it can be seen from figure 2.2, hazardous situations can be a risk if there is someone exposed to that risk and that hazard can be turned into an incident where a person either get an accident or a near miss. Or if workers are exposed to hazardous situations directly, that can lead to an incident where they are exposed to either accident or near miss. So risk is exposure to hazardous events and/or situations. Accidents happen when there is exposure to hazardous events.

There will be no risk when there is no hazard. A hazard can be a risk if there is exposure to that hazard and its result could be either an accident or a near miss. Therefore, risk in this context is the uncertainty in the likelihood of this hazard causing an incident, depending on the probability and severity (impact) of that hazard.

### 2.6.1. Safety risks factors

The OSHA 2021 identifies only five major safety factors, but different researchers have identified more or like different safety risk factors as presented in the Table 2.1 below:

Table 2. 1 Identified safety risk factors from different literatures

| **Safety risk factors** | **References** | **Definition** |
| --- | --- | --- |
| Caught in between/ Compressed by equipment or objects | Bernard R. Fortunato Et Al 2012, Matthew R. Hallowell 2008, Yousif S. Saeed 2017 | A workplace accident in which a worker is injured as a result of being caught in a machine or equipment, |

| | | |
|---|---|---|
| | | or being squashed between two objects. |
| Trench failure/Excavation Accidents | Abdul Rahim Abdul Hamid et al 2003, Lucy Fekele et al 2016, Muizz O. Sanni-Anibire et al 2019 | When the walls of a trench fail to withstand the pressure of the tons of soil pressing down on it, the trench collapses. |
| Struck-By or Against something | Matthew R. Hallowell 2008, Kai Chen Goh et al 2016, Lucy Fekele et al 2016, HSE 2021 | When the worker is hit by something within the site |
| Repetitive motion | Matthew R. Hallowell 2008, Bernard R. Fortunato et al 2012 | These are injuries to muscles, nerves, ligaments, and tendons that occur as a result of repeatedly performing the same motion. |
| Being hit by moving objects like vehicles | Yousif S. Saeed 2017 | When the worker is hit by moving objects within the site like vehicles loading or unloading and others |
| Slips, trips and falls | Fiktor Belachew 2020, Devdatt P Purohit et al 2018, Dheeraj Benny and D. Jaishree 2017, OSHA 2016 | When the foot collides with, strikes, or hits an item in its course; or when one steps down unexpectedly from a higher to a lower surface, one falls on the same level due to lack of balance (misstep). |
| Electrical/Heat/ burns | Fiktor Belachew 2020, Hanna Mersha et al 2017, Purohit et al 2018, OSHA 2016 | An electrical burn is a tissue injury caused by contact with an electric current such as live wires or lightning. |
| Chemical burns | OSHA 2016, Fiktor Belachew 2020, Hanna Mersha et al 2017 | Chemical burns are caused by powerful acids, drain cleaners, paint thinner, gasoline, and a variety of other agents that cause tissue damage. |

| | | |
|---|---|---|
| Falls from heights | Matthew R. Hallowell 2008, Fiktor Belachew 2020, Hanna Mersha et al 2017, Lucy Fekele et al 2016, Abiy Girma 2020 | Falling from a height is described as falling from one level to another. It can be as short as falling from the first rung of a ladder to as long as falling from a high-rise structure. |
| Falling objects | Muizz O. Sanni-Anibire et al 2019 | Objects falling from great heights, such as displaced, dropped, or blown goods, tools, debris, or waste material, are referred to as falling objects. |
| Fire outbreak/explosions | OSHA 2016, Fiktor Belachew 2020, Devdatt P Purohit et al 2018 | A violent release of energy induced by a physical or chemical reaction is known as an explosion and fire outbreak can be the result of it. |
| Scaffold accidents | Dheeraj Benny and D. Jaishree 2017, Muizz O. Sanni-Anibire et al 2019, Lucy Fekele et al 2016 | Scaffolding accidents mainly involve people falling, incorrect operating procedures, environmental conditions and falling materials due to equipment failure. |
| Ladder accidents | Dheeraj Benny and D. Jaishree 2017, Devdatt P Purohit et al 2018, Bilal Manzoor et al 2022 | This one is falling from a ladder due to various causes. |
| Structural collapse | Muizz O. Sanni-Anibire et al 2019, Nurzawani Md Sofwan et al 2015 | When internal load bearing structural elements fail, a building will collapse into itself and exterior walls are pulled into the falling structure. |
| Manual handling | Fiktor Belachew 2020, Devdatt P Purohit et al 2018, HSE 2021 | Manual Handling relates to the moving of items either by lifting, lowering, carrying, pushing or pulling. Incorrect manual handling |

| | | |
|---|---|---|
| | | is one of the most common causes of injury at work. |
| Noise | Fiktor Belachew 2020, Devdatt P Purohit et al 2018 | a sound, especially one that is loud or unpleasant or that causes disturbance |
| Crane Accident | Muizz O. Sanni-Anibire et al 2019 | Crane accidents, including fatalities and serious injuries, will occur if cranes are not inspected, maintained and used properly. |

## 2.7. Construction safety risk and accident in Ethiopia

The construction industry is the major contributor to Ethiopia's economy and one of the fastest growing industries. Mechanization and development of this sector in a country shows how developed a country is in construction of schools, hospitals, housing complexes, shops, offices, highways, power plants, industries, bridges and other infrastructures. However, the construction sector in developing countries like Ethiopia suffers a loss in terms of safety of workers due to different reasons like illiteracy, poverty, lack of health and safety training and information on health hazards and risks at the work place (Betelhem Bekele 2019). The impact of construction safety hazards is 10 to 20 times higher than other industries and most of work forces are located on construction sites (Dong 2005). Building industry is the second leading cause of injury in Ethiopia, following traffic accidents, and the rate of death is five times higher in the construction sector than in manufacturing industries (Teferi Gebru Gebremeskel and Tesfaye Yimer 2019).

There are many contributing factors to why safety is such undermined factor in management staff in Ethiopia as well as other developing countries. Lack of; Top Management Support, Clear and Reasonable Objective, Personal Attitude, Teamwork, Efficient Enforcement System, Safety Training, Suitable Supervision, Preventive and Protective Measures, Administrative or Organizational Controls, proper use Personal Protective Equipment (PPE), First-Aid Arrangements, are among contributing factors (Betelhem Bekele 2019). Due to this and other perhaps unknown factors, construction workers at site in Ethiopia are exposed to the following accidents; 68.9% were injured in more than one way, 36.2% cuts and 26.6% abrasions, 46.1 % sharp instrument injuries, 37.3 % fall accidents, 8.9 %  and injuries caused by falling, splinting, or splashing objects. The majority, 86.7 %, were absent from work for 7 days or less (Hanna Mersha et al., 2017).

Addis Ababa, the capital of Ethiopia and all of Africa was first established in the 19$^{th}$ century. It is now home to over 3million people according to the 2007 national census. The city has been undergoing many changes and developments in the last decades. It has been building houses, roads, schools, hospitals, hotels, real estates and other important infrastructures. It is now getting used to building tall buildings and currently it has over 23 under construction high-rise labeled buildings, that are mentioned below according to the information obtained from (EMPORIS 2019);

Table 2. 2 List of High-rise buildings in Addis Ababa

| Building name | Estimated height in meters | Floors | Type of building |
|---|---|---|---|
| Amhara Credit & Saving Institution HQ | 135 | 36 | High-rise building |
| United Bank Headquarters | 131 | 35 | High-rise building |
| NIB Bank Headquarters | 131 | 35 | High-rise building |
| EEPCo Headquarters | 127 | 34 | High-rise building |
| Four Points by Sheraton | 120 | 32 | High-rise building |
| Zemen Bank Headquarters | 112 | 30 | High-rise building |
| Red Cross Headquarters | 112 | 30 | High-rise building |
| ORDA Headquarters | 101 | 27 | High-rise building |
| Nile Insurance Company Headquarters | 94 | 25 | High-rise building |
| Kebede Ketema Tower (KK Tower) | 82 | 22 | High-rise building |
| Eleli building | 79 | 21 | High-rise building |
| Sileshi Sihen Business center | 86 | 22 | High-rise building |
| Bank of Abyssinia | 79 | 21 | High-rise building |

| | | | |
|---|---|---|---|
| ZED building | 75 | 20 | High-rise building |
| Chelelek Alsam tower | 75 | 20 | High-rise building |
| Nyala insurance | 71 | 19 | High-rise building |
| Bole housing project X | 71 | 19 | High-rise building |
| Zenith building | 64 | 17 | High-rise building |
| Solomon Tilahun building project | 67 | 18 | High-rise building |
| Ayat real estate apartments | 67 | 18 | High-rise building |
| Pullman hotel | 64 | 17 | High-rise building |
| Radisson Blue hotel | 60 | 16 | High-rise building |
| Tebaber Berta building | 56 | 15 | High-rise building |

Having over 23 high-rise buildings under construction and over 12 finished ones suggests how much the construction industry in Addis Ababa as well as Ethiopia is advancing further. The first skyscraper built by Commercial Bank of Ethiopia is already at work since 2022. Despite this advancement in construction, the industry seems lame in terms of taking care of its workers and focusing on the safety of workers (Fasil Argaw, 2017).

## 2.8. Safety risk management process

Defining risk and risk management is very difficult as many researchers define it in their own ways. But risk always contains the terms "loss" and "uncertainty". Risk management generally is a scientific way of dealing with risks by systematically identifying, analyzing, and responding to risks. Along with these tasks, risk prioritization is the main task of the risk management process or RMP (Schieg 2006). Risk can be responded to in different ways by coordinating managerial resources to minimize the probability and/or impact of risk events. These responding mechanisms can be retention, reduction, transfer, and avoidance (Douglas 2009, Smith et al 2006, PMI, 2007). According to Cooper et al 2005 risk management is application of management policies, processes and procedures that enables for identification, analysis, assessment, treatment, monitoring, and communication of risks (Cooper et al., 2005). Risk management process (RMP) is the basic principle of understanding and managing risks in a project. The processes can be summarized as below in figure 2.3:

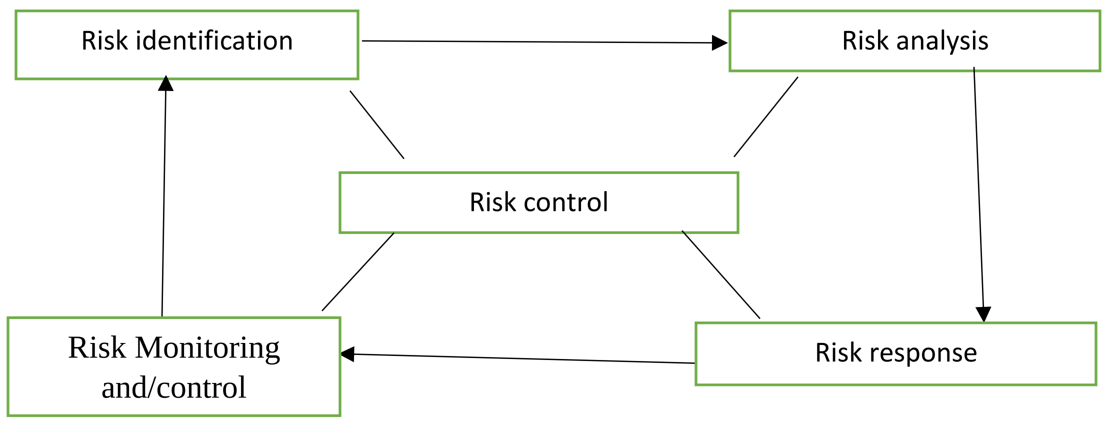


Figure 2. 3 the process of managing risks (Smith et al. 2006)

### 2.8.1. Risk identification

Risk identification is the most important and an early stage within the risk management process (Banaitene & Banaitis, 2012). Safety risk management is one of the important techniques to be performed in large construction projects (Aghaei et al., 2022). A Hazard Identification and Risk (HIRA) is mainly focused on identifying major hazards associated with a process. However, hazardous situations or activities can only be managed when we have identified hazards for the process. Moreover, it is a systematic way of identifying and analyzing hazards to determine their scope, impact and the vulnerability of the built environment to such hazards and its purpose is to ensure that there is a formal process for hazard identification, risk assessment and control to effectively manage hazards that may occur within the workplaces. Hazard identification and risk analysis (HIRA) is a term that encompasses identification and evaluation of risks throughout the life cycle of a project (Devdatt P. Purhot et al., 2018). The aim is not to provide a perfect predictions about future events, rather it is the recognizing or foreseeing of potential risk factors and risk sources which have a high impact on the project objectives directly or indirectly. It is quite impossible to identify all potential risks and the purpose should not be to do so (Smith et al., 2006). The purpose is to identify risks list which can cause potential damage manage them during the course of the project. There are different techniques to identify potential risks. According to Ewelina Gajewska and Mikaela Ropel (2011) they, i.e. risk identification techniques, are summarized as below:-

Table 2. 3 risk identification techniques

| | |
|---|---|
| Information gathering methods | Workshops |
| | Brainstorming |
| | Interviews |
| | Questionnaires |
| | Benchmarking |
| | Consulting experts |
| | Past experience |
| | Delphi technique |
| | Risk breakdown structure |
| | Visit locations |
| Documentation | Databases, historical data from similar projects |
| | Templates |
| | Checklists |
| | Study project documentation (plan, files and others.) |
| | Study specialist literature |
| Research | Stakeholder analysis |
| | Research assumptions |
| | Research interfaces |

### 2.8.2. Risk analysis/assessment

Risk analysis is the second step in risk management process in which identified risks are further analyzed. The main purpose of risk analysis/assessment is to describe the situation as best as possible and to prioritize the factors (Schieg, 2006). Risk analysis includes number of methods for prioritizing the identified risks for further action, such as risk response (Risk management guideline, 2017). In order to prioritize them there are generally two methods namely qualitative and quantitative approach. Qualitative analysis includes interviews, checklists and brainstorming while the latter is performed through a data driven methodology (Banaitene & Banaitis, 2012).

*2.8.2.1 Qualitative method:*

Qualitative method is based on descriptive scales, and are used for describing the likelihood and impact of a risk (Ewelina Gajewska and Mikaela Ropel 2011). This method can be applied when quick assessment is required. It can also be applied to small and minimum projects, inadequate, limited or unavailable numerical data as well as limited resources of time and money (Radu 2009, Heldman 2005). The main target is to prioritize potential threat to focus on the most important ones and to improve the overall performance of the project (Cooper et al 2005, PMI 2004). For this method to be accurate there has to be precise set of data from credible sources. qualitative data usually needs to be quantified for different purposes in order to present numerical values that best describes the scenario under investigation, and in order to gather and present quantitative data descriptive scales and qualitative data are usually needed thus qualitative method is usually related to quantitative data and vice versa (PMI, 2004). Qualitative risk assessment techniques are presented below (PMI 2004, Ewelina Gajewska and Mikaela Ropel 2011, PMBOK 6$^{th}$ edition).

a) Risk probability and impact assessment:

PMBOK 6$^{th}$ edition describes qualitative risk analysis as “assessing the priority of identified individual project risks using their probability of occurrence, the corresponding impact on project objectives if the risks occur, and other factors” (PMBOK 6$^{th}$ edition). By using this technique, the likelihood of occurrence of a specific risk is evaluated. Events that tend to maximize the project’s objectives and threats that tends to negatively affect the project’s objective should be identified and listed comprehensively. Probability of occurrence of an event and its impact on project objectives such as time, cost, and quality are studied. In order to do this probability and impact should be defined and tailored and the resulting value may range from very low to very high.

b) Probability/impact risk rating matrix:

Using the findings in the previous method, risks are prioritized by multiplying value of impact and probability. This phenomenon is best described in project management institute or PMI 2004 as shown in figure 2.4 below.

Risk Management Matrix Showing Probability and Impact and High Low Risk

| Risk Management Matrix | | Impact | | | | |
|---|---|---|---|---|---|---|
| | | Negligible | Marginal | Moderate | Critical | Catastrophic |
| Probability | Almost Certain | Low Risk | Moderate Risk | High Risk | Extreme Risk | Extreme Risk |
| | Likely | Minimum Risk | Low Risk | Moderate Risk | High Risk | Extreme Risk |
| | Possible | Minimum Risk | Low Risk | Moderate Risk | High Risk | High Risk |
| | Unlikely | Minimum Risk | Low Risk | Low Risk | Moderate Risk | High Risk |
| | Rare | Minimum Risk | Minimum Risk | Low Risk | Moderate Risk | High Risk |

Figure 2. 4 Probability and Impact Matrix (PMI, 2004*)*

Using these values risks can be prioritized starting from events that has a high probability of happening and high threat level to those that have low probability of happening and low threat level.

c) Risk categorization, and Risk Urgency Assessment

Unlike the previous techniques risks are categorized according to a specific information about them like their source which helps to identify which areas of the project are risk prone than others. Work breakdown structures (WBS) or risk breakdown structures (RBS) can be used to develop effective risk response. Risk breakdown structures (RBS) categorizes risks and shows their dependencies (Dallas, 2006). Risk urgency needed to determine which prioritized risk needs quick response.

#### *2.8.2.2 Quantitative risk assessment*

PMBOK 6$^{th}$ edition defines quantitative analysis as Numerical analysis of risks and other sources of uncertainty on the objectives of a project. The main advantage of this analysis is that it numerically expresses project's exposure to those risks and assist in risk response planning by providing additional quantitative risk information (PMBOK 6$^{th}$ edition). This method needs a lot of works and is suitable for medium to large scale projects (Heldman, 2005). The following techniques can be used when using quantitative method:

a) Monte Carlo Simulation, or Scenario technique

This technique evaluates the combined effect of individual risks and other uncertainties to evaluate or analyze their impact on the project objectives. The simulation produced by this technique is used for forecasting, estimations and risk analysis by generating different scenarios from threats and opportunities (Mun 2006). The source of data can be from previous projects. Different software like risk simulator software for large scale projects and Microsoft excel for small scale ones.

b) Sensitivity analysis (Modeling technique)

This analysis helps to determine which individual project risk among the listed ones affect the project objective more than others do. The risk factors which are the most influential to the project are the most sensitive and appropriate action needs to be taken. The aim is to look at the sensitivity of various elements of the risk model on project outcome, by changing the values of one variable at a time and then showing the impact on the project. This analysis better be taken at the initial phase of the project in order to identify critical areas during the project (Smith et al 2006).

c) Decision tree analysis

It is used to select the best course of action among many other possible solutions or actions. This method is commonly used when some risks have an exceptionally high impact on the two main project objectives: like time and cost (Heldman, 2005). This method involves visually outlining the potential outcomes, costs, and consequences of a complex decision involving different risk factors.

There are many other techniques of risk assessment techniques. But generally they can all be categorized into two parts; multi-criteria decision making and statistical approach (Agnieszka Dziadosz et al 2012).

