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MINERALS TO METALS INITIATIVE

A SYSTEMIC STUDY OF MINING ACCIDENT CAUSALITY: AN ANALYSIS OF 100 ACCIDENTS FROM A COPPER MINING COMPANY IN ZAMBIA.

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Submitted in partial fulfillment of the requirement for the degree of Master of Philosophy Specializing in Sustainable Mineral Resource Development, MPhil.

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Declaration

I declare that this dissertation, submitted for the degree of Master of Philosophy Specializing in Sustainable Mineral Resource Development at the University of Cape Town, is my own unaided work. It has not been submitted before, for any degree or examination, at this or at any other university.

Signed by candidate

Daniel Mabeti

ABSTRACT

The mining industry has remained Zambia's dominant industry for almost a century. According to the report by International Council for Mines and Minerals (ICMM) for 2013, Zambia is highly dependent on copper mining as the core productive industry. Mining contributes to direct employment (approximately at 1.7%), foreign direct investment (approximately at 86%), gross domestic product (more than 12%) and government revenue (more than 25%). Regardless of these economical enactments, the accident frequency across the mines is very significant. In general, the mining industry is perceived to be a high-risk industry.

The increase in the number of mining accidents is extremely costly, whether measured in terms of medical expenses and disability compensation, loss of production and wages or damage to plant and equipment. The human cost, in terms of death and suffering, is beyond calculation. In recent years, there has been some innovations in terms of technology regarding mining methods, and this has resulted in decreased accident occurrence in the mines. The human factors involved in the mine accidents need to be addressed further to reduce these rates. Therefore, the best approach is first to understand mine accident causality, and then this will be a foremost step in a pursuit to diminish the high rate of accidents. Effective remedies and measures can be designed if only accident process is properly understood. The understanding and interpretation of causes of accidents at workplaces can only be achieved by accident modelling techniques.

The effective way of analysing industrial accidents has been proven by the Swiss Cheese Model, which is also applicable to this study. The Swiss Cheese Model describes an accident as an event which happen within organization due to the combination of different unsafe acts which may include latent conditions and front-line operators.

The purpose of this study was to determine how systemic factors contribute to accidents at a copper mining company in Zambia. The analysed results were compared with those of other local mines as well as mines from developed and developing countries. The approach in this study involves using the existing framework developed by Bonsu (2013). The framework had used the concepts from the Mark III of the Swiss Cheese Model, Incident Cause Analysis, safety management principles and the Nertney Wheel.

The sections involved in the existing framework of Bonsu (2013) are *metadata*, *accident barrier analysis* and *causal analysis*. The *accident causality* section is designed and described in the same way as the Mark III version of the SCM. This section is used for analysis of *accident causality* and is categorized into *proximal*, *work place* and *systemic factors*. The *metadata* section offers explanations on different factors that influence the happening of accidents at this copper mining company in Zambia. Metadata section captures the information on accidents analysed under the barriers and causing agency section of the framework. The variables under the metadata are time and date of accident, place of the accident, accident type, activity involved which resulted in the accidents, task schedule of the accidents, age of the victim, experience of the victim, job status, etc. The last section of the existing framework is the agency and barrier analysis and was designed by Bonsu (2013) to capture data on the safety barriers which were breached and accident causing agents in the accident report. The accident reports collected from the copper mining company in Zambia were used in the existing framework and the analysed results were presented as unsafe acts, workplace and systemic factors with linkages to each other.

The most prominent type of unsafe acts recognized were *routine violation* (recognized in 38% of all the accident analysed), closely followed by *slips and lapses* (identified in 30%) and then *mistakes* (21%). *Exceptional violation* and *non-human cause* were the lowest at 9% and 2% respectively. *Systemic* and *workplace factors* were involved in 78.2% of the accident reports that were analysed. The most prominent workplace factor recognized was *behavioural environment* (25.8% of all cases analysed), closely followed by *physical environment* (23.4% of all cases analysed), then *unsafe work practices* (18.8% of the accidents analysed), then *fit-for purpose equipment* (16.4% of the accidents analysed) and finally *competent people* (15.6% of the accidents analysed). In general, under the category of accident analysis on workplace factors, all the five factors were significantly contributing to the causes of accidents at the mine site that was investigated as demonstrated by the closeness in percentages. In the case of systemic factors, inadequate *supervision* or *leadership* was the most prominent factor identified (22.6% in all accidents analysed). It was also found that *physical environment* (23.4% of all cases considered) was the second most dominant workplace factor recognized.