#### *2.8.2.3 Multi-criteria decision-making methods (MCDM)*

Decision making in construction industry is too important that it can mean the difference between success and failure. As the construction industry involves many changing variables like tasks, operations and requirements, managing them and deciding in the favor of the project is difficult. Multi-criteria decision making (MCDM) arose to model complex problems in decision making which are too complicated for other analysis techniques. It emerged as a branch of operations research destined to facilitate the resolution of complex decision making with number of criteria. This approach is well suited to the problem related to selection, including: the variant of a project, investment, contractor, location, technology of production of particular structure elements in a building, choice of a tender strategy, evaluation of tenders, specifying utility state of a building, estimation of construction costs, evaluation of accident situation in the construction industry, etc. according to the predefined criteria (the qualitative ones and the quantitative ones) (O.Kapliński et al 2011, O.Kapliński et al 2010, M. Rejment et al 2017, S. Shevchenko, et al 2008, E.K. Zavadskas et al 2004, G.Zhang et al 2007). Though this method helps in decision making it does not make the decision. In other words, MCDM does not prescribe how decisions should be made. It only helps to make logical and reasonable decision rankings. Among MCDM techniques, Analytical Hierarchical Process (AHP), Analytical Network Process (ANP), Simple Multi-Attribute Rated Technique (SMART), Et Choice Translating Reality (ELECTRE), Decision Making Trial and Evaluation Laboratory (DEMATEL), Preference Ranking Organization Method for Enrichment Evaluation (PROMETHEE) are the most common ones (Fatma Eltarabishi et al 2020). The following table 2.4 will summarize all these methods.

Table 2. 4 MCDM techniques

| Method | Description | Advantage | Disadvantage | Common areas of application |
|---|---|---|---|---|
| AHP | Analytical Hierarchy Process or AHP was developed by Thomas Saaty in 1980 to help in complex decision making by decomposing a decision making problem into a system of hierarchies of objectives, attributes (or criteria), and alternatives. Due to | -Easy to use<br><br>-Scalable<br><br>-Hierarchy structure can easily adjust to fit many sized problems(can have many alternatives and criteria)<br><br>-Not data intensive (it does | -Susceptible to rank reversal<br><br>- Problems due to interdependence between criteria and alternatives which can lead to inconsistencies between judgment and ranking criteria. | -Resource management,<br><br>-Corporate policy and strategy,<br><br>-Public policy,<br><br>-Political strategy,<br><br>-Planning. |

| | | | | |
|---|---|---|---|---|
| | its hierarchical structure, scalability and pairwise comparison that allows to weight factors it addresses the problem of making logical scientific decision and making good selection among alternatives. | not need big data for computation). | | |
| ANP | Analytical Network Process is a more generalized form of AHP (Saaty and Vergas 2006). It is more concerned with network than hierarchical structure. It can prioritize clusters or groups of elements and allows interdependence or feedback which the AHP cannot have. ANP can support a complex, networked decision-making with various intangible criteria" (Tsai et al. 2010). | -The ability to prioritize groups or clusters of elements<br><br>- Simplifies complex decisions<br><br>-Allow dependence and feedback in hierarchy | -Ignores the different effects among clusters<br><br>-Dependent on expert's judgment | -Project selection,<br><br>-Product planning,<br><br>-Green supply chain management,<br><br>-Optimal scheduling problems |
| SMART | SMART was first proposed by Edwards in 1971. It has been applied in business and management fields, social sciences (Mark Velasquez and Patrick T. Hester 2013). SMART (Simple Multi-attribute Rating Technique) is | -Simplicity in comparison with other decision making tools<br><br>-Allows for any type of weight assignment technique<br><br>-Less effort by decision makers. | - Inconvenient procedure considering the framework. | -Environmental, construction,<br><br>-Transportation and logistics,<br>-military,<br><br>-Manufacturing and assembly problems. |

| | | | | |
|---|---|---|---|---|
| | a simple form of a multi-attribute utility method. The alternatives are rated directly in the natural scales and the different scales of criteria are converted to a common scale mathematically using a simple value function | | | |
| ELECTRE | Elimination Et Choix Traduisant la Realite (ELECTRE) was first used by Bernard Roy in making decision in 1968. This method begins with pair wise comparisons of all listed alternatives under each criterion. Its basic concept is to deal with outranking relations between alternatives under each criterion using pair-wise comparison. ELECTRE is a multi-criteria decision-making procedure that can be used when a set of alternatives must be ranked according to a set of criteria reflecting the decision maker's preferences (Behnam Vahdani et al 2010). | -Takes uncertainty and vagueness into account which no other technique does | Its process and outcome can be difficult to explain to non-professionals;<br><br>-Outranking causes the strengths and weaknesses of the alternatives to not be directly identified. | -Energy,<br><br>-Economics,<br><br>-Environmental,<br><br>-Water management,<br><br>-Transportation problems. |
| PROMETHEE | The PROMETHEE method (preference | -Easy to use; | -Does not provide a clear | -Environmental, |

| | | | | |
|---|---|---|---|---|
| | ranking organization method for enrichment evaluation) is a multi-criteria decision-making method developed by Brans et al in 1986. It is based on mutual comparison of each alternative pair with respect to each of the selected criteria. It is well adapted to problems where a finite number of alternatives are to be ranked considering several, sometimes conflicting criteria (Akbar Esfahanipour 2007). | -Does not require assumption that criteria are proportionate. | method by which to assign weights. | -Hydrology,<br><br>-Water management,<br><br>-Business and finance,<br><br>-Chemistry,<br><br>-Logistics and transportation,<br><br>-Manufacturing and assembly,<br><br>-Energy, agriculture. |
| DEMATEL | This method was developed by Fontela & Gabus in 1976 at Geneva Research Center of Battelle Memorial Institute. They developed the DEMATEL method to find integrated solutions for the fragmented and antagonistic phenomena of world societies (Babak & Farzad, 2012). | - Especially practical and useful for visualizing the structure of complicated causal relationships with matrices or digraphs.<br>- can convert the relationship between the causes and effects of criteria into an intelligible structural model of the system (Ming-Lang Tseng 2008). | - Typically needs to be used in combination with other MCDM methods to weight coefficients. | -Production planning,<br><br>-Scheduling,<br><br>-Health care,<br>-Portfolio selection,<br><br>-Distribution systems,<br><br>-Energy planning, |

As presented in table 2.4 it is quite uneasy to reach a direct and objective conclusion about the unique characters of MCDM methods (Mahmut Bayda and Dragan Pamu 2022). Despite their differences in methodology they have common characteristics as follows:

- Relatively easy in application and interpretation of the results and in their implementation.
- This approach is mainly used in the selection of the decision-making variants, hierarchy of problem solutions.
- They allow the application in the decision-making process of the twofold character of the data: qualitative and quantitative.
- Possibility of combining with other methods forming the so-called “hybrids”.
- The scale of measurement of variant of a given criterion is the contractual scale.

#### *2.8.2.4 Statistical approach*

The second method in risk analysis is statistical approach which uses statistical data to determine effects on the quality of the obtained results. This method can be based on data extrapolation or probabilistic modelling. The minority of statistical indicators base their analysis on the quantitative data, by what it would seem that the results will be qualitatively better than the results obtained in other techniques (Zijing Zhang, 2017). The quality of data and reliability of their collection and classification are very important too. The incorrect data will generate a misleading results. The methods, that can be used to determine the relationship between the variables risk factors, we can include the following: the correlation, the regression analysis, analysis of variance. Regression analysis is to determine the strength and direction of the relationship between variables. Quantitative data are preferred for this method. Thus, it was adopted the numerical scales for the qualitative features (the level of risk and the realization system). After developing a regression model the key issue plays the degree of fit of the model to the empirical data, as well as checking the type of relationships between variables (linear, nonlinear). The authors of the paper have focused on the possibility of using the regression analysis in determining the amount of the reserve at a risk for a contract developing the model based on the data from the previously completed projects.

Characteristic features statistic approach:

- o Fulfillment of restrictive assumptions (size of research sample, type of data).
- o Impact of the data character (no possible application of certain measures for qualitative data).
- o An introduction to simulation with known distribution of the random variable.
- o The standard deviation, coefficient of variation and coefficient of variation are the basis for the selection of projects and determine the safety margin of projects.

#### 2.8.3. Risk response

Risk response is the third step in risk management process, which is defined by PMBOK as the process of as the developing options and determining actions to enhance opportunities as well as reduce threats to the project objectives. This step signifies what actions should be taken towards the various risks and threats previously identified (Mhetre et al., 2016). This process involves the assignment of parties to take responsibility for each agreed risk response, and the efficiency of this phase will determine if the risks increase or decrease for the project (Dario Petrovic 2017). Previous analysis are done to select the best risk response plan to meet control or at least the impact of risk on the project objective, thus, this step is a product of previously done important steps. Among risk response plans Avoidance/Prevention, Reduction/Mitigation, Transfer, and Retention are the most common ones (Ewelina Gajewska and Mikaela Ropel 2011, PMBOK, 2004).

#### 2.8.4. Risk monitoring and/control

Potential risks and hazards should be continuously looked for after a planned risk response as the project continues. PMBOK defines this step in risk management process as “the process of identifying, analyzing, and planning for newly arising risks, keeping track of the identified risks and those on the watch list, reanalyzing existing risks, monitoring triggering conditions for contingency plans, monitoring residual risks, and execution of risk responses while evaluating their effectiveness” (PMBOK, 2004). This step involves choosing alternative strategies, executing a contingency plan or fallback plan, taking correcting actions, and modifying the project management plan. This step is as equally important as other steps.

## 2.9. Necessity for modeling construction safety risk

Despite the amount of substantial research and improvements that have been made through the years, accident rates in construction are still high (Mosly, 2015). Solutions and methods or strategies that are directed towards enhancing safety performance in the construction industry are still lacking. Though, some researchers (Fund et al., 2010; Liu and Tsai, 2012; Patel and Jha, 2016; Gunduz et al., 2018; Amiri et al., 2017) have provided safety performance tools, it can only be effectively implemented through systematic, quantitative analysis of potential risk (Muizz O. et al 2019). This systematic quantitative analysis gives rise to a model which will help in different ways. It will help to be well prepared i.e. possible potential risks have to be identified in advance in order to deal with them if they occur. Risk register is a part of risk modelling framework that enables us to be well-aware and well-prepared about all possible scenario and to deal with them if any of them is to occur. It also helps to improve communication between stakeholders about potential risks. Creating a risk model ensures that the project management team, organizational executives, and project stakeholders are all aware of potential risks from the beginning. It can also be used to make sure judgments made throughout the risk management process is sound. Attempting to mitigate the negative consequences of a risk reactively rather than proactively can give stakeholders the impression that decisions are not made throughout the progress of the project, which will severely harm the projects' connection, integrity, and reputation. The third benefit is to improve the maturity of the organization's risk management and assign clear responsibilities. Developing a risk model will surely improve risk maturity (Diogo et al., 2017, David 1997). Risk maturity is the ability to effectively manage risk by focusing on really important once. It is a continuous progress like humans maturity. After all, if there is no a solid risk model in place, the risk maturity scale will be at the bottom that shows the risk management is at its worst (Robert J.Chapman 2011). If hazards arise, risk model will ensure that involved parties don't play the terrible "blame game." It's more vital to get to work on mitigating risk's negative repercussions than to waste time pointing fingers, and a risk model will ensure that this occurs. Finally it increases the Probability of Exceeding Expectations. Implementing a successful risk model can increase the chances of completing a project on time and on budget.

## 2.10. ANP modeling use and compatibility to model safety risk

Analysis has been the fundamental instrument of scientific research to test hypotheses and solve issues which breaks down a problem into its basic components to analyze their behavior. People that work in decision-making employ generally extremely simple hierarchic frameworks consisting of a goal, criteria, and alternatives to simplify and deal with complexity. However, not only are judgments made from a simple three-level hierarchy different from those made from a multilevel hierarchy, but decisions made from a network might also differ dramatically from those made from a multilevel hierarchy (Salvatore Greco et al 2016 2nd edition). We shouldn't hope to record the outcome of interactions in the form of extremely condensed judgments that accurately reflect everything that happens in the world by reducing complexity to a simple framework of two levels, criteria, and alternatives. Researchers have discovered that decomposing these judgments through more elaborate frameworks to organize our thinking and calculations in sophisticated yet easy ways to serve our knowledge of the complexity around us is not difficult, based on previous experience. In order to deal with such complex situations ANP was developed by Thomas Saaty in the 1980s.

The Analytic Network Process (ANP) is a multi-criteria decision making technique or theory that allows interactions and feedback within clusters (inner dependence) and between clusters (outer dependence). It extends the AHP to cases of dependence and feedback and generalizes on the super matrix approach introduced in Thomas Saaty's 1980 book on the Analytic Hierarchy Process. Feedback can better capture the complex effects of interplay in judgments. The ANP provides a thorough framework to include clusters of elements connected in any desired way to investigate the process of deriving ratio scales priorities from the distribution of importance or influence among elements and among clusters. The power of the Analytic Network Process (ANP) lies in its use of ratio scales to capture all kinds of interactions and make accurate predictions, and, even further, to make better decisions. So far, it has proven itself to be a success when expert knowledge was used with it to predict sports outcomes, economic turns, and business, social and political events (ANP super decision manual). Since its release, it has been adopted to facilitate several multi-criteria decision-making problems such as project selection (Cheng and Li 2005; Dikmen et al. 2007), product planning (Karsak et al. 2003), strategic decision making (Cheng and Li 2004; Dagdeviren et al. 2005), performance prediction (Ozorhon et al. 2007), and optimal scheduling (Momoh and Zhu 2003). It is "used to derive relative priority scales of absolute numbers from individual judgments that also belong to fundamental scale of absolute numbers" (Saaty 2005). The judgments reflect the relative importance or influence of one of two elements over the other in a pairwise comparison process on a third element in the system (Saaty 2005). In ANP, pairwise comparisons of the elements in each level are conducted with respect to their relative importance towards their control criterion. The outcome of the comparison process is used in the development of the super matrix. The super matrix has to be raised to exponential powers until weights converge and remain stable to get the limit super matrix. Thus, all columns of the limit super matrix are the same and final priorities of all elements in the matrix can be obtained by normalizing each cluster of the limit super matrix. This is where the final ranking values are determined.

The world is far more interdependent than we know how to deal with using our existing ways of thinking and acting. Especially when we have different choices to choose between and each choices are interdependent, ANP is our logical way to deal with it. ANP is desirable especially when dealing with situations where there is data limitation and when dealing with intangible variables such as war risk, political issues etc (Thomas Saaty 2013). "The ANP modeling process replaces the many criteria of the hierarchy by a proper network relationship connectivity between elements and clusters, so the problem is represented in a closer way to what occurs in real life" (Claudio Garuti et al 2017). The ANP modeling process provides a way to explicit all the relationships among variables, reducing significantly the gap between model and reality. The way that ANP deals with the relations among variables (through pair-wise comparisons), helps to drive the attention to a given connection at a time, allowing a more accurate and comprehensive analysis.

However, ANP is not absolutely consistent with no errors. Inconsistency in ANP modeling is a measure of how the scales given from 1 to 9 are consistent considering relationship between factors. Inconsistency measures the logical inconsistency of a judgments. For example, if A is more important than B and B is more important than C and then C is more important than A, this is not being consistent. A measurable inconsistent situation would arise if it were that A is 3 times more important than B, B is 2 times more important than C, and that C is 8 times more important than A. In general, the inconsistency ratio should be less than 0.1 or so to be considered reasonably consistent (Thomas Saaty 2013). The inconsistency measure is useful for identifying possible errors in judgments as well as actual inconsistencies in the judgments themselves (Rozann Saaty 2016). Inconsistency in judgment is allowed and a measure for it is provided which can direct the decision maker in both improving judgment and arriving at a better understanding of the problem. Having a tolerable inconsistency is important as it helps in gaining more knowledge and develop the method further (Thomas Saaty 2006).

## 2.11. Development and use of MCDM

Decision-making has been the main concern of many intellectuals since ancient times. As decision made by an individual may not be representative of others, aggregating the opinion or the preferences of voters or individuals of a community into collective or social preferences is quite similar problem to devising comprehensive preferences of a decision-maker from a set of conflicting criteria in MCDM analysis (Salvatore Greco et al 2016). With the rise of big data and the advent of dynamic data visualization tools, there is a growing need to use data analysis to manage risk. However, there are limits to data analysis, one of which is that the historical data used is inherently backward looking. Therefore, one can see how the system has worked in the past and look for correlations that can give clues about causality. However, in order to make predictions, one cannot extrapolate these results into the future, assuming that the system will behave in the future as it did in the past. Situations and variables are constantly changing and the past may not be a good predictor of the future. This is where MCDM and other decision making tools are found worth looking forward to. Multi-Criteria Decision Making is a useful tool in decision making in a variety of economic, manufacturing, material selection, military, constructional, and other sectors (Rohan K. Gavade 2019). It is particularly beneficial in the areas of investment decision, project evaluation, economic benefit evaluation, and staff appraisal. Many strategies have been presented to tackle problems involving many attributes decision making. Despite the fact that the concept of MCDM has matured, it is natural and appealing that there have been far too many articles and research papers written about it. On October 26–27, 1972, the University of South Carolina's Capstone House hosted the first Multiple Criteria Decision Making (MCDM) Conference. There were approximately 250 researchers in attendance, and 63 papers were presented. The term "MCDM" was originally coined at this meeting (Yong Shi et al 2011). Since then, several studies in other domains like economics, sociology, psychology, mathematical programming, even medicine and archaeology have been undertaken in order to better understand and improve this method. Now this method is far more advanced than it ever were. Along with many other techniques developed under MCDM method, ANP is one of the most frequently used and advanced technique.

## 2.12. Empirical review

Various researches have been done on construction safety management both globally and locally. Though most researches on safety of high-rise buildings are focused on fire hazard protection, there are few researches done on safety risk of high-rise building constructions.

Mathew Hallowel and John Gambatese (2007) came up with an equilibrium model for managing safety risks. The authors selected 29 construction safety experts and have those safety experts identify safety programs that are being used by general contractors. They used the concept of equilibrium to select safety programs for each construction process and safety risks. Each construction activity will have safety risks and to mitigate each safety risks there are safety programs which have safety mitigations. Their model helps to determine which safety program better fits each construction activity and better mitigate safety risks.

Zhangang Su (2014) compile safety risks in high-rise building constructions by collecting information, determining risk events and consequences, classifying risk factors, and compiling safety risk list. The author compiled the following safety risks; falling accidents from high places (more than 2 meters), object strike, collapse, mechanical injury, electrical shock, lifting harm, vehicle hazard, fire hazard, explode harm and others. After compiling these safety risks as potential safety risks, the author suggested hierarchical modeling to be done for those listed safety risks for future study.

Nurzawani etal (2016) identified safety risks in high-rise building construction and put them into a smaller set of dimensions using factor analysis method. They found out that working environment, exposure to hazardous conditions, work at elevation, inadequate safety procedure, and temporary structures were found to be principal safety risk factors with others under these categories. The authors also suggested that these identified safety risks be modeled/prioritized for future research.

Fiktor Belachew (2020) assessed the current safety practices in high-rise building construction sites in Addis Ababa. The author found out that objects falling from a height, workers falling from scaffolding during construction and stairways and ladders collapse are the major causes for fatal individual injuries as well as death in high rising construction sites in Addis Ababa and also found out that most construction firms have safety policies and “Safety first” motto in their working environment. The author further explains that there is lack of commitment from top management levels and governmental policies concerning safety of construction workers is considerably low.

Amanual Temesgen Mosie (2022) did an assessment of challenges, identifying the main factors which affect the construction process of high rise building construction. The author identified cost overrun, delay, safety risks, and vertical transportation of materials and manpower to be the major challenges for high-rise buildings. After identifying these major challenges, the author also identified improper safety-net system, failure to secure heavy materials during lifting, and fall from height, unprotected shaft or hole, unprotected outside edge of a slab or balcony, fix scaffold without adequate fall protection, and exposed sharp edge of a reinforcing bar or mesh, communication difficulties at the height of the building, insufficient space to fix tower cranes, and concrete pump line blockage due to the pipeline itself to be major safety risks for construction of high-rise buildings in Addis Ababa.

Girma Geremew Belay (2018) claims that the study is the first study in Ethiopia that separately deals with foreign and domestic contractors. It is a comparative evaluation of high rise building safety practice between domestic and foreign contractor's in Addis Ababa high-rise building construction projects. The author used Likert scale to evaluate the safety practice and found out that there is a greater disagreement by 8.5% regarding safety management arrangement on their site the respondents from foreign managed projects response show than the projects managed by domestic ones, and agreement to the statements is lesser than by 19%. Regarding work place precaution and active monitoring there is only a 5% difference under foreign managed projects. Regarding challenges in exercising safety practice at project sites indicate that there is no any significant difference in agreeing and disagreeing to the statements there exist a 6% higher response from foreign managed project in the response that indicate neutrality. The author finally suggested that safety issues should be taken seriously and there should be amendments in the law that helps to better manage safety of construction sites. So far, no research has been done to prioritize safety risks in Ethiopia using network modeling or so that distinguishes between foreign and domestic (local) contractors.

Most of the above researches are focused on just improving safety practices and evaluating or assessing safety practices in high-rise building constructions. They lack prioritizing safety risks based on some criteria like importance or influence and they also lack to determine which construction phase is risky than others. This is the first study so far that prioritize safety risks based on importance and determine which phase is risky that distinguishes between foreign contractor held and local contractor held high-rise construction sites.

## 2.13. Summary and observed gap in literatures

Building high rise structures are exposed to safety risks than conventional buildings. Researchers have been endeavoring to minimize or even make the industry achieve zero accidents and have ultimate safety performance (Zwetsloot et al. 2013; 2017). They have been assessing, evaluating and investigating safety practices and laws directed towards enhancing safety. But, they did not identify and evaluate safety risks themselves. Modeling risk is one of the most widely used methods to analyze and predict risks. It is a quantification of risk which helps to precisely predict and manage risks before they occur and cause danger. It is proactive kind of safety management approach. Safety is better managed when we have a risk model which can help in assessing and predicting risks. Studies concerning safety assessment and management have been done in Ethiopia but they lacked to rank which safety risk is high along with which construction phase is risky and also lacks to distinguish between foreign contractor held and local contractor held construction sites. As presented in the background of this study, Ethiopia suffers high rate of construction workers' injury. Most high-rise buildings have been constructed by foreign contractors and their safety practices are different from those of local contractors. Hence, the author found it compelling to identify and prioritize safety risks and the most risky construction phase for both local and foreign contractors and compare the results to determine which safety risk is prominent in their respective sites. Moreover, there is a huge gap in prioritizing safety risks for both local and foreign contractors in a way that enables safety managers and concerned bodies to compare their safety risk exposure. In order to make the model useful it must represent real life situations, which is why ANP risk modeling is chosen. ANP is risk assessment and modeling technique which allows interdependence between variables at the same cluster and give feedback.

Studies have been conducted to make the working environment for construction workers safer. So far researches has been conducted in safety practices and regulations focusing to enhance the safety of workers in occupational health perspective only. It has been believed that applying more and more safety packages and safety practices will help manage safety better. Since the past few years, there are some researches that are focused on identifying what kind of safety risks are there in high-rise buildings construction. Safety managers and/or safety management team or any concerned body see accident rates and reports as a signal or red flag to improve safety and not by determining which safety risks is likely important than others and thus manage that properly. It has also been undermined that there is an opposite relationship between safety and risk that while safety is a state of being free from danger, risk is the “probability or threat of damage, injury, liability or loss, or any other negative occurrence that is caused by external or internal vulnerabilities, and that may be avoided by preemptive action”. And if we want to increase safety we must first consider risk and manage it properly to minimize it. Note that risk can be avoided by preemptive action and identifying safety risks and prioritizing them helps to manage safety in proactive manner not in reactive one. But, no matter how thorough the safety management is, unless we manage risk effectively it will be difficult to be free from any danger as risk is inevitable in construction. So to better manage safety it will be effective and efficient if we manage risk better. This is why this research is mainly focused on safety risk modeling, than assessing or evaluating safety practices, to better manage risk and enhance safety at the same time. Moreover, the identified safety risks have not yet been studied in terms of modeling or prioritizing those safety risks using different modeling techniques in both local contractor’s construction sites and foreign contractor’s construction sites which will give a chance to determine which safety risk is prominent and what is the riskiest construction phase in their respective sites. This has not been done so far.

# CHAPTER THREE

# METHODOLOGY

## 3.1. Introduction

In this chapter methodological approach implemented, type of data used, sources of data, and method of data analysis are mainly explained along with justification as to why those methods are chosen.

## 3.2. Study Area

The study is conducted in Addis Ababa city because most of high-rise building in Ethiopia as well as foreign contractors working on high-rise buildings are found in the capital (EMPORIS 2019). Addis Ababa is the most safety risk exposed city in all of Ethiopia (Yoseph Merkeb Alamnehet al 2020). The capital city Addis Ababa has 11 sub cities whose map is shown below in figure 3.1.


Figure 3. 1 Study Area

## 3.3. Study design and methodology

Research methodology is a systematic procedure a researcher uses to solve a defined research questions and it is perhaps the most critical part of any thesis or research papers. Choosing the correct research methodology can determine the success and overall quality of a paper. The research questions listed in chapter one of this thesis paper are "what" and "which" which basically tells what kind of research method best answers those questions and consequently choose a research method. The research method is descriptive kind of research because it involves describing a subject matter both qualitatively and quantitatively without influencing it in any way. Descriptive research is defined as a research method used to describe the existing phenomena as accurately as possible (Haryanto Atmowardoyo 2018). The phenomena observed through descriptive study have already been documented, i.e. there is a detailed information/data about the phenomenon under investigation. A researcher's job is to collect data using research instruments such as tests, questionnaires, interviews, and other data collection methods.

Haryanto Atmowardoyo stated that the primary purpose of descriptive research is to characterize existing phenomena in a systematic manner. It is best suited to represent characteristics of individual data and sample thereof. It provides information useful to the solutions of a problem in hand. The survey may be qualitative or quantitative in verbal or mathematical form of expression; such studies are factual and hence supply practical information (Neeru Salaria 2012). According to Neeru Salaria this research method employs applications of scientific method by critically analyzing and examining the source materials, by analyzing and interpreting data, and by arriving at generalization and prediction. And since the objective of the study is to analyze existing construction safety risks the researcher find it useful to use descriptive kind of research which helps to analyze already existing phenomena and represent it accurately. In order to answer research questions previously mentioned in chapter one of this study in section 1.3, both qualitative and quantitative data was used. Literature review was used in order to identify safety risks and panel of discussion was conducted in order to identify the most common safety risk factors that the Ethiopian high-rise building construction suffers, and after identifying these common safety risk factors questionnaire was used to determine the relationship between those safety risks and weigh them in order to rank them. Excel was used to aggregate individual judgments and ANP super-decision software were used for analysis of the collected data and for the final modeling/prioritization.

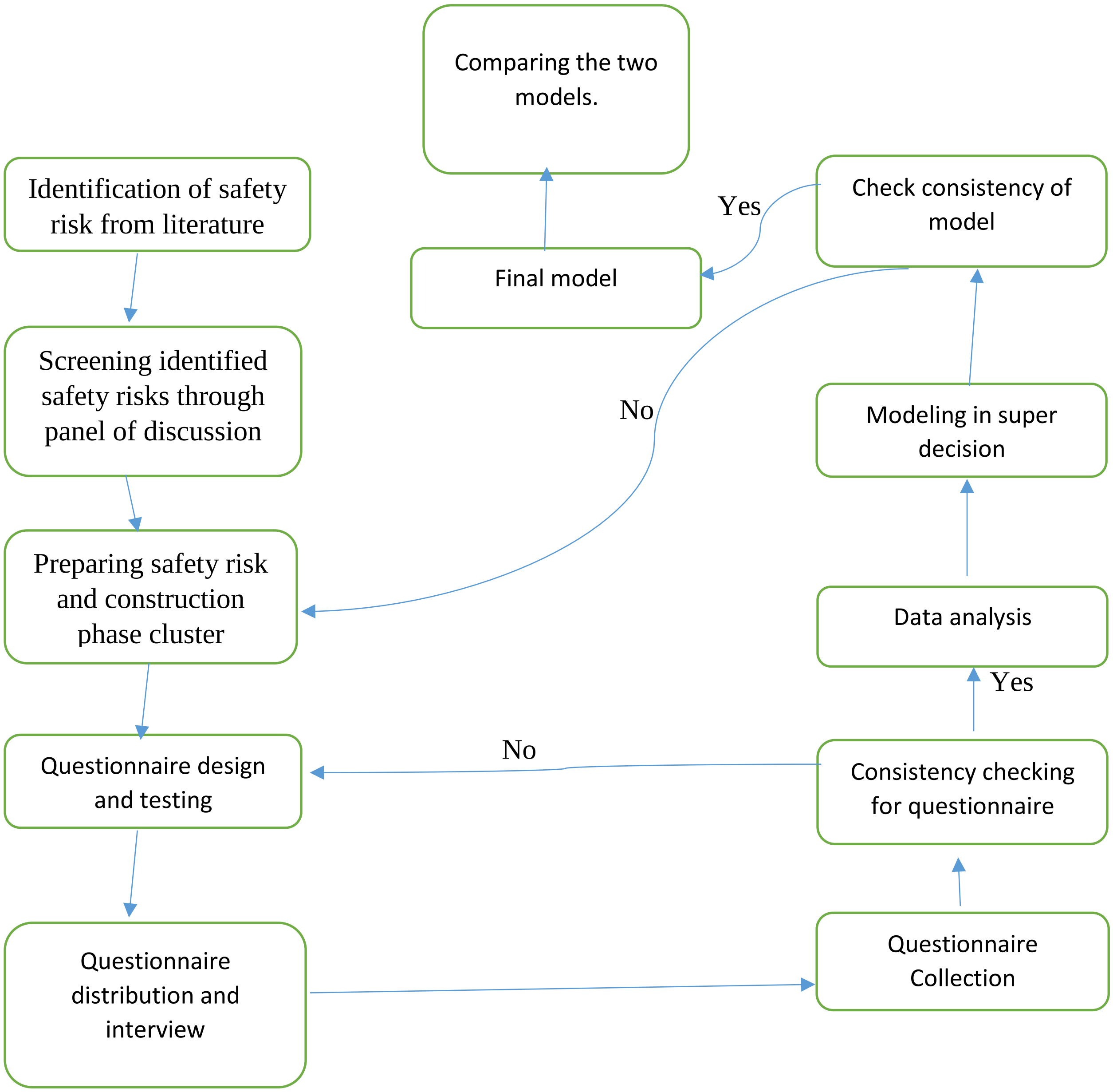


Figure 3. 2 Study design.

The study followed the design as stated in the above figure 3.2 where it starts from identification of safety risks and ends with comparison of foreign and local contractors' prioritization of safety risks.

## 3.4. Study population and sampling

### 3.4.1. Target population

The target population of this study are active high rise building construction projects that are found in Addis Ababa. According to Yonatan Taddesse (2020) high rise buildings in Ethiopia are totally 32. But according to Addis Ababa city building permits and control Authority there are 104 buildings which the authority permit to construct high-rise buildings and among these projects there are only 41 active projects among which 16 are being constructed by foreign contractors and the remaining 25 by local contractors. These 41 projects are target population and safety officers and their staff members are respondents.

### 3.4.2. Sampling technique

Sample can be defined as a group chosen from a larger population with the aim of yielding information about this population as a whole (Neetij Rai and Bikash Thapa 2004). It is a smaller representation of a larger whole. And sampling is the process by which a relatively small number of individuals or measures of individuals, objects or events is chosen and analyzed in order to find out something about the entire population from which it was chosen from. Sampling method provides generalizations on the basis of relatively small preparations of the population.

Since the study looks forward to select which construction phase is risky and which safety risk is important than others, the researcher choose purposive sampling. Purposive sampling is a type of non-probability sampling in which the researcher makes decisions about who should be included in the sample based on a range of criteria (Neetij Rai and Bikash Thapa 2004). The main goal of purposive sampling is to focus on particular characteristics of a population that are of interest, which will best enable the researcher to answer the research questions. And since the number of population under this study are small it will best enable the researcher to answer research questions raised previously. The construction phase at which the target population are in during the time of conduct of the study and whether foreign or local contractors are building it are used as a criteria to select them and hence purposive sampling fits in perfectly with respect to the objective of the study. Among those 41 high-rise building constructions in Addis Ababa that are under construction, 23 are selected as a sample where 13 from local contractor sites and 10 from foreign contractors. Among those 13 sites under construction by local contractors 5 sites are in sub-structure phase, 4 under superstructure, and 4 under finishing phase. And among those 10 sites of foreign contractors 4 are in sub-structure, 3 under super-structure, and 3 under finishing phase which will give us a total of 23 sites.

## 3.5. Sources of data

The source of data for the study is both primary and secondary data. Primary data includes all data collected by the researcher like direct questionnaires. While secondary data includes the ones that are obtained from already published sources like articles, journals, thesis papers and other researches including websites.

## 3.6. Data collection

The researcher found all necessary data from primary sources of information from questionnaire. Questionnaire provides firsthand information on the subject matter (Abiy et al., 2009). The questionnaire for this research is prepared in a way that fits ANP modeling technique. Literature review was used to identify safety risks. After identifying them from both international and national literatures, 2 safety engineers who have been working for foreign contractors and 3 who have been working for local contractors was selected using a criteria of work experience. Two from foreign contractors' side has a working experience of 6 and 7 years and 3 that are from local contractors have a working experience of 5, 6, and 8 years. After identifying safety risks from literature, panel of discussion were held among those safety experts to check if the high-rise construction trend in Ethiopia suffer all or some of the identified safety risks. They agreed that the only safety risks that the high-rise buildings suffer in Ethiopia are 12 out of 18. The reason why they were odd numbered participants is that in case they disagree on which safety risk must be included for prioritization odd numbers help to decide than even numbers. After these safety engineers identified safety risks that the high-rise construction trend in Ethiopia suffer, the author prepared ANP based questionnaire using ANP super-decision software and excel and distributed it to 68 safety officers and their staff members, among which only 60 was collected. 32 was successfully collected from local contractors' construction site and 28 from foreign contractors' construction sites.

## 3.7. Data analysis

### 3.7.1. ANP modeling

To achieve the project objectives the data analysis method the researcher used is statistical analysis method. Statistical analysis means investigating trends, patterns, and relationships using quantitative data. After collecting data, the researcher organized and summarized the data using descriptive statistics which helps to summarize and organize characteristics of a data set. A data set is a collection of responses from a sample. The data collected from experts was analyzed using Excel and ANP super decision software which helps to prioritize safety risks depending on experts scale included in the questionnaire and weigh them accordingly.

As mentioned in section 3.6 of this study, literature review and panel of discussion were used to identify safety risks. After identification ANP modeling or prioritizing technique was used for prioritizing those safety risks and graphical presentation using excel was used for comparison.

### 3.7.2. ANP procedures

An Analytic Network Model of a problem may consist of a single network or a number of networks. To build an Analytic Network Process (ANP) network, you need to:

- Think about the elements in it and decide what kind of logical groupings of nodes and clusters would best describe the problem;
- Build a cluster first, then create the nodes within it
- Select one node as a potential parent node and examine all the clusters in turn to determine if they have nodes that the parent node either influences or is influenced by to select its children nodes in that cluster.
- Create the links between the parent node and all its children nodes in each cluster – this is how the comparison sets of nodes are created.
- Clusters are linked automatically when nodes are linked.
- Make sure the questions are is posed in a consistent way throughout this network. Make pairwise comparison judgments on nodes and clusters and synthesize. (Rozann Saaty 2016)

## 3.8. Data validity and reliability

Reliability is about the consistency of a measure, and validity is about the accuracy of a measure. Reliability tells us the extent to which the results can be reproduced when the research is repeated under the same conditions. Validity is about the extent to which the results really measure what they are supposed to measure. The validity of the research is checked by panel of discussion held between safety professionals, two of which has been working for foreign contractors for more than 4 years and three of them are from local contractor firms who worked for more than 4 years. These safety professionals scrutinize the identified safety risks from literature. The reliability of the data is checked by inconsistency index (C.I) in ANP modeling. This index determines whether the judgment is reliable or not. The index is calculated by software automatically, but, for the matter of convenience it can be manually calculated using the following steps and the software calculates it using the same technique:

$C.I = (\lambda max - n)/ (n-1)$

Random consistency (R.I) is given as:

Table 3. 1 Random consistency index (R.I)

| N | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|
| R.I | 0 | 0 | 0.52 | 0.89 | 1.11 | 1.25 | 1.35 | 1.4 | 1.45 | 1.49 |

Source of table (Thomas Saaty 2008)

$\lambda$max is the maximum eigenvalue of the matrix, and n is the order of matrix. According to rule of thumb, the comparison matrix is consistent only if the value of CR is less than 0.1.

The inconsistency test includes the following four steps:

Step 1: Calculate the max of one comparison matrix.

Step 2: Calculate the value of CI using the formula $C.I= (\lambda max - n)/(n-1)$

Step 3: Calculate the CR using the formula C.R=C.I/R.I and the above table

Step 4: Compare the value of CR with the consistency threshold 0.1 to judge whether the comparison is consistent.

Using these steps the model (priorities) is checked for consistency. It is considered to be consistent if the inconsistency index is less than 0.1. The judgment with inconsistency index of more than 0.1 is considered to be invalid and do not represent the problem under consideration (Thomas Saaty 2008, Daji Ergu et al 2011). The inconsistency index is calculated automatically by the software. The inconsistency index for all judgments and comparison matrices will be shown in result and discussion chapter of this study.