The results obtained also revealed that some systemic factors were associated with specific workplace factors more than others. For instance, the result of behavioural environment (workplace factor) was usually due to poor leadership problem (systemic factor), problems seen in housekeeping (systemic factor), hazard identification (systemic factor), risk management (systemic factor), and designs (systemic factor), these were also the causes of poor physical environment. In the unsafe work practices (workplace factor), hazard identification was the most common systemic factor that was recognized whereas in fit for purpose equipment (workplace factor) the most common associated systemic factors were risk management, leadership, hazard identification and design.

The results obtained in this study were compared to those obtained in the study of Mwansa (2021), which also applied the framework used in this study to the analysis of accident reports from another mine site of the same mining company in Zambia as used in this study. Similarities and differences were obtained under the accident characterization and causation sections. The operations in both studies are different in terms of mining methods and metallurgical processing plants. This may be responsible for some of the differences in the results obtained in both studies. For instance, in Mwansa's (2021) study, the most dominant unsafe act recognized was also routine violation (36% of all cases considered) whereas the most prominent workplace factors recognized were physical environment (36% of all cases considered) and unsafe work practices (27% of all cases considered). In Mwansa's (2021) study, the most prominent systemic factors recognized as contributing to physical environment were hazard identification, work schedule, risk management, maintenance management, leadership, housekeeping, and contractor management.

The results obtained in this study were also compared with previous studies from different commodities across the globe. This was done to have broader picture when dealing with mine accidents. The causes of accidents identified in this study are of significance to the safety of the industry.

Overall, based on the analysis carried out in this study for the copper mining site investigated, it can be concluded that systemic factors are the main causes of accidents rather than human error and violations.

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List of Acronym and Abbreviations

BHP	Broken Hill Property
CMSHA	Coal Mining Safety and Health Act
ETA	Event Tree Analysis
FOG	Fall of Ground
FMEA	Failure Modes and Effect Analysis
FM	Failure Modes
FTA	Fault Tress Analysis
GDP	Gross Domestic Product
HOF	Human and Organizational Factors
HFAC	Human Factor Analysis and Classification
HFAC-MI	Human Factor Analysis and Classification Methods
ICAM	Incident Cause Analysis Model
ICMM	International Council for Mines and Minerals
ILO	International Labour Organization
JSA	Job Safety Analysis
KCM	Konkola Copper Mines
LCM	Luanshya Copper Mines
LTI	Lost Time Injury
MCM	Mopani Copper Mines

MPD	Mining Partnership for Development
MSD	Mine Safety Department
MSHA	Mine Safety and Health Administration
MQSHA	Mining and Quarrying Safety and Health Act
NIOSH	National Institute for Occupational Safety and Health
NFCA	Non Ferrous Metals
NSW	New South Wales
PIC	Personal Incharge
PPE	Personal Protective Equipment
PTO	Planned Task Observation
RWI	Return to Work Injury
SAMRASS	South Africa Mines Reportable Accident Statistical System
SCM	Swiss Cheese Model
SHEL	Software, Hardware, Environment, Liveware Model
SLAM	Stop Look Assess and Manage
SLC	Subleve Caving
SLOS	Sublevel Open Stoping
SOP	Standard Operating Procedure
STAMP	Systems - Theoretic Accident Model and Processes
TSF	Tailing Storage Facility
UG 1	Underground Site 1
UG 2	Underground Site 2
UG 3	Underground Site 3
UG 4	Underground Site 4
UG 5	Underground Site 5

VFL	Visible Felt Leadership
ZCCM	Zambia Consolidated Copper Mines
ZDA	Zambia Development Agency
ZRA	Zambia Revenue Authority

DEDICATION

To my family; my parents, my children, Bukata, Munshya, Mpatso and my wife, Bertha. Your support and prayers have brought me this far.

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CHAPTER ONE

1.1 Introduction

The mining industry has remained Zambia's dominant industry for almost a century. The Copperbelt and North Western provinces of Zambia are the centre for mining in the country, hosting most of Zambia's copper mines, including those formerly run by Zambia Consolidated Copper Mines (ZCCM). According to the report by International Council for Mines and Minerals (ICMM) for 2013, Zambia is highly dependent on copper mining as the core productive industry. The country largely adapts to the inverted pyramid arrangement of macroeconomic contributions seen in previous presentations of the mining partnership for development (MPD) toolkit in other countries. It has very high contributions in some macro areas (remarkably exports and investment) but progressively lower contributions in other areas such as government revenues, gross domestic product (GDP) and employment as shown in Figure 1.