# CHAPTER FOUR

# RESULT AND DISCUSSION

## 4.1. Introduction

In this chapter, the findings from the questionnaire are presented and discussed. The analysis and interpretation of data is carried out in three sections. The first section presents the respondents' background, then second section is the presentation of result and the third section presents discussion of the questioner survey. Based on the result, ANP network model is built with prioritized safety risks along with construction phase. The result is presented in tables, figures and networks.

## 4.2. Questionnaire response rate

Among 68 questionnaires that was distributed to all safety officers and their staff, 3 was incomplete, 4 was incorrect, and 1 was not responded to. Only 60 questionnaires was responded to successfully.

Table 4. 1 Response Rate

| Respondents | Total no of questionnaires distributed | Successfully responded | Incomplete response | Incorrect response | Not responded |
|---|---|---|---|---|---|
| Safety Engineers and their staff members | 68 | 60 | 3 | 4 | 1 |
| Percentage | 100% | 88% | 4% | 6% | 1.5% |

As presented in table 4.1 above, among 68 questionnaires distributed only 6% response was incorrect and only 4% of it was incomplete showing how the participants carefully filled the questionnaire. The 60 questionnaires that was correctly filled and passed consistency check, 32 or 53.3% was in local contractor held construction sites and 28 or 46.7% was in foreign contractors held construction sites. And the number of both local and foreign contractors held sites are in figure 4.1 below:-

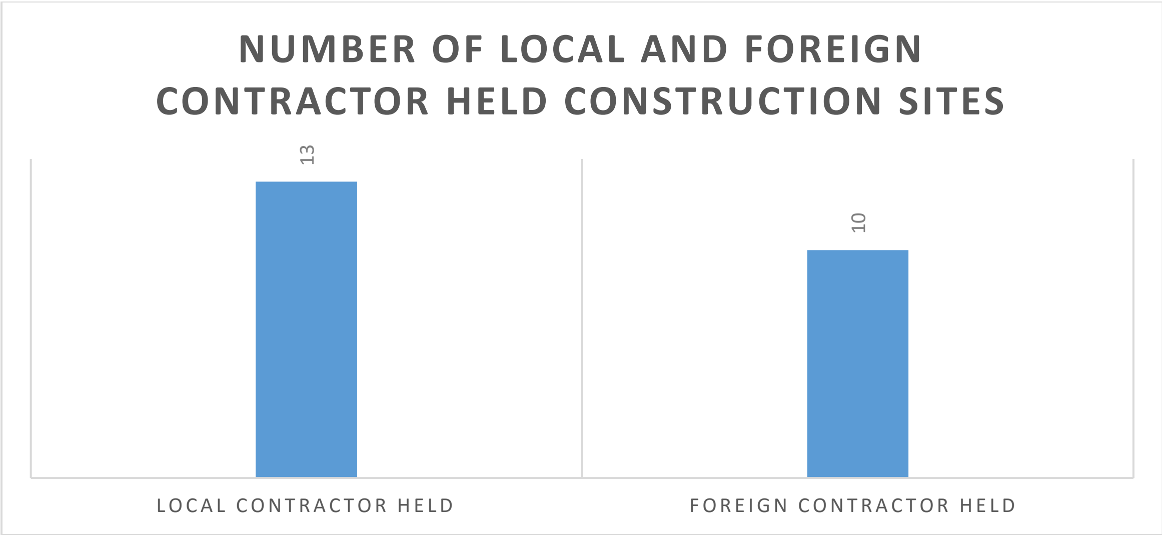


Figure 4. 1 Number of local and foreign contractors held construction sites.

## 4.3. Respondents' profile

Among the 60 safety engineers, 62% or 42 have a Bsc degree and 26% or 18 have Msc. this is presented in figure 4.2 below.

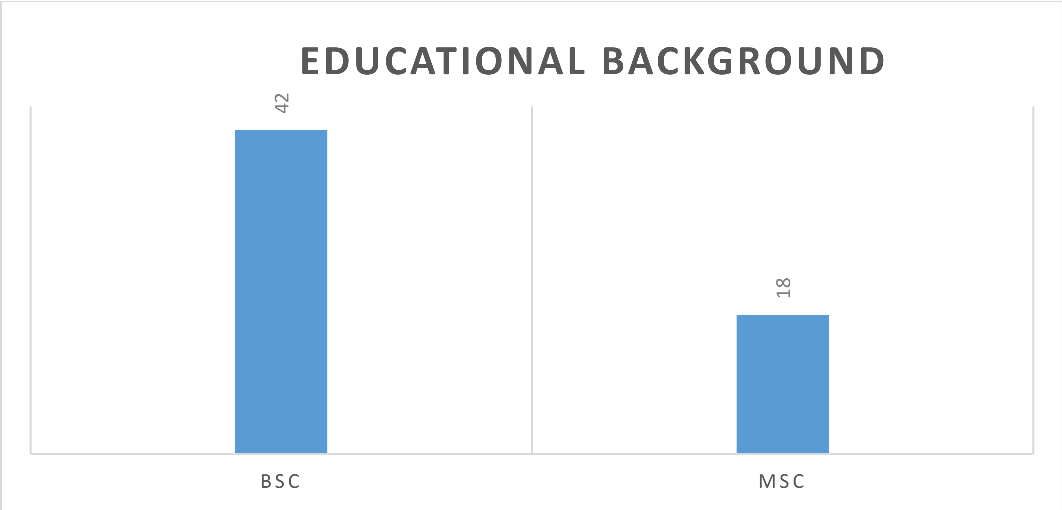


Figure 4. 2 Educational background of respondents.

And as presented in figure 4.3 below 52% or 31 of the respondents have a working experience that varies from 0 to 5 years, 27% or 16 have from 5 to 10 years and 22% or 13 have a working experience of more than 10 years.

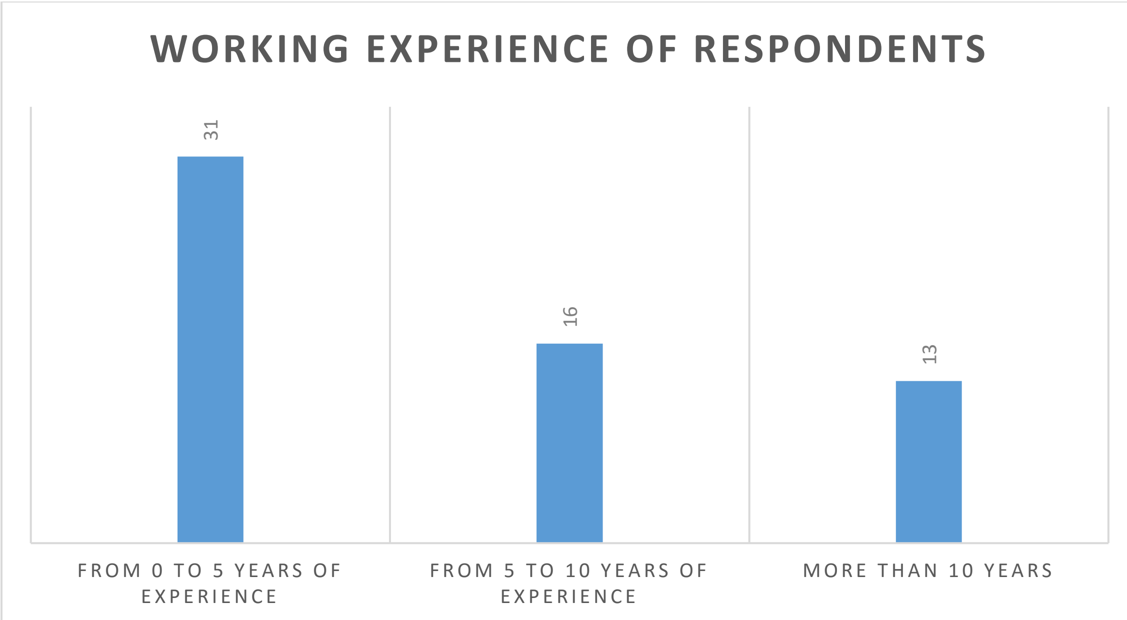


Figure 4. 3 Working experience of all respondents

## 4.4. Prioritization of safety risks and construction phase

The study identifies safety risk factors that the high-rise construction suffers in Ethiopia, prioritizes them and depending on whether local and foreign contractor hold these sites a comparison is carried out.

Safety risks that the high-rise building construction in Ethiopia currently suffer are identified to be (result from pilot survey) the following:-

Trench failure/excavation accident, being hit by moving objects like vehicle, falling objects, struck by or against something, caught in/compressed by equipment or objects, slips, trips, and falls, repetitive motion, ladder accident, falling from height, electric or heat burn, scaffolding accident, and manual handling.

The overall hierarchy for both local and foreign prioritization can be represented as the following in figure 4.4.

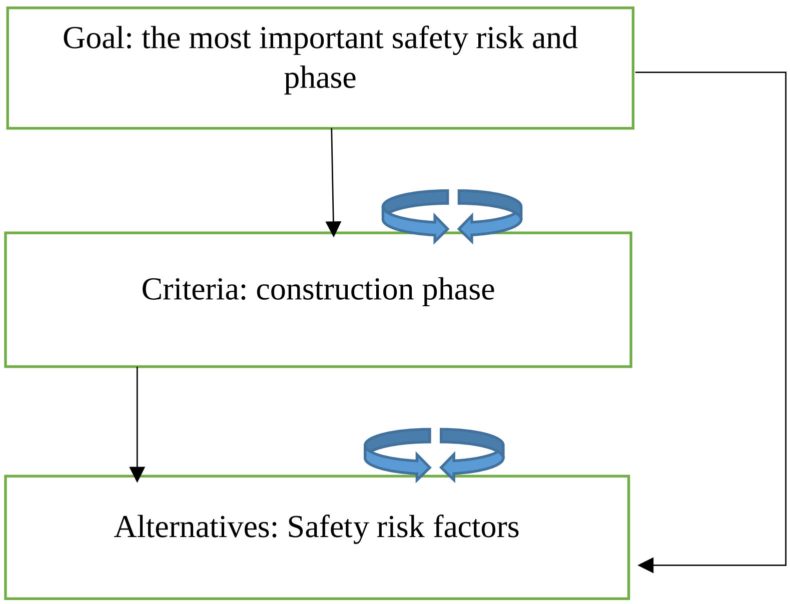

Figure 4. 4 Hierarchy of network

After collecting the 60 consistent questionnaires, geometric mean was calculated separately for local and foreign contractors. After inserting the geometric mean into the data analysis tool Super Decision Software, the following results were obtained.

### 4.4.1. Results for local contractors held construction sites.

With respect to the goal node construction phases has a prioritization as presented in table 4.2 below, which shows that sub-structure phase is the most risky phase in local contractors' case. The inconsistency for this prioritization is 0.01748, which is below the maximum inconsistency value that is 0.1 and shows that the judgment is reliable.

Table 4. 2 Priorities among construction phases.

| Name | Normalized | Rankings |
|---|---|---|
| Sub-Structure | 0.5208 | 1 |
| Super-Structure | 0.2979 | 2 |
| Finishing | 0.1813 | 3 |

The following table 4.3 shows that trench failure/excavation accident is the most important safety risk when safety risks are compared with respect to sub-structure phase in case of local contractors.

The inconsistency of this judgment is 0.04249, which is below maximum inconsistency index allowed 0.1, and the judgment is reliable or consistent.

Table 4. 3 Priorities with respect to Sub-Structure.

| Name | Normalized | Rankings |
|---|---|---|
| Trench failure/excavation accident | 0.2775 | 1 |
| Falling objects | 0.165 | 2 |
| Falling from height | 0.1364 | 3 |
| Slips, trips, and falls | 0.0943 | 4 |
| Repetitive motion | 0.0604 | 5 |
| Being hit by moving objects like vehicle | 0.0554 | 6 |
| Manual handling | 0.052 | 7 |
| Struck by or against something | 0.044 | 8 |
| Caught in/compressed by equipment or objects | 0.042 | 9 |
| Scaffolding accident | 0.039 | 10 |
| Ladder accident | 0.034 | 11 |

The following table 4.4 shows that falling objects is the most important safety risk when safety risks are compared with respect super-structure phase in case of local contractors. The inconsistency of this judgment is 0.02944 which is below maximum inconsistency index allowed 0.1.

Table 4. 4 Priorities with respect to Super-Structure.

| Name | Normalized | Rankings |
|---|---|---|
| Falling objects | 0.2408 | 1 |
| Falling from height | 0.2208 | 2 |
| Slips, trips, and falls | 0.1634 | 3 |
| Repetitive motion | 0.075 | 4 |
| Being hit by moving objects like vehicle | 0.064 | 5 |
| Caught in/compressed by equipment or objects | 0.054 | 6 |
| Struck by or against something | 0.051 | 7 |
| Scaffolding accident | 0.046 | 8 |

| | | |
|---|---|---|
| Manual handling | 0.048 | 9 |
| Ladder accident | 0.037 | 10 |

The following table 4.5 shows that falling from height is the most important safety risk when safety risks are compared with respect finishing phase in case of local contractors. The inconsistency of this judgment is 0.04172 which is below maximum inconsistency index allowed 0.1

Table 4. 5 Priorities with respect to Finishing.

| Name | Normalized | Rankings |
|---|---|---|
| Falling from height | 0.2376 | 1 |
| Electric or heat burn | 0.1588 | 2 |
| Falling objects | 0.146 | 3 |
| Slips, trips, and falls | 0.1424 | 4 |
| Being hit by moving objects like vehicle | 0.0576 | 5 |
| Repetitive motion | 0.0575 | 6 |
| Caught in/compressed by equipment or objects | 0.0471 | 7 |
| Scaffolding accident | 0.045 | 8 |
| Struck by or against something | 0.041 | 9 |
| Manual handling | 0.035 | 10 |
| Ladder accident | 0.032 | 11 |

As presented in table 4.6 below, falling from height is the most important safety risk in local contractors held sites when compared with respect to the goal or the most important safety risk. The inconsistency of the whole prioritization is 0.03843. This shows that the result is internally valid and the judgments are reliable.  Falling from height is also identified as the most important safety risk factor in high-rise construction trend (Girma Geremew 2018, Lucy Feleke et al., 2016) using relative importance index method which uses a 1 to 5 scale for prioritization. RI index is a simple prioritization tool that is often used by researchers when trying to simply find out which factor is the most important one by assigning a 1 to 5 scale for each alternative without having a comparing node or a control criterion and a goal node. The drawbacks of this prioritization method is discussed in the discussion section of this chapter.

Table 4. 6 Final Rankings of safety risks for local.

| Name | Normal | Rankings |
|---|---|---|
| Falling from height | 0.1946 | 1 |
| Falling objects | 0.1704 | 2 |
| Slips, trips, and falls | 0.127 | 3 |
| Trench failure/excavation accident | 0.109 | 4 |
| Electric or heat burn | 0.068 | 5 |
| Repetitive motion | 0.062 | 6 |
| Being hit by moving objects like vehicle | 0.058 | 7 |
| Caught in/compressed by equipment or objects | 0.046 | 8 |
| Manual handling | 0.043 | 9 |
| Struck by or against something | 0.044 | 10 |
| Scaffolding accident | 0.043 | 11 |
| Ladder accident | 0.035 | 12 |

The model as presented in the super decision software is presented respectively for both local and foreign held construction sites as follows:

The arrows show the relationship between them. And since it may not be seen from the model, the factors that do not have relationship are Sub-structure and Electric/heat burn, Super-structure and Trench failure/excavation accident, Super-structure and Electric/heat burn, Finishing and Trench failure.

The ANP model looks like the following with arrows showing relationship and the inconsistency of the model was determined to be 0.03843, which is less than the maximum threshold 0.1, which shows the model as acceptable. The arrows represent importance relationship or safety risk factors and phases that are being compared. And while "arrow in" nodes represent factors that are being compared, "arrow out" nodes represent the criteria that are being compared against or "with respect to" nodes. And note that the results does not show which party among local and foreign contractor held sites is riskier, i.e. it is independent result that shows which construction phase and which safety risk important in their respective sites. The percentage values does not show which is riskier. These works for both local and foreign network structure.

Goal **=** the most important safety risk and the most risky construction phase

Criteria = Construction phase i.e sub-structure, super-structure, and finishing phases

Alternatives= Safety risks that are:-

CR1 = Trench failure/excavation accident

CR2= Falling objects

CR3= Caught in/compressed by equipment or objects

CR4= Repetitive motion

CR5= Falling from height

CR6= Scaffolding accident

CR7= Being hit by moving objects like vehicle

CR8= Struck by or against something

CR9= Slips, trips, and falls

CR10= Ladder accident

CR11= Electric or heat burn

CR12= Manual handling

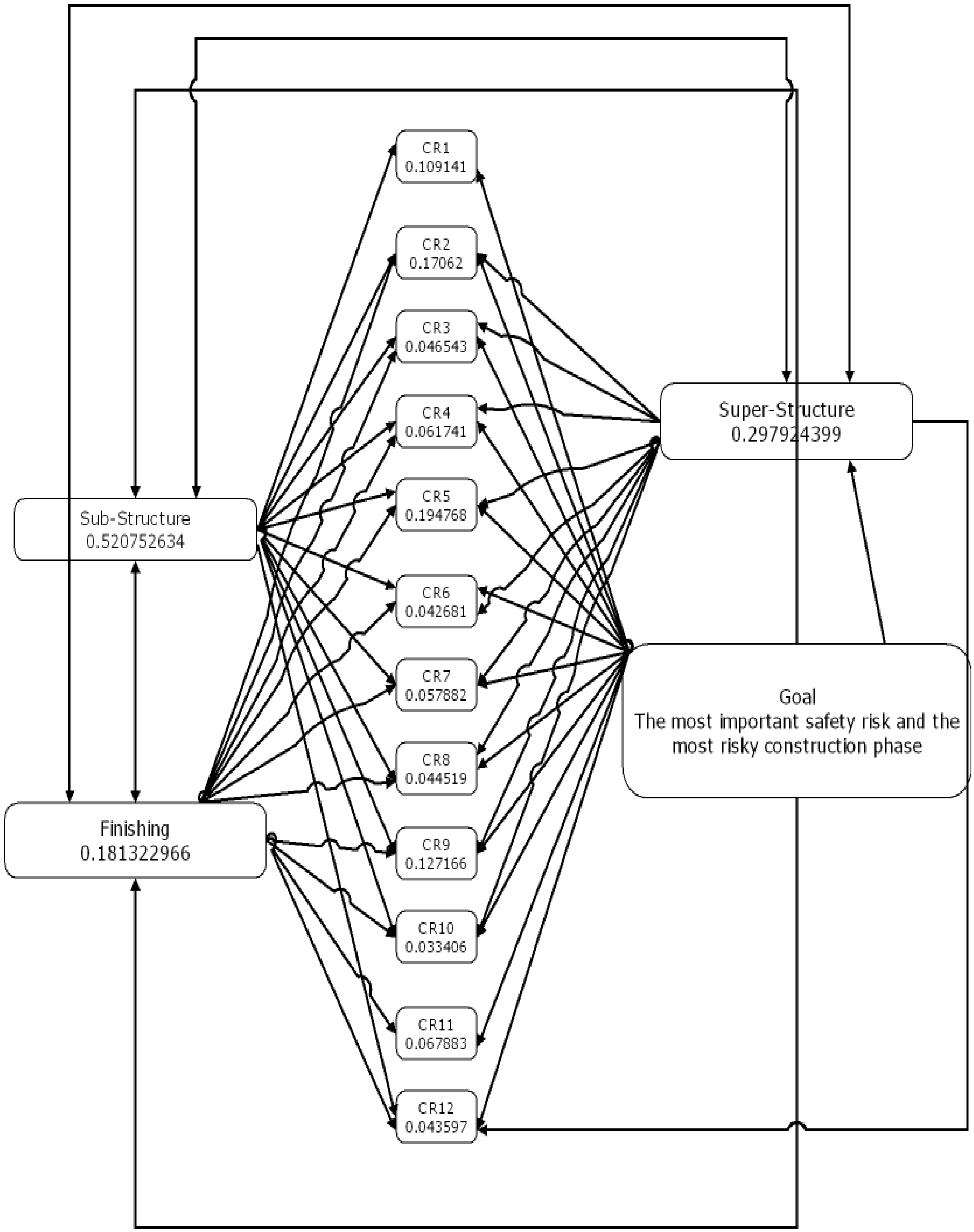


Figure 4. 5 ANP modeling of local contractor held sites.

The figure above, figure 4.4, shows the network structuring or modeling of locals in which the comparison and weight of all safety risk factors along with construction phases is put together.

#### 4.4.2. Results for foreign contractor held construction sites

With respect to the goal node construction phases has a prioritization as presented in table 4.7 below which shows that super-structure phase is the most risky phase in foreign contractors' case. The inconsistency for this prioritization is 0.05838, which is below the maximum inconsistency value that is 0.1.

Table 4. 7 most risky construction phase.

| Name | Normalized | Rankings |
|---|---:|---:|
| Super-Structure | 0.6101 | 1 |
| Sub-Structure | 0.2242 | 2 |
| Finishing | 0.1657 | 3 |

The results show that super-structure is the most risky phase than others in foreign contractor held sites.

Table 4.8 below shows that trench failure/excavation accident is the most important safety risk when safety risks are compared with respect to sub-structure phase in case of foreign contractors. The inconsistency of this judgment is 0.04318, which is below maximum inconsistency index allowed 0.1.

Table 4. 8 Priorities with respect to Sub-structure.

| Name | Normalized | Rankings |
|---|---:|---:|
| Trench failure/excavation accident | 0.2133 | 1 |
| Falling objects | 0.1788 | 2 |
| Falling from height | 0.1507 | 3 |
| Slips, trips, and falls | 0.1318 | 4 |
| Struck by or against something | 0.067 | 5 |
| Caught in/compressed by equipment or objects | 0.0571 | 6 |
| Scaffolding accident | 0.053 | 7 |
| Repetitive motion | 0.0458 | 8 |

| | | |
|---|---|---|
| Being hit by moving objects like vehicle | 0.0405 | 9 |
| Manual handling | 0.0322 | 10 |
| Ladder accident | 0.0298 | 11 |

Table 4.9 below shows that falling objects is the most important safety risk when safety risks are compared with respect to super-structure phase in case of foreign contractors. The inconsistency of this judgment is 0.04223, which is below maximum inconsistency index allowed 0.1.

Table 4. 9 Priorities with respect to Super-Structure.

| Name | Normalized | Rankings |
|---|---|---|
| Falling objects | 0.2717 | 1 |
| Falling from height | 0.1862 | 2 |
| Slips, trips, and falls | 0.1667 | 3 |
| Repetitive motion | 0.0797 | 4 |
| Struck by or against something | 0.0677 | 5 |
| Scaffolding accident | 0.0609 | 6 |
| Caught in/compressed by equipment or objects | 0.0514 | 7 |
| Being hit by moving objects like vehicle | 0.048 | 8 |
| Manual handling | 0.0357 | 9 |
| Ladder accident | 0.032 | 10 |

Table 4.10 below shows that falling objects again is the most important safety risk when safety risks are compared with respect to finishing phase in case of foreign contractors. The inconsistency of this judgment is 0.04338, which is below maximum inconsistency index allowed 0.1.

Table 4. 10 Priorities with respect to Finishing.

| Name | Normalized | Ranking |
|---|---|---|
| Falling objects | 0.2051 | 1 |
| Falling from height | 0.1933 | 2 |
| Slips, trips, and falls | 0.1478 | 3 |
| Electric or heat burn | 0.1134 | 4 |
| Struck by or against something | 0.0762 | 5 |

| | | |
|---|---|---|
| Repetitive motion | 0.0632 | 6 |
| Scaffolding accident | 0.0515 | 7 |
| Caught in/compressed by equipment or objects | 0.0437 | 8 |
| Being hit by moving objects like vehicle | 0.041 | 9 |
| Manual handling | 0.035 | 10 |
| Ladder accident | 0.0298 | 11 |

As presented in table 4.11 below, falling object is the most important safety risk in foreign contractors held sites when compared with respect to the goal node or the most important safety risk. The inconsistency of the whole prioritization is 0.0468, which shows that the judgment is reliable or consistent. This also shows that the result is internally valid. Falling objects is also identified as the most important safety risk in Ethiopian high-rise construction trend (Fasil Argaw 2017, Fiktor Belachew 2020) using RI index.

The whole model was synthesized to have the following priorities with an inconsistency index of 0.0468.

Table 4. 11 Final Rankings of safety risks for foreign contractors.

| Name | Normals | Rankings |
|---|---|---|
| Falling objects | 0.2232 | 1 |
| Falling from height | 0.1752 | 2 |
| Slips, trips, and falls | 0.1498 | 3 |
| Trench failure/excavation accident | 0.074 | 4 |
| Struck by or against something | 0.0695 | 5 |
| Repetitive motion | 0.064 | 6 |
| Scaffolding accident | 0.056 | 7 |
| Caught in/compressed by equipment or objects | 0.0515 | 8 |
| Being hit by moving objects like vehicle | 0.0435 | 9 |

| | | |
|---|---|---|
| Manual handling | 0.0345 | 10 |
| Ladder accident | 0.0308 | 11 |
| Electric or heat burn | 0.028 | 12 |

The model is presented in the same way as presented for local in figure 4.5. The difference is weight of each safety risks or prioritization with inconsistency 0.0468.

Thomas Saaty the founder of this method in his book states that having inconsistency is important in order to advance further for future development (Thomas Saaty 2005).

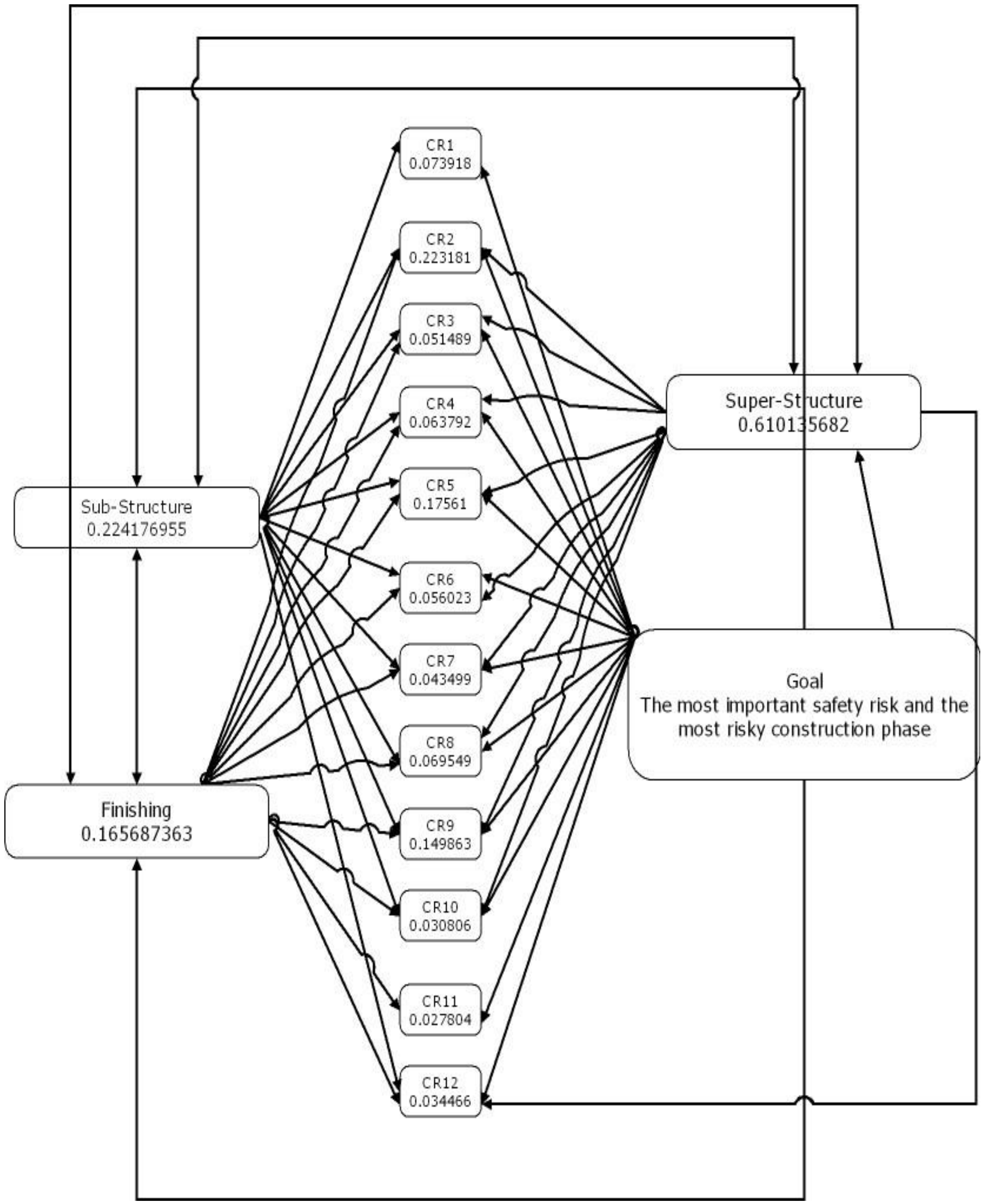


Figure 4. 6 ANP model of foreign held sites.

## 4.5. Discussion

This study aimed to identify, prioritize and compare which safety risk is the most important one and which construction phase is the most risky in high-rise buildings that are under construction in Addis Ababa city by local contractors and foreign contractors.

After analyzing the data using super decision software the results show that trench failure/excavation accident, falling object, falling from height, and slips, trips and falls are the top four most important safety risk factors in both local and foreign held construction sites in Sub structure phase. And in super-structure phase; falling from height, falling objects, slips, trips and falls, and repetitive motion are the top four most important safety risk factors in local held construction sites and in foreign held construction sites; falling objects, falling from height, slips, trips and falls and repetitive motion are the top four most important safety risk factors. While in the Finishing phase; fall from height, electric/heat burn, falling objects, and slips trips and falls are the top four most important safety risk factors in local held construction sites. In foreign held construction sites; falling object, falling from height, slips, trips and falls, and electric/heat burn are the top four most important safety risk factors.

In terms of determining which construction phase is risky in both local and foreign contractors held construction sites, the data shows that Sub structure is the most risky construction phase for local held construction sites while superstructure is the most risky for foreign held construction sites. To help us compare, the following chart shows how they vary in terms of being risky.

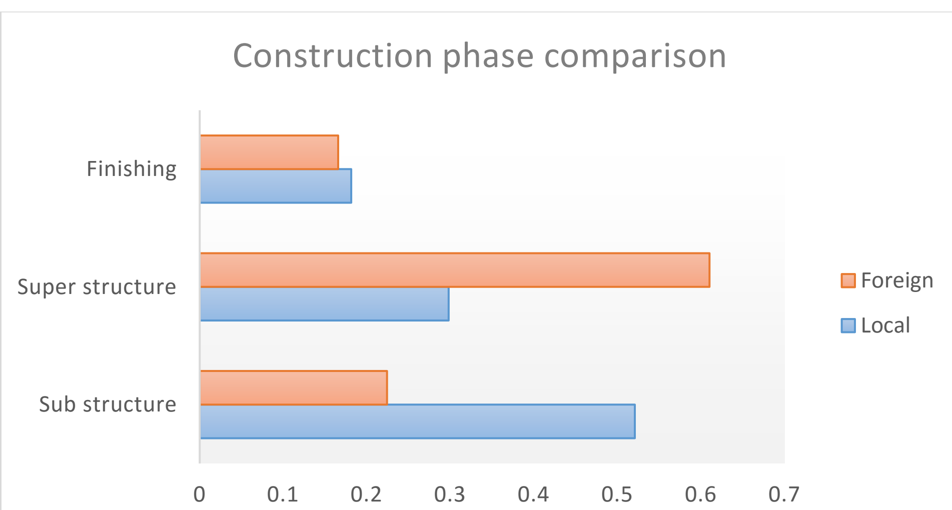


Figure 4. 7 Most risky construction phase comparison

The above chart shows that safety risks decrease from substructure to finishing phase in local held construction sites while in foreign held construction sites it starts low then increases to a peak point in super-structure phase and then decreases back as the project progresses to the finishing phase. When local held construction sites suffer more safety risk in substructure phase, the foreign held construction sites do not suffer as much as locals do in substructure, showing that most of the safety risk factors happening in local held construction sites are likely to happen in substructure phase than super structure and finishing phase. While for foreign held construction sites the story is different in a way that they start with less safety risks and it increases as the construction advances towards the construction of super-structure and the de-escalate back as the construction goes to the finishing phase. Most of safety risks in foreign contractors held construction sites happen in super-structure phase. The similarity here is that both local and foreign contractors held construction sites have less safety risk towards the finishing phase.

In terms of determining which safety risk is the most important safety risk as whole without pointing to a specific construction phase which has a value of more than 7%, falling from height, falling objects, slips, trips and falls, trench failure/excavation accident, and electric/heat burn are the top five most important safety risk factors in local held construction sites. In foreign held construction sites; falling objects, falling from height, slips, trips and falls, trench failure/excavation accidents are the top four most important safety risk factors. To help us compare the results let us see the following chart obtained from the priority weights of each safety risk factors in both local and foreign held construction sites:

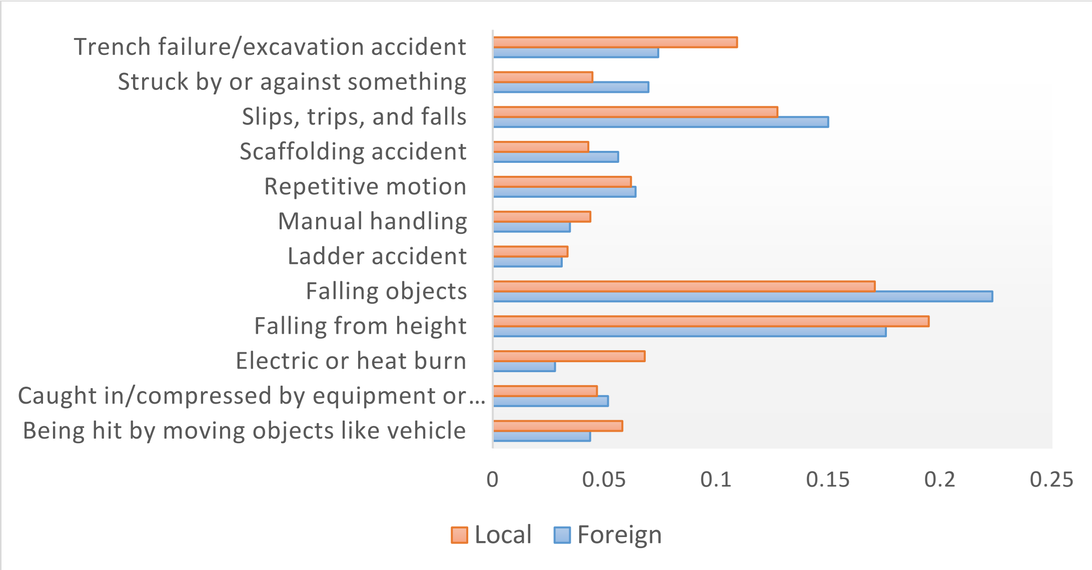


Figure 4. 8 Safety risk factors comparison

The above chart clearly shows how each safety risk is compared with respect to local and foreign contractors held construction sites. In the case of foreign contractor held construction sites, falling object is the most important safety risk factor and for local held construction sites Falling from height is the most important safety risk factor. As of the rest factors; being hit by moving objects is by 1.44% more important in locals than foreign held sites, caught in between/compressed by equipment is by 0.5% more important in foreign than in locals, electric/heat burn is by 4% more important in local than foreign held sites, falling from height is by 1.92% more important in local than foreign, falling objects is by 5.3% more important in foreign held sites than local ones, ladder accident is almost similar in both but is slightly more important in foreign by 0.26%, manual handling is slightly more important in local held sites by 0.9%, repetitive motion is slightly more important in foreign by 0.21%, scaffolding accident is by 1.33% more important in foreign held sites than locals, slips trips and falls is also more important in foreign held sites than local ones by 2.27%, struck by or against something is also more important in foreign than it is in locals 2.5%, and finally trench failure or excavation accident is more important factor in local held sites than foreign ones by 3.52%.

### 4.5.1. Correlation coefficient

Correlation coefficient is a statistical measurement of the strength of a linear relationship between two variables. Its values can be between -1 and 1 (Jason Fernando, 2021). A correlation coefficient of -1 indicates a perfect negative, or inverse, correlation, which means where values in one series increase as those in the other decrease and vice versa. A coefficient of 1 denotes a perfect positive correlation or a straight line. There is no linear relationship when the correlation coefficient is 0. The Pearson correlation coefficient (r) is the most common way of measuring a linear correlation (Shaun Turney 2022). It was discovered by Bravais in 1846, but Karl Pearson was the first to describe, in 1896, the standard method of its calculation and show it to be the best one possible (Jan Hauke and Tomasz Kossowski, 2011). Therefore, to determine the rank relationship between foreign and domestic contractors, the researcher chose Pearson's correlation coefficient since it is on of the ways to determine relationship between two datasets. The values and interpretations for this coefficient is presented below in table 4.12.

Table 4.12 Pearson's correlation coefficient interpretation.

| Pearson correlation coefficient (r) | Correlation type | Interpretation |
|---|---|---|
| Between 0 and 1 | Positive correlation | When one variable changes, the other variable changes in the same direction. |
| 0 | No correlation | There is no relationship between the variables. |
| Between 0 and –1 | Negative correlation | When one variable changes, the other variable changes in the opposite direction. |

The correlation coefficient for safety risks (alternatives) between foreign and local contractors is determined to be 0.91 as shown below in table 4.13.

Table 4.13 correlation coefficient for safety risks.

| | Foreign | Local |
|---|---|---|
| Foreign | 1 | 0.91 |
| Local | 0.91 | 1 |

As shown in table 4.12, the correlation coefficient is positive 0.91 which shows that the relationship is positive and strong which signifies that both local and foreign contractors suffer much more similar safety risks. And the correlation coefficient for construction phase for both local and foreign contractors is shown below in table 4.14

Table 4.14 Correlation coefficient for construction phase

| | Local | Foreign |
|---|---|---|
| Local | 1 | -0.05738 |
| Foreign | -0.05738 | 1 |

The construction phase correlation in the above table 4.14 shows that there is a very low degree of correlation between local and foreign contractors when it comes to the most risky construction phase. The negative sign shows that their relationship is also negative and therefore the most risky construction phase does not coincide with each other, which apparently supports the result. While substructure is the most risky phase in local contractors', superstructure is the most risky in foreign contractors' case.

In addition to studies mentioned previously which confirms the findings of this study, other international as well as national studies also comply with the findings of this study by identifying falling from height, falling objects, slips, trips, and falls and trench failure/excavation accident as the major safety risks in high-rise building construction sites (Yonatan Taddese 2020, Amanual Tsegaye 2022, Abiy Girma 2020, Kai Chen Goh et al., 2016, ILO 2005, Nurzawani Md Sofwan et al., 2015, Fung et al., 2010). The above studies identified and some of them ranked safety risk factors using RI index (Relative importance index) which is a simple way of ranking alternatives by rating each of the alternatives from 1 to 5 where 5 represents extremely important factor and 1 representing a not at all important factor (Vishal D. Sakhare and Gomatesh S. Patil, 2019). This method is not the best way for ranking safety risks because of the fact that it does not support either feedback or interdependence between factors under consideration, which does not allow to compare between factors. RI index also do not compare safety risk factors from a comparing criteria/node, i.e., it does not let the researcher see which safety risk is dominant in which phase or which safety risk important is important with respect to some criteria. Moreover, some safety risks do not happen in all construction phases, for example trench electric accident do not happen in sub-structure or super-structure phase, this case is neglected when using RI index. Unlike those studies, the current study is different in a way that it prioritizes those safety risks based on importance in addition to identifying them using a methodology that eliminate previously mentioned shortcomings of RI index and other ranking techniques. This paper is different in a way that it also determines the most risky construction phase which most of studies have not yet determined. This study is not only different in terms of methodology, using ANP to prioritize safety risks and construction phases (also refer to section 2.8.2.3 of this study), but also it separately study foreign held construction sites and local held construction sites.

# CHAPTER FIVE

# CONCLUSIONS AND RECOMMENDATIONS

## 5.1. Introduction

As presented in chapter one, the objective of the study is to identify, prioritize and compare the most important safety risks and the most risky construction phase in high-rise buildings under construction in Addis Ababa by local contractors and foreign contractors. In this chapter the results are synthesized into major takeaways and recommendations to better understand the subject matter for future studies is done.

## 5.2. Conclusion

After the results were synthesized, the following conclusions were made;

- Identified safety risks are Trench failure/excavation accident, Being hit by moving objects like vehicle, Falling objects, Struck by or against something, Caught in/compressed by equipment or objects, Slips, trips, and falls, Repetitive motion, Ladder accident, Falling from height, Electric or heat burn, Scaffolding accident, and Manual handling. Among these safety risks caught in/compressed by equipment or objects, manual handling, being hit by moving objects like vehicle, and repetitive motion are identified as new safety risk factors from reviewing literature in Ethiopian context.
- Among these safety risk factors; falling from height, falling objects, slips, trips and falls and trench failure/excavation accident are the most important ones in local contractor held construction sites. And among those factors falling objects, falling from height, slips, trips and falls, and Trench failure or excavation accident are the most important ones in foreign contractor held construction sites.
- Among sub-structure, super-structure, and finishing phases, Sub structure is the most risky phase in case of local contractors held sites and super-structure in case of foreign held sites. While most of safety risk factors happen in local contractor held sites in sub-structure and deescalate towards the finishing phase, in foreign contractor held sites, it starts low and escalates and reaches a peak point in super-structure and deescalates back to finishing phase. So both local and foreign contractor held construction sites suffer less risk towards the finishing of their project.

## 5.3. Recommendations

**Recommendation for construction companies involving in high-rise construction**

- Construction professionals specially the safety management team and safety engineers should give more emphasis to these most important safety risks and construction phases, i.e., sub-structure in local contractors and super-structure in foreign contractors case, than others and manage them properly to ensure the wellbeing of workers.
- Site accident can be decreased by using proper method to decrease these safety risks from happening in both local and foreign contractor held construction sites in Addis Ababa.

**Recommendation for further study**

- Based on these conclusions, further studies should be considered in addressing which safety practices and packages better fit to both local and foreign held construction sites that can address these important safety risks.
- To better understand the implication of these results further studies should be conducted that helps to determine the influence of each identified safety risks with each other.
- Further prioritization should be carried out using different methods of prioritization techniques.

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# Appendices

ADAMA SCIENCE AND TECHNOLOGY UNIVERSITY DEPARTMENT CIVIL ENGINEERING SCHOOL OF CIVIL ENGINEERING AND ARCBEING HITECTURE

HIGH RISE BUILDING CONSTRUCTION ONSITE SAFETY RISK MODELLING IN ADDIS ABABA

The questionnaire you will be filling will only be used for research purpose and the information you provide is completely confidential and will not be used for other purposes other than this research and will not be used by other third party.

This questionnaire helps to model safety risk factors in three different construction phases i.e. during the construction of substructure, super structure, and finishing works in high-rise buildings in Addis Ababa using analytic network process (ANP) and determine the most important safety risk and the most risky construction phase.

BY: ABEBE BIZUALEM

ADVISOR NAME: FIKREYESUS DEMEKE (Dr)

Name of the organization ______________________________________________

Position in the organization ____________________________________________

Experience (in years) ______________________________

Level pf study

a. Undergraduate (Bachelor Degree) ☐
b. Masters ☐
c. PhD ☐

Tren/exc = Trench failure/excavation accident Hit = Being Being hit by moving objects like vehicle

Fal obj = Falling objects Strk = Struck by or against something

Caug/comp = Caught in/compressed by equipment or objects Sli,tri,fal = Slips, trips, and falls

Rep mot = Repetitive motion ladd = Ladder accident

Fall = Falling from height Ele/heat = Electric or heat burn

Scaf = Scaffolding accident Man han = Manual handling

SUB = Substructure works SUP = Superstructure works

FIN = Finishing works

Here is how to fill the questionnaire.

If there is a relationship between factors with respect to the comparing criteria/node/ mark the “YES” section and then mark by how much is one factor more important than the other. If there is no relationship between the factors mark “NO” section and do not mark the next section.

| Factors | With respect to the most important construction phase | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Is There A Relationship Between The Two Factors? (Does The First Factor Influence The Second One?) | | If They Do Have Relationship, How Important Is The First Factor Than The Second Factor Or Vice Versa? | | | | | | | | | | |
| | YES | NO | | 9(Extrem | 7(Very Strong) | 5(Strong | 3(Moderately | 1(Equal) | 3(Moderately | 5(Strong | 7(Very Strong) | 9(Extrem | |
| Sub-Structure and Finishing | ★ | | Sub-Structure | | | | ★ | | | | | | Finishing |
| Finishing and Super-Structure | ★ | | Finishing | | | | | | | | ★ | | Super-Structure |
| Sub-Structure and Super-structure | ★ | | Sub-Structure | | | | | | ★ | | | | Super-structure |
| | | | With respect to the most important safety risk | | | | | | | | | | |
| Factor1 and Factor2 | | ★ | Factor1 | | | | | | | | | | Factor2 |
| Factor1 and Factor3 | | ★ | Factor1 | | | | | | | | | | Factor3 |
| Factor1 and Factor4 | ★ | | Factor1 | | | | ★ | | | | | | Factor4 |
| Factor2 and Factor3 | ★ | | Factor2 | | | | | | ★ | | | | Factor3 |
| Factor2 and Factor4 | | ★ | Factor2 | | | | | | | | | | Factor4 |

The questionnaire starts in the next page.

| Factors | With respect to the most important construction phase | | | | | | | | | | | | |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| | Is There A Relationship Between The Two Factors? (Does The First Factor Influence The Second One?) | | If They Do Have Relationship, How Important Is The First Factor Than The Second Factor Or Vice Versa? | | | | | | | | | | |
| | YES | NO | | 9(Extreme | 7(Very Strong) | 5(Strong) | 3(Moderately strong | 1(Equal) | 3(Moderately Strong) | 5(Strong) | 7(Very Strong) | 9(Extreme | |
| Sub-Structure and Finishing | | | Sub-Structure | | | | | | | | | | Finishing |
| Finishing and Super-Structure | | | Finishing | | | | | | | | | | Super-Structure |
| Sub-Structure and Super-structure | | | Sub-Structure | | | | | | | | | | Super-structure |
| | | | With respect to the most important safety risk | | | | | | | | | | |
| Being hit and Caught in/compressed | | | Being hit | | | | | | | | | | Caught in/compressed |
| Being hit and Electric or heat burn | | | Being hit | | | | | | | | | | Electric or heat burn |
| Being hit and Falling from height | | | Being hit | | | | | | | | | | Falling from height |
| Being hit and Falling objects | | | Being hit | | | | | | | | | | Falling objects |
| Being hit and Ladder accident | | | Being hit | | | | | | | | | | Ladder accident |
| Being hit and Manual handling | | | Being hit | | | | | | | | | | Manual handling |
| Being hit and Repetitive motion | | | Being hit | | | | | | | | | | Repetitive motion |
| Being hit and Scaffolding accident | | | Being hit | | | | | | | | | | Scaffolding accident |
| Being hit and Slips, trips, and falls | | | Being hit | | | | | | | | | | Slips, trips, and falls |
| Being hit and Struck by or against something | | | Being hit | | | | | | | | | | Struck by or against something |

| Being hit and Trench failure/excavation accident | | | Being hit | | | | | | | | | | Trench failure/exc accident |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | YES | NO | | 9(Extreme) | 7(Very Strong) | 5(Strong) | 3(Moderately strong | 1(Equal) | 3(Moderately Strong) | 5(Strong) | 7(Very Strong) | 9(Extreme) | |
| Caught in/compressed and Electric or heat burn | | | Caught in/compressed | | | | | | | | | | Electric or heat burn |
| Caught in/compressed and Falling objects | | | Caught in/compressed | | | | | | | | | | Falling objects |
| Caught in/compressed and Ladder accident | | | Caught in/compressed | | | | | | | | | | Ladder accident |
| Caught in/compressed and Manual handling | | | Caught in/compressed | | | | | | | | | | Manual handling |
| Caught in/compressed and Repetitive motion | | | Caught in/compressed | | | | | | | | | | Repetitive motion |
| Caught in/compressed and Scaffolding accident | | | Caught in/compressed | | | | | | | | | | Scaffolding accident |
| Caught in/compressed and Slips, trips, and falls | | | Caught in/compressed | | | | | | | | | | Slips, trips, and falls |
| Caught in/compressed and Struck by or against something | | | Caught in/compressed | | | | | | | | | | Struck by or against something |
| Caught in/compressed and Trench failure/excavation accident | | | Caught in/compressed | | | | | | | | | | Trench failure/excavation accident |
| Caught in/compressed and Falling from height | | | Caught in/compressed | | | | | | | | | | Falling from height |
| Elec/heat burn and Falling from height | | | Elec/heat burn | | | | | | | | | | Falling from height |
| Elec/heat burn and Falling objects | | | Elec/heat burn | | | | | | | | | | Falling objects |
| Elec/heat burn and Ladder accident | | | Elec/heat burn | | | | | | | | | | Ladder accident |
| Elec/heat burn and Manual handling | | | Elec/heat burn | | | | | | | | | | Manual handling |
| Elec/heat burn and Repetitive motion | | | Elec/heat burn | | | | | | | | | | Repetitive motion |
| Elec/heat burn and Scaffolding accident | | | Elec/heat burn | | | | | | | | | | Scaffolding accident |

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Elec/heat burn and Slips, trips, and falls | | | Elec/heat burn | | | | | | | | | | Slips, trips, and falls |
| Elec/heat burn and Struck by or against something | | | Elec/heat burn | | | | | | | | | | Struck by or against something |
| | YES | NO | | 9(Extreme) | 7(Very Strong) | 5(Strong) | 3(Moderately strong | 1(Equal) | 3(Moderately Strong) | 5(Strong) | 7(Very Strong) | 9(Extreme) | |
| Elec/heat burn and Trench failure/excavation accident | | | Elec/heat burn | | | | | | | | | | Trench failure/excavation accident |
| Falling from height and Falling objects | | | Falling from height | | | | | | | | | | Falling objects |
| Falling from height and Manual handling | | | Falling from height | | | | | | | | | | Manual handling |
| Falling from height and Repetitive motion | | | Falling from height | | | | | | | | | | Repetitive motion |
| Falling from height and Scaffolding accident | | | Falling from height | | | | | | | | | | Scaffolding accident |
| Falling from height and Slips, trips, and falls | | | Falling from height | | | | | | | | | | Slips, trips, and falls |
| Falling from height and Struck by or against something | | | Falling from height | | | | | | | | | | Struck by or against something |
| Falling from height and Trench failure/excavation accident | | | Falling from height | | | | | | | | | | Trench failure/excavation accident |
| Falling from height and ladder accide | | | Falling from height | | | | | | | | | | ladder accident |
| Falling objects and Ladder accident | | | Falling objects | | | | | | | | | | Ladder accident |
| Falling objects and Manual handling | | | Falling objects | | | | | | | | | | Manual handling |
| Falling objects and Repetitive motion | | | Falling objects | | | | | | | | | | Repetitive motion |
| Falling objects and Scaffolding accident | | | Falling objects | | | | | | | | | | Scaffolding accident |
| Falling objects and Slips, trips, and falls | | | Falling objects | | | | | | | | | | Slips, trips, and falls |
| Falling objects and Struck by or against something | | | Falling objects | | | | | | | | | | Struck by or against something |

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Falling objects and Trench failure/excavation accident | | | Falling objects | | | | | | | | | | Trench failure/excavation accident |
| Ladder accident and Manual handling | | | Ladder accident | | | | | | | | | | Manual handling |
| Ladder accident and Repetitive motion | | | Ladder accident | | | | | | | | | | Repetitive motion |
| Ladder accident and Scaffolding accident | | | Ladder accident | | | | | | | | | | Scaffolding accident |
| | YES | NO | | 9(Extreme) | 7(Very Strong) | 5(Strong) | 3(Moderately strong | 1(Equal) | 3(Moderately Strong) | 5(Strong) | 7(Very Strong) | 9(Extreme) | |
| Ladder accident and Slips, trips, and falls | | | Ladder accident | | | | | | | | | | Slips, trips, and falls |
| Ladder accident and trench failure/excavation accident | | | Ladder accident | | | | | | | | | | trench failure/excavation accident |
| Ladder accident and Struck by or against something | | | Ladder accident | | | | | | | | | | Struck by or against something |
| Manual handling and Repetitive motion | | | Manual handling | | | | | | | | | | Repetitive motion |
| Manual handling and Scaffolding accident | | | Manual handling | | | | | | | | | | Scaffolding accident |
| Manual handling and Slips, trips, and falls | | | Manual handling | | | | | | | | | | Slips, trips, and falls |
| Manual handling and Struck by or against something | | | Manual handling | | | | | | | | | | Struck by or against something |
| Manual handling and Trench failure/excavation accident | | | Manual handling | | | | | | | | | | Trench failure/excavation accident |
| Repetitive motion and Scaffolding accident | | | Repetitive motion | | | | | | | | | | Scaffolding accident |
| Repetitive motion and Slips, trips, and falls | | | Repetitive motion | | | | | | | | | | Slips, trips, and falls |
| Repetitive motion and Struck by or against something | | | Repetitive motion | | | | | | | | | | Struck by or against something |
| Repetitive motion and Trench failure/excavation accident | | | Repetitive motion | | | | | | | | | | Trench failure/excavation accident |
| Scaffolding accident and Slips, trips, and falls | | | Scaffolding accident | | | | | | | | | | Slips, trips, and falls |

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Scaffolding accident and Struck by or against something | | | Scaffolding accident | | | | | | | | | | Struck by or against something |
| Scaffolding accident and Trench failure/excavation accident | | | Scaffolding accident | | | | | | | | | | Trench failure/excavation accident |
| Slips, trips, and falls and Struck by or against something | | | Slips, trips, and falls | | | | | | | | | | Struck by or against something |
| Slips, trips, and falls and Trench failure/excavation accident | | | Slips, trips, and falls | | | | | | | | | | Trench failure/excavation accident |
| Struck by or against something and Trench failure/excavation accident | | | Struck by or against something | | | | | | | | | | Trench failure/excavation accident |
| | With respect to Sub-Structure | | | | | | | | | | | | |
| | Is There A Relationship Between The Two Factors? (Does The First Factor Influence The Second One?) | | If They Do Have Relationship, How Important Is The First Factor Than The Second Factor Or Vice Versa? | | | | | | | | | | |
| | YES | NO | | 9(Extreme | 7(Very Strong) | 5(Strong) | 3(Moderately strong | 1(Equal) | 3(Moderately | 5(Strong) | 7(Very Strong) | 9(Extreme | |
| Super-Structure and Finishing | | | Super-Structure | | | | | | | | | | Finishing |
| Being hit and Caught in/compressed | | | Being hit | | | | | | | | | | Caught in/compressed |
| Being hit and Electric or heat burn | | | Being hit | | | | | | | | | | Electric or heat burn |
| Being hit and Falling from height | | | Being hit | | | | | | | | | | Falling from height |
| Being hit and Falling objects | | | Being hit | | | | | | | | | | Falling objects |
| Being hit and Ladder accident | | | Being hit | | | | | | | | | | Ladder accident |
| Being hit and Manual handling | | | Being hit | | | | | | | | | | Manual handling |

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Being hit and Repetitive motion | | | Being hit | | | | | | | | | | Repetitive motion |
| Being hit and Scaffolding accident | | | Being hit | | | | | | | | | | Scaffolding accident |
| Being hit and Slips, trips, and falls | | | Being hit | | | | | | | | | | Slips, trips, and falls |
| Being hit and Struck by or against something | | | Being hit | | | | | | | | | | Struck by or against something |
| Being hit and Trench failure/excavation accident | | | Being hit | | | | | | | | | | Trench failure/excavation accident |
| Caught in/compressed and Electric or heat burn | | | Caught in/compressed | | | | | | | | | | Electric or heat burn |
| | YES | NO | | 9(Extreme) | 7(Very Strong) | 5(Strong) | 3(Moderately strong | 1(Equal) | 3(Moderately Strong) | 5(Strong) | 7(Very Strong) | 9(Extreme) | |
| Caught in/compressed and Falling from height | | | Caught in/compressed | | | | | | | | | | Falling from height |
| Caught in/compressed and Falling objects | | | Caught in/compressed | | | | | | | | | | Falling objects |
| Caught in/compressed and Ladder accident | | | Caught in/compressed | | | | | | | | | | Ladder accident |
| Caught in/compressed and Manual handling | | | Caught in/compressed | | | | | | | | | | Manual handling |
| Caught in/compressed and Repetitive motion | | | Caught in/compressed | | | | | | | | | | Repetitive motion |
| Caught in/compressed and Scaffolding accident | | | Caught in/compressed | | | | | | | | | | Scaffolding accident |
| Caught in/compressed and Slips, trips, and falls | | | Caught in/compressed | | | | | | | | | | Slips, trips, and falls |
| Caught in/compressed and Struck by or against something | | | Caught in/compressed | | | | | | | | | | Struck by or against something |
| Caught in/compressed and Trench failure/excavation accident | | | Caught in/compressed | | | | | | | | | | Trench failure/excavation accident |
| Elec/heat burn and Falling from height | | | Elec/heat burn | | | | | | | | | | Falling from height |
| Elec/heat burn and Falling objects | | | Elec/heat burn | | | | | | | | | | Falling objects |

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Elec/heat burn and Ladder accident | | | Elec/heat burn | | | | | | | | | | Ladder accident |
| Elec/heat burn and Manual handling | | | Elec/heat burn | | | | | | | | | | Manual handling |
| Elec/heat burn and Repetitive motion | | | Elec/heat burn | | | | | | | | | | Repetitive motion |
| Elec/heat burn and Scaffolding accident | | | Elec/heat burn | | | | | | | | | | Scaffolding accident |
| Elec/heat burn and Slips, trips, and falls | | | Elec/heat burn | | | | | | | | | | Slips, trips, and falls |
| Elec/heat burn and Struck by or against something | | | Elec/heat burn | | | | | | | | | | Struck by or against something |
| Elec/heat burn and Trench failure/excavation accident | | | Elec/heat burn | | | | | | | | | | Trench failure/excavation accident |
| | YES | NO | | 9(Extreme) | 7(Very Strong) | 5(Strong) | 3(Moderately strong | 1(Equal) | 3(Moderately Strong) | 5(Strong) | 7(Very Strong) | 9(Extreme) | |
| Falling from height and Falling objects | | | Falling from height | | | | | | | | | | Falling objects |
| Falling from height and Ladder accident | | | Falling from height | | | | | | | | | | Ladder accident |
| Falling from height and Manual handling | | | Falling from height | | | | | | | | | | Manual handling |
| Falling from height and Repetitive motion | | | Falling from height | | | | | | | | | | Repetitive motion |
| Falling from height and Scaffolding accident | | | Falling from height | | | | | | | | | | Scaffolding accident |
| Falling from height and Slips, trips, and falls | | | Falling from height | | | | | | | | | | Slips, trips, and falls |
| Falling from height and Struck by or against something | | | Falling from height | | | | | | | | | | Struck by or against something |
| Falling from height and Trench failure/excavation accident | | | Falling from height | | | | | | | | | | Trench failure/excavation accident |
| Falling objects and Ladder accident | | | Falling objects | | | | | | | | | | Ladder accident |
| Falling objects and Manual handling | | | Falling objects | | | | | | | | | | Manual handling |
| Falling objects and Repetitive motion | | | Falling objects | | | | | | | | | | Repetitive motion |

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| Falling objects and Scaffolding accident | | | Falling objects | | | | | | | | | | Scaffolding accident |
| Falling objects and Slips, trips, and falls | | | Falling objects | | | | | | | | | | Slips, trips, and falls |
| Falling objects and Struck by or against something | | | Falling objects | | | | | | | | | | Struck by or against something |
| Falling objects and Trench failure/excavation accident | | | Falling objects | | | | | | | | | | Trench failure/excavation accident |
| Ladder accident and Manual handling | | | Ladder accident | | | | | | | | | | Manual handling |
| Ladder accident and Repetitive motion | | | Ladder accident | | | | | | | | | | Repetitive motion |
| Ladder accident and Scaffolding accident | | | Ladder accident | | | | | | | | | | Scaffolding accident |
| Ladder accident and Slips, trips, and falls | | | Ladder accident | | | | | | | | | | Slips, trips, and falls |
| | YES | NO | | 9(Extreme) | 7(Very Strong) | 5(Strong) | 3(Moderately strong | 1(Equal) | 3(Moderately Strong) | 5(Strong) | 7(Very Strong) | 9(Extreme) | |
| Ladder accident and Struck by or against something | | | Ladder accident | | | | | | | | | | Struck by or against something |
| Ladder accident and Trench failure/excavation accident | | | Ladder accident | | | | | | | | | | Trench failure/excavation accident |
| Manual handling and Repetitive motion | | | Manual handling | | | | | | | | | | Repetitive motion |
| Manual handling and Scaffolding accident | | | Manual handling | | | | | | | | | | Scaffolding accident |
| Manual handling and Slips, trips, and falls | | | Manual handling | | | | | | | | | | Slips, trips, and falls |
| Manual handling and Struck by or against something | | | Manual handling | | | | | | | | | | Struck by or against something |
| Manual handling and Trench failure/excavation accident | | | Manual handling | | | | | | | | | | Trench failure/excavation accident |
| Repetitive motion and Scaffolding accident | | | Repetitive motion | | | | | | | | | | Scaffolding accident |
| Repetitive motion and Slips, trips, and falls | | | Repetitive motion | | | | | | | | | | Slips, trips, and falls |

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| Repetitive motion and Struck by or against something | | | Repetitive motion | | | | | | | | | | Struck by or against something |
| Repetitive motion and Trench failure/excavation accident | | | Repetitive motion | | | | | | | | | | Trench failure/excavation accident |
| Scaffolding accident and Slips, trips, and falls | | | Scaffolding accident | | | | | | | | | | Slips, trips, and falls |
| Scaffolding accident and Struck by or against something | | | Scaffolding accident | | | | | | | | | | Struck by or against something |
| Scaffolding accident and Trench failure/excavation accident | | | Scaffolding accident | | | | | | | | | | Trench failure/excavation accident |
| Slips, trips, and falls and Struck by or against something | | | Slips, trips, and falls | | | | | | | | | | Struck by or against something |
| Slips, trips, and falls and Trench failure/excavation accident | | | Slips, trips, and falls | | | | | | | | | | Trench failure/excavation accident |
| Struck by or against something and Trench failure/excavation accident | | | Struck by or against something | | | | | | | | | | Trench failure/excavation accident |
| | With respect to Super-Structure | | | | | | | | | | | | |
| | Is There A Relationship Between The Two Factors? (Does The First Factor Influence The Second One?) | | If They Do Have Relationship, How Important Is The First Factor Than The Second Factor Or Vice Versa? | | | | | | | | | | |
| | YES | NO | | 9(Extreme) | 7(Very Strong) | 5(Strong) | 3(Moderately strong | 1(Equal) | 3(Moderately Strong) | 5(Strong) | 7(Very Strong) | 9(Extreme) | |
| Sub-Structure and Finishing | | | Sub-Structure | | | | | | | | | | Finishing |
| Being hit and Caught in/compressed | | | Being hit | | | | | | | | | | Caught in/compressed |
| Being hit and Electric or heat burn | | | Being hit | | | | | | | | | | Electric or heat burn |

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Being hit and Falling from height | | | Being hit | | | | | | | | | | Falling from height |
| Being hit and Falling objects | | | Being hit | | | | | | | | | | Falling objects |
| Being hit and Ladder accident | | | Being hit | | | | | | | | | | Ladder accident |
| Being hit and Manual handling | | | Being hit | | | | | | | | | | Manual handling |
| Being hit and Repetitive motion | | | Being hit | | | | | | | | | | Repetitive motion |
| Being hit and Scaffolding accident | | | Being hit | | | | | | | | | | Scaffolding accident |
| Being hit and Slips, trips, and falls | | | Being hit | | | | | | | | | | Slips, trips, and falls |
| Being hit and Struck by or against something | | | Being hit | | | | | | | | | | Struck by or against something |
| Being hit and Trench failure/excavation accident | | | Being hit | | | | | | | | | | Trench failure/excavation accident |
| Caught in/compressed and Electric or heat burn | | | Caught in/compressed | | | | | | | | | | Electric or heat burn |
| Caught in/compressed and Falling from height | | | Caught in/compressed | | | | | | | | | | Falling from height |
| | YES | NO | | 9(Extreme) | 7(Very Strong) | 5(Strong) | 3(Moderately strong | 1(Equal) | 3(Moderately Strong) | 5(Strong) | 7(Very Strong) | 9(Extreme) | |
| Caught in/compressed and Falling objects | | | Caught in/compressed | | | | | | | | | | Falling objects |
| Caught in/compressed and Ladder accident | | | Caught in/compressed | | | | | | | | | | Ladder accident |
| Caught in/compressed and Manual handling | | | Caught in/compressed | | | | | | | | | | Manual handling |
| Caught in/compressed and Repetitive motion | | | Caught in/compressed | | | | | | | | | | Repetitive motion |
| Caught in/compressed and Scaffolding accident | | | Caught in/compressed | | | | | | | | | | Scaffolding accident |
| Caught in/compressed and Slips, trips, and falls | | | Caught in/compressed | | | | | | | | | | Slips, trips, and falls |

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Caught in/compressed and Struck by or against something | | | Caught in/compressed | | | | | | | | | | Struck by or against something |
| Caught in/compressed and Trench failure/excavation accident | | | Caught in/compressed | | | | | | | | | | Trench failure/excavation accident |
| Elec/heat burn and Falling from height | | | Elec/heat burn | | | | | | | | | | Falling from height |
| Elec/heat burn and Falling objects | | | Elec/heat burn | | | | | | | | | | Falling objects |
| Elec/heat burn and Ladder accident | | | Elec/heat burn | | | | | | | | | | Ladder accident |
| Elec/heat burn and Manual handling | | | Elec/heat burn | | | | | | | | | | Manual handling |
| Elec/heat burn and Repetitive motion | | | Elec/heat burn | | | | | | | | | | Repetitive motion |
| Elec/heat burn and Scaffolding accident | | | Elec/heat burn | | | | | | | | | | Scaffolding accident |
| Elec/heat burn and Slips, trips, and falls | | | Elec/heat burn | | | | | | | | | | Slips, trips, and falls |
| Elec/heat burn and Struck by or against something | | | Elec/heat burn | | | | | | | | | | Struck by or against something |
| Elec/heat burn and Trench failure/excavation accident | | | Elec/heat burn | | | | | | | | | | Trench failure/excavation accident |
| Falling from height and Falling objects | | | Falling from height | | | | | | | | | | Falling objects |
| | YES | NO | | 9(Extreme) | 7(Very Strong) | 5(Strong) | 3(Moderately strong | 1(Equal) | 3(Moderately Strong) | 5(Strong) | 7(Very Strong) | 9(Extreme) | |
| Falling from height and Ladder accident | | | Falling from height | | | | | | | | | | Ladder accident |
| Falling from height and Manual handling | | | Falling from height | | | | | | | | | | Manual handling |
| Falling from height and Repetitive motion | | | Falling from height | | | | | | | | | | Repetitive motion |
| Falling from height and Scaffolding accident | | | Falling from height | | | | | | | | | | Scaffolding accident |
| Falling from height and Slips, trips, and falls | | | Falling from height | | | | | | | | | | Slips, trips, and falls |
| Falling from height and Struck by or against something | | | Falling from height | | | | | | | | | | Struck by or against something |

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| Falling from height and Trench failure/excavation accident | | | Falling from height | | | | | | | | | | Trench failure/excavation accident |
| Falling objects and Ladder accident | | | Falling objects | | | | | | | | | | Ladder accident |
| Falling objects and Manual handling | | | Falling objects | | | | | | | | | | Manual handling |
| Falling objects and Repetitive motion | | | Falling objects | | | | | | | | | | Repetitive motion |
| Falling objects and Scaffolding accident | | | Falling objects | | | | | | | | | | Scaffolding accident |
| Falling objects and Slips, trips, and falls | | | Falling objects | | | | | | | | | | Slips, trips, and falls |
| Falling objects and Struck by or against something | | | Falling objects | | | | | | | | | | Struck by or against something |
| Falling objects and Trench failure/excavation accident | | | Falling objects | | | | | | | | | | Trench failure/excavation accident |
| Ladder accident and Manual handling | | | Ladder accident | | | | | | | | | | Manual handling |
| Ladder accident and Repetitive motion | | | Ladder accident | | | | | | | | | | Repetitive motion |
| Ladder accident and Scaffolding accident | | | Ladder accident | | | | | | | | | | Scaffolding accident |
| Ladder accident and Slips, trips, and falls | | | Ladder accident | | | | | | | | | | Slips, trips, and falls |
| Ladder accident and Struck by or against something | | | Ladder accident | | | | | | | | | | Struck by or against something |
| | YES | NO | | 9(Extreme) | 7(Very Strong) | 5(Strong) | 3(Moderately strong | 1(Equal) | 3(Moderately Strong) | 5(Strong) | 7(Very Strong) | 9(Extreme) | |
| Ladder accident and Trench failure/excavation accident | | | Ladder accident | | | | | | | | | | Trench failure/excavation accident |
| Manual handling and Repetitive motion | | | Manual handling | | | | | | | | | | Repetitive motion |
| Manual handling and Scaffolding accident | | | Manual handling | | | | | | | | | | Scaffolding accident |
| Manual handling and Slips, trips, and falls | | | Manual handling | | | | | | | | | | Slips, trips, and falls |
| Manual handling and Struck by or against something | | | Manual handling | | | | | | | | | | Struck by or against something |

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Manual handling and Trench failure/excavation accident | | | Manual handling | | | | | | | | | | Trench failure/excavation accident |
| Repetitive motion and Scaffolding accident | | | Repetitive motion | | | | | | | | | | Scaffolding accident |
| Repetitive motion and Slips, trips, and falls | | | Repetitive motion | | | | | | | | | | Slips, trips, and falls |
| Repetitive motion and Struck by or against something | | | Repetitive motion | | | | | | | | | | Struck by or against something |
| Repetitive motion and Trench failure/excavation accident | | | Repetitive motion | | | | | | | | | | Trench failure/excavation accident |
| Scaffolding accident and Slips, trips, and falls | | | Scaffolding accident | | | | | | | | | | Slips, trips, and falls |
| Scaffolding accident and Struck by or against something | | | Scaffolding accident | | | | | | | | | | Struck by or against something |
| Scaffolding accident and Trench failure/excavation accident | | | Scaffolding accident | | | | | | | | | | Trench failure/excavation accident |
| Slips, trips, and falls and Struck by or against something | | | Slips, trips, and falls | | | | | | | | | | Struck by or against something |
| Slips, trips, and falls and Trench failure/excavation accident | | | Slips, trips, and falls | | | | | | | | | | Trench failure/excavation accident |
| Struck by or against something and Trench failure/excavation accident | | | Struck by or against something | | | | | | | | | | Trench failure/excavation accident |
| | With respect to Finishing | | | | | | | | | | | | |
| | Is There A Relationship Between The Two Factors? (Does The First Factor Influence The Second One?) | | If They Do Have Relationship, How Important Is The First Factor Than The Second Factor Or Vice Versa? | | | | | | | | | | |

| | YES | NO | | 9(Extreme) | 7(Very Strong) | 5(Strong) | 3(Moderately strong | 1(Equal) | 3(Moderately Strong) | 5(Strong) | 7(Very Strong) | 9(Extreme) | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Sub-Structure and Super-Structure | | | Sub-Structure | | | | | | | | | | Super-Structure |
| Being hit and Caught in/compressed | | | Being hit | | | | | | | | | | Caught in/compressed |
| Being hit and Electric or heat burn | | | Being hit | | | | | | | | | | Electric or heat burn |
| Being hit and Falling from height | | | Being hit | | | | | | | | | | Falling from height |
| Being hit and Falling objects | | | Being hit | | | | | | | | | | Falling objects |
| Being hit and Ladder accident | | | Being hit | | | | | | | | | | Ladder accident |
| Being hit and Manual handling | | | Being hit | | | | | | | | | | Manual handling |
| Being hit and Repetitive motion | | | Being hit | | | | | | | | | | Repetitive motion |
| Being hit and Scaffolding accident | | | Being hit | | | | | | | | | | Scaffolding accident |
| Being hit and Slips, trips, and falls | | | Being hit | | | | | | | | | | Slips, trips, and falls |
| Being hit and Struck by or against something | | | Being hit | | | | | | | | | | Struck by or against something |
| Being hit and Trench failure/excavation accident | | | Being hit | | | | | | | | | | Trench failure/excavation accident |
| Caught in/compressed and Electric or heat burn | | | Caught in/compressed | | | | | | | | | | Electric or heat burn |
| Caught in/compressed and Falling from height | | | Caught in/compressed | | | | | | | | | | Falling from height |
| | YES | NO | | 9(Extreme) | 7(Very Strong) | 5(Strong) | 3(Moderately strong | 1(Equal) | 3(Moderately Strong) | 5(Strong) | 7(Very Strong) | 9(Extreme) | |
| Caught in/compressed and Falling objects | | | Caught in/compressed | | | | | | | | | | Falling objects |
| Caught in/compressed and Ladder accident | | | Caught in/compressed | | | | | | | | | | Ladder accident |

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Caught in/compressed and Manual handling | | | Caught in/compressed | | | | | | | | | | Manual handling |
| Caught in/compressed and Repetitive motion | | | Caught in/compressed | | | | | | | | | | Repetitive motion |
| Caught in/compressed and Scaffolding accident | | | Caught in/compressed | | | | | | | | | | Scaffolding accident |
| Caught in/compressed and Slips, trips, and falls | | | Caught in/compressed | | | | | | | | | | Slips, trips, and falls |
| Caught in/compressed and Struck by or against something | | | Caught in/compressed | | | | | | | | | | Struck by or against something |
| Caught in/compressed and Trench failure/excavation accident | | | Caught in/compressed | | | | | | | | | | Trench failure/excavation accident |
| Elec/heat burn and Falling from height | | | Elec/heat burn | | | | | | | | | | Falling from height |
| Elec/heat burn and Falling objects | | | Elec/heat burn | | | | | | | | | | Falling objects |
| Elec/heat burn and Ladder accident | | | Elec/heat burn | | | | | | | | | | Ladder accident |
| Elec/heat burn and Manual handling | | | Elec/heat burn | | | | | | | | | | Manual handling |
| Elec/heat burn and Repetitive motion | | | Elec/heat burn | | | | | | | | | | Repetitive motion |
| Elec/heat burn and Scaffolding accident | | | Elec/heat burn | | | | | | | | | | Scaffolding accident |
| Elec/heat burn and Slips, trips, and falls | | | Elec/heat burn | | | | | | | | | | Slips, trips, and falls |
| Elec/heat burn and Struck by or against something | | | Elec/heat burn | | | | | | | | | | Struck by or against something |
| Elec/heat burn and Trench failure/excavation accident | | | Elec/heat burn | | | | | | | | | | Trench failure/excavation accident |
| Falling from height and Falling objects | | | Falling from height | | | | | | | | | | Falling objects |
| | YES | NO | | 9(Extreme) | 7(Very Strong) | 5(Strong) | 3(Moderately strong | 1(Equal) | 3(Moderately Strong) | 5(Strong) | 7(Very Strong) | 9(Extreme) | |
| Falling from height and Ladder accident | | | Falling from height | | | | | | | | | | Ladder accident |

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| Falling from height and Manual handling | | | Falling from height | | | | | | | | | | Manual handling |
| Falling from height and Repetitive motion | | | Falling from height | | | | | | | | | | Repetitive motion |
| Falling from height and Scaffolding accident | | | Falling from height | | | | | | | | | | Scaffolding accident |
| Falling from height and Slips, trips, and falls | | | Falling from height | | | | | | | | | | Slips, trips, and falls |
| Falling from height and Struck by or against something | | | Falling from height | | | | | | | | | | Struck by or against something |
| Falling from height and Trench failure/excavation accident | | | Falling from height | | | | | | | | | | Trench failure/excavation accident |
| Falling objects and Ladder accident | | | Falling objects | | | | | | | | | | Ladder accident |
| Falling objects and Manual handling | | | Falling objects | | | | | | | | | | Manual handling |
| Falling objects and Repetitive motion | | | Falling objects | | | | | | | | | | Repetitive motion |
| Falling objects and Scaffolding accident | | | Falling objects | | | | | | | | | | Scaffolding accident |
| Falling objects and Slips, trips, and falls | | | Falling objects | | | | | | | | | | Slips, trips, and falls |
| Falling objects and Struck by or against something | | | Falling objects | | | | | | | | | | Struck by or against something |
| Falling objects and Trench failure/excavation accident | | | Falling objects | | | | | | | | | | Trench failure/excavation accident |
| Ladder accident and Manual handling | | | Ladder accident | | | | | | | | | | Manual handling |
| Ladder accident and Repetitive motion | | | Ladder accident | | | | | | | | | | Repetitive motion |
| Ladder accident and Scaffolding accident | | | Ladder accident | | | | | | | | | | Scaffolding accident |
| Ladder accident and Slips, trips, and falls | | | Ladder accident | | | | | | | | | | Slips, trips, and falls |
| Ladder accident and Struck by or against something | | | Ladder accident | | | | | | | | | | Struck by or against something |
| | YES | NO | | 9(Extreme) | 7(Very Strong) | 5(Strong) | 3(Moderately strong | 1(Equal) | 3(Moderately Strong) | 5(Strong) | 7(Very Strong) | 9(Extreme) | |

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Ladder accident and Trench failure/excavation accident | | | Ladder accident | | | | | | | | | | Trench failure/excavation accident |
| Manual handling and Repetitive motion | | | Manual handling | | | | | | | | | | Repetitive motion |
| Manual handling and Scaffolding accident | | | Manual handling | | | | | | | | | | Scaffolding accident |
| Manual handling and Slips, trips, and falls | | | Manual handling | | | | | | | | | | Slips, trips, and falls |
| Manual handling and Struck by or against something | | | Manual handling | | | | | | | | | | Struck by or against something |
| Manual handling and Trench failure/excavation accident | | | Manual handling | | | | | | | | | | Trench failure/excavation accident |
| Repetitive motion and Scaffolding accident | | | Repetitive motion | | | | | | | | | | Scaffolding accident |
| Repetitive motion and Slips, trips, and falls | | | Repetitive motion | | | | | | | | | | Slips, trips, and falls |
| Repetitive motion and Struck by or against something | | | Repetitive motion | | | | | | | | | | Struck by or against something |
| Repetitive motion and Trench failure/excavation accident | | | Repetitive motion | | | | | | | | | | Trench failure/excavation accident |
| Scaffolding accident and Slips, trips, and falls | | | Scaffolding accident | | | | | | | | | | Slips, trips, and falls |
| Scaffolding accident and Struck by or against something | | | Scaffolding accident | | | | | | | | | | Struck by or against something |
| Scaffolding accident and Trench failure/excavation accident | | | Scaffolding accident | | | | | | | | | | Trench failure/excavation accident |
| Slips, trips, and falls and Struck by or against something | | | Slips, trips, and falls | | | | | | | | | | Struck by or against something |
| Slips, trips, and falls and Trench failure/excavation accident | | | Slips, trips, and falls | | | | | | | | | | Trench failure/excavation accident |
| Struck by or against something and Trench failure/excavation accident | | | Struck by or against something | | | | | | | | | | Trench failure/excavation accident |

The super-matrices of both local and foreign held construction sites are presented below:

The unweighted super matrix for local held construction sites is:

| | Being h~ | Caught ~ | Electri~ | Falling~ | Falling~ | Ladder ~ | Manual ~ | Repetit~ | Scaffol~ | Slips, ~ | Struck ~ | Trench ~ | Finishi~ | Sub-Str~ | Super-S~ | The mos~ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Being h~** | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.05763 | 0.05546 | 0.06380 | 0.03442 |
| **Caught ~** | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.04707 | 0.04125 | 0.05688 | 0.03273 |
| **Electri~** | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.15876 | 0.00000 | 0.00000 | 0.07511 |
| **Falling~** | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.23754 | 0.13656 | 0.22043 | 0.11032 |
| **Falling~** | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.14599 | 0.16550 | 0.24091 | 0.09956 |
| **Ladder ~** | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.03175 | 0.03384 | 0.03641 | 0.03120 |
| **Manual ~** | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.03543 | 0.05198 | 0.04468 | 0.04332 |
| **Repetit~** | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.05748 | 0.06035 | 0.07496 | 0.04452 |
| **Scaffol~** | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.04450 | 0.03885 | 0.04675 | 0.03532 |
| **Slips, ~** | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.14239 | 0.09417 | 0.16323 | 0.09049 |
| **Struck ~** | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.04145 | 0.04447 | 0.05195 | 0.04596 |
| **Trench ~** | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.27757 | 0.00000 | 0.35704 |
| **Finishi~** | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.74937 | 0.74160 | 0.18132 |
| **Sub-Str~** | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.81132 | 0.00000 | 0.25840 | 0.52075 |
| **Super-S~** | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.18868 | 0.25063 | 0.00000 | 0.29792 |
| **The mos~** | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 |

The cluster matrix of local

| | Alternatives (Safety risks) | Construction phases | Goal |
|---|---|---|---|
| **Alternatives (Safety risks)** | 0.000000 | 0.500000 | 0.500000 |
| **Construction phases** | 0.000000 | 0.500000 | 0.500000 |
| **Goal** | 0.000000 | 0.000000 | 0.000000 |

The weighted super matrix of local is:

| | Being h~ | Caught ~ | Electri~ | Falling~ | Falling~ | Ladder ~ | Manual ~ | Repetit~ | Scaffol~ | Slips, ~ | Struck ~ | Trench ~ | Finishi~ | Sub-Str~ | Super-S~ | The mos~ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Being h~** | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.02882 | 0.02773 | 0.03190 | 0.01721 |
| **Caught ~** | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.02354 | 0.02063 | 0.02844 | 0.01637 |
| **Electri~** | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.07938 | 0.00000 | 0.00000 | 0.03755 |
| **Falling~** | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.11877 | 0.06828 | 0.11022 | 0.05516 |
| **Falling~** | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.07299 | 0.08275 | 0.12046 | 0.04978 |
| **Ladder ~** | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.01588 | 0.01692 | 0.01820 | 0.01560 |
| **Manual ~** | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.01772 | 0.02599 | 0.02234 | 0.02166 |
| **Repetit~** | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.02874 | 0.03017 | 0.03748 | 0.02226 |
| **Scaffol~** | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.02225 | 0.01943 | 0.02338 | 0.01766 |
| **Slips, ~** | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.07119 | 0.04709 | 0.08162 | 0.04525 |
| **Struck ~** | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.02073 | 0.02224 | 0.02597 | 0.02298 |
| **Trench ~** | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.13878 | 0.00000 | 0.17852 |
| **Finishi~** | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.37469 | 0.37080 | 0.09066 |
| **Sub-Str~** | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.40566 | 0.00000 | 0.12920 | 0.26038 |
| **Super-S~** | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.09434 | 0.12531 | 0.00000 | 0.14896 |
| **The mos~** | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 |

The limit matrix of local is

| | Being h~ | Caught ~ | Electri~ | Falling~ | Falling~ | Ladder ~ | Manual ~ | Repetit~ | Scaffol~ | Slips, ~ | Struck ~ | Trench ~ | Finishi~ | Sub-Str~ | Super-S~ | The mos~ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Being h~** | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.02894 | 0.02894 | 0.02894 | 0.02894 |
| **Caught ~** | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.02327 | 0.02327 | 0.02327 | 0.02327 |
| **Electri~** | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.03394 | 0.03394 | 0.03394 | 0.03394 |
| **Falling~** | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.09738 | 0.09738 | 0.09738 | 0.09738 |
| **Falling~** | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.08534 | 0.08534 | 0.08534 | 0.08534 |
| **Ladder ~** | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.01670 | 0.01670 | 0.01670 | 0.01670 |
| **Manual ~** | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.02180 | 0.02180 | 0.02180 | 0.02180 |
| **Repetit~** | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.03087 | 0.03087 | 0.03087 | 0.03087 |
| **Scaffol~** | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.02134 | 0.02134 | 0.02134 | 0.02134 |
| **Slips, ~** | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.06358 | 0.06358 | 0.06358 | 0.06358 |
| **Struck ~** | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.02226 | 0.02226 | 0.02226 | 0.02226 |
| **Trench ~** | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.05457 | 0.05457 | 0.05457 | 0.05457 |
| **Finishi~** | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.21379 | 0.21379 | 0.21379 | 0.21379 |
| **Sub-Str~** | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.19660 | 0.19660 | 0.19660 | 0.19660 |
| **Super-S~** | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.08961 | 0.08961 | 0.08961 | 0.08961 |
| **The mos~** | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 |

The unweighted super matrix of foreign is

| | Being h~ | Caught ~ | Electri~ | Falling~ | Falling~ | Ladder ~ | Manual ~ | Repetit~ | Scaffol~ | Slips, ~ | Struck ~ | Trench ~ | Finishi~ | Sub-Str~ | Super-S~ | The mos~ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Being h~** | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.04065 | 0.04027 | 0.04795 | 0.03174 |
| **Caught ~** | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.04370 | 0.05708 | 0.05143 | 0.03994 |
| **Electri~** | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.11324 | 0.00000 | 0.00000 | 0.07254 |
| **Falling~** | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.19326 | 0.15072 | 0.18613 | 0.11364 |
| **Falling~** | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.20508 | 0.17885 | 0.27172 | 0.13473 |
| **Ladder ~** | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.02981 | 0.02983 | 0.03223 | 0.02464 |
| **Manual ~** | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.03561 | 0.03221 | 0.03569 | 0.02638 |
| **Repetit~** | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.06317 | 0.04557 | 0.07964 | 0.03512 |
| **Scaffol~** | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.05148 | 0.05348 | 0.06092 | 0.04255 |
| **Slips, ~** | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.14784 | 0.13160 | 0.16659 | 0.09213 |
| **Struck ~** | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.07617 | 0.06704 | 0.06769 | 0.04807 |
| **Trench ~** | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.21335 | 0.00000 | 0.33852 |
| **Finishi~** | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.30675 | 0.34130 | 0.16569 |
| **Sub-Str~** | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.31646 | 0.00000 | 0.65870 | 0.22418 |
| **Super-S~** | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.68354 | 0.69325 | 0.00000 | 0.61014 |
| **The mos~** | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 |

The cluster matrix of foreign is

| | Alternatives (Safety risks) | Construction phases | Goal |
|---|---|---|---|
| **Alternatives (Safety risks)** | 0.000000 | 0.500000 | 0.500000 |
| **Construction phases** | 0.000000 | 0.500000 | 0.500000 |
| **Goal** | 0.000000 | 0.000000 | 0.000000 |

The weighted super matrix of foreign is

| | Being h~ | Caught ~ | Electri~ | Falling~ | Falling~ | Ladder ~ | Manual ~ | Repetit~ | Scaffol~ | Slips, ~ | Struck ~ | Trench ~ | Finishi~ | Sub-Str~ | Super-S~ | The mos~ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Being h~** | **0.00000** | **0.00000** | **0.00000** | **0.00000** | **0.00000** | **0.00000** | **0.00000** | **0.00000** | **0.00000** | **0.00000** | **0.00000** | **0.00000** | **0.02033** | **0.02014** | **0.02398** | **0.01587** |
| **Caught ~** | **0.00000** | **0.00000** | **0.00000** | **0.00000** | **0.00000** | **0.00000** | **0.00000** | **0.00000** | **0.00000** | **0.00000** | **0.00000** | **0.00000** | **0.02185** | **0.02854** | **0.02571** | **0.01997** |
| **Electri~** | **0.00000** | **0.00000** | **0.00000** | **0.00000** | **0.00000** | **0.00000** | **0.00000** | **0.00000** | **0.00000** | **0.00000** | **0.00000** | **0.00000** | **0.05662** | **0.00000** | **0.00000** | **0.03627** |
| **Falling~** | **0.00000** | **0.00000** | **0.00000** | **0.00000** | **0.00000** | **0.00000** | **0.00000** | **0.00000** | **0.00000** | **0.00000** | **0.00000** | **0.00000** | **0.09663** | **0.07536** | **0.09306** | **0.05682** |
| **Falling~** | **0.00000** | **0.00000** | **0.00000** | **0.00000** | **0.00000** | **0.00000** | **0.00000** | **0.00000** | **0.00000** | **0.00000** | **0.00000** | **0.00000** | **0.10254** | **0.08942** | **0.13586** | **0.06736** |
| **Ladder ~** | **0.00000** | **0.00000** | **0.00000** | **0.00000** | **0.00000** | **0.00000** | **0.00000** | **0.00000** | **0.00000** | **0.00000** | **0.00000** | **0.00000** | **0.01491** | **0.01492** | **0.01612** | **0.01232** |
| **Manual ~** | **0.00000** | **0.00000** | **0.00000** | **0.00000** | **0.00000** | **0.00000** | **0.00000** | **0.00000** | **0.00000** | **0.00000** | **0.00000** | **0.00000** | **0.01781** | **0.01610** | **0.01785** | **0.01319** |
| **Repetit~** | **0.00000** | **0.00000** | **0.00000** | **0.00000** | **0.00000** | **0.00000** | **0.00000** | **0.00000** | **0.00000** | **0.00000** | **0.00000** | **0.00000** | **0.03158** | **0.02278** | **0.03982** | **0.01756** |
| **Scaffol~** | **0.00000** | **0.00000** | **0.00000** | **0.00000** | **0.00000** | **0.00000** | **0.00000** | **0.00000** | **0.00000** | **0.00000** | **0.00000** | **0.00000** | **0.02574** | **0.02674** | **0.03046** | **0.02128** |
| **Slips, ~** | **0.00000** | **0.00000** | **0.00000** | **0.00000** | **0.00000** | **0.00000** | **0.00000** | **0.00000** | **0.00000** | **0.00000** | **0.00000** | **0.00000** | **0.07392** | **0.06580** | **0.08329** | **0.04607** |
| **Struck ~** | **0.00000** | **0.00000** | **0.00000** | **0.00000** | **0.00000** | **0.00000** | **0.00000** | **0.00000** | **0.00000** | **0.00000** | **0.00000** | **0.00000** | **0.03808** | **0.03352** | **0.03385** | **0.02404** |
| **Trench ~** | **0.00000** | **0.00000** | **0.00000** | **0.00000** | **0.00000** | **0.00000** | **0.00000** | **0.00000** | **0.00000** | **0.00000** | **0.00000** | **0.00000** | **0.00000** | **0.10668** | **0.00000** | **0.16926** |
| **Finishi~** | **0.00000** | **0.00000** | **0.00000** | **0.00000** | **0.00000** | **0.00000** | **0.00000** | **0.00000** | **0.00000** | **0.00000** | **0.00000** | **0.00000** | **0.00000** | **0.15337** | **0.17065** | **0.08284** |
| **Sub-Str~** | **0.00000** | **0.00000** | **0.00000** | **0.00000** | **0.00000** | **0.00000** | **0.00000** | **0.00000** | **0.00000** | **0.00000** | **0.00000** | **0.00000** | **0.15823** | **0.00000** | **0.32935** | **0.11209** |
| **Super-S~** | **0.00000** | **0.00000** | **0.00000** | **0.00000** | **0.00000** | **0.00000** | **0.00000** | **0.00000** | **0.00000** | **0.00000** | **0.00000** | **0.00000** | **0.34177** | **0.34663** | **0.00000** | **0.30507** |
| **The mos~** | **0.00000** | **0.00000** | **0.00000** | **0.00000** | **0.00000** | **0.00000** | **0.00000** | **0.00000** | **0.00000** | **0.00000** | **0.00000** | **0.00000** | **0.00000** | **0.00000** | **0.00000** | **0.00000** |

The limiting super matrix of the foreign is

| | Being h~ | Caught ~ | Electri~ | Falling~ | Falling~ | Ladder ~ | Manual ~ | Repetit~ | Scaffol~ | Slips, ~ | Struck ~ | Trench ~ | Finishi~ | Sub-Str~ | Super-S~ | The mos~ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Being h~** | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.02175 | 0.02175 | 0.02175 | 0.02175 |
| **Caught ~** | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.02575 | 0.02575 | 0.02575 | 0.02575 |
| **Electri~** | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.01390 | 0.01390 | 0.01390 | 0.01390 |
| **Falling~** | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.08780 | 0.08780 | 0.08780 | 0.08780 |
| **Falling~** | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.11159 | 0.11159 | 0.11159 | 0.11159 |
| **Ladder ~** | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.01540 | 0.01540 | 0.01540 | 0.01540 |
| **Manual ~** | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.01723 | 0.01723 | 0.01723 | 0.01723 |
| **Repetit~** | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.03190 | 0.03190 | 0.03190 | 0.03190 |
| **Scaffol~** | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.02801 | 0.02801 | 0.02801 | 0.02801 |
| **Slips, ~** | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.07493 | 0.07493 | 0.07493 | 0.07493 |
| **Struck ~** | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.03477 | 0.03477 | 0.03477 | 0.03477 |
| **Trench ~** | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.03696 | 0.03696 | 0.03696 | 0.03696 |
| **Finishi~** | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.12277 | 0.12277 | 0.12277 | 0.12277 |
| **Sub-Str~** | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.17323 | 0.17323 | 0.17323 | 0.17323 |
| **Super-S~** | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.20401 | 0.20401 | 0.20401 | 0.20401 |
| **The mos~** | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 |