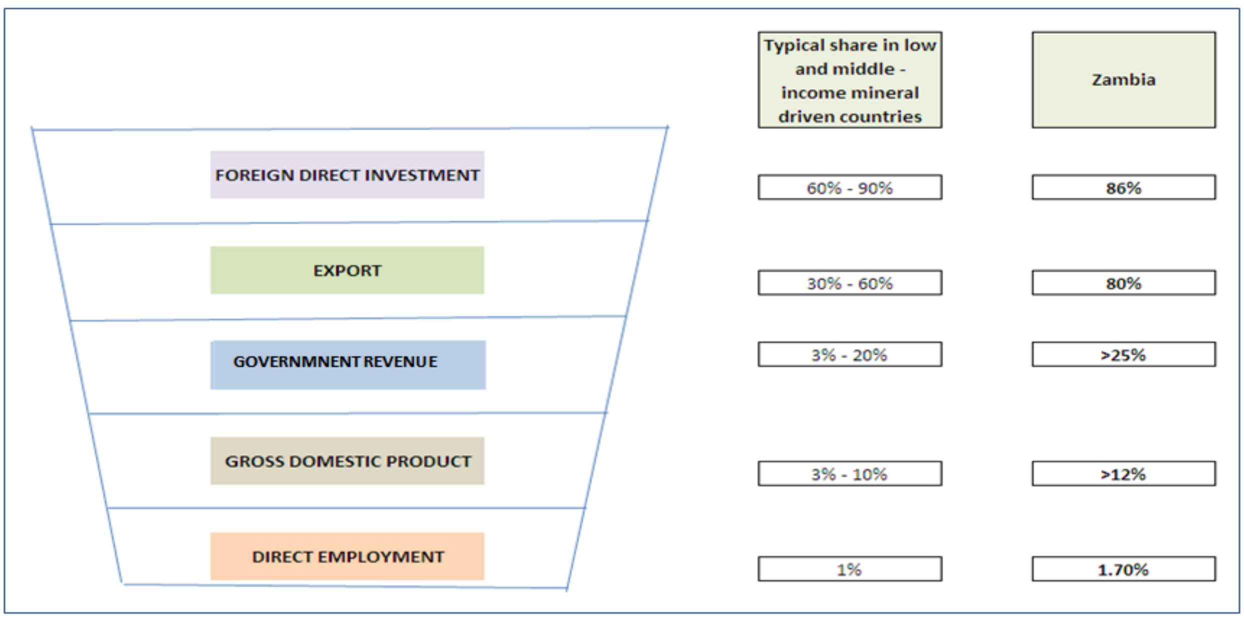

Figure 1: National contribution of mining in Zambia

(Source: ICMM, 2013)

According to the official report of Zambia Revenue Authority (ZRA) for 2012, government revenues collected from mining companies increased suddenly in recent years to over 30% of the total tax revenues. The report further shows that government incomes from the mining industry used to be low (around 16% of total tax revenues) until around 2008 when the aforementioned sudden increase occurred (see Table 1). However, the contribution of mining to gross domestic product (GDP) is less clear. The International Council on Mining and Metals (ICMM) in 2013 also reported that the total approximation of mining contribution to Zambian GDP is at least 12% (ICMM, 2013). The employment contribution of mining is the smallest of the direct macro contributions but still large in absolute terms (ICMM, 2013). The absolute numbers of jobs in mining have increased significantly in response to higher levels of investment and production.

Table 1: Zambia's mining taxes for 2008 and 2012 as a share of GDP

Year	GDP (Kw billion)	Total taxes collected (Kw billion)	Mining taxes collected (Kw billion)	Mining taxes (% GDP)	Mining taxes (% total tax)
2008	54,839	9,670	1,541	2.81%	16%
2012	111,049	20,723	6,619	5.9%	32%

(Source: Zambia Revenue Authority, 2012)

Note: The Figures used for kwacha are for un-rebased

1.2 Background

This study has been necessitated by several concerns raised by members of the public, trade unions and the Zambian government regarding the poor safety performance of the mines. This has affected the sustainable development of the mining industry in Zambia. Jackie Range of Dow Jones Newswire (2005) published an article highlighting the increased number of injuries and fatalities in mining industry in Zambia where more than 20 fatalities were reported at one mine in the year 2005. This was the worst year in terms of accident records in the mining industry in Zambia in which about 80 people died. Most of the fatalities in that year happened at one of the explosive manufacturing companies called Brigmme explosive (see Figure 2).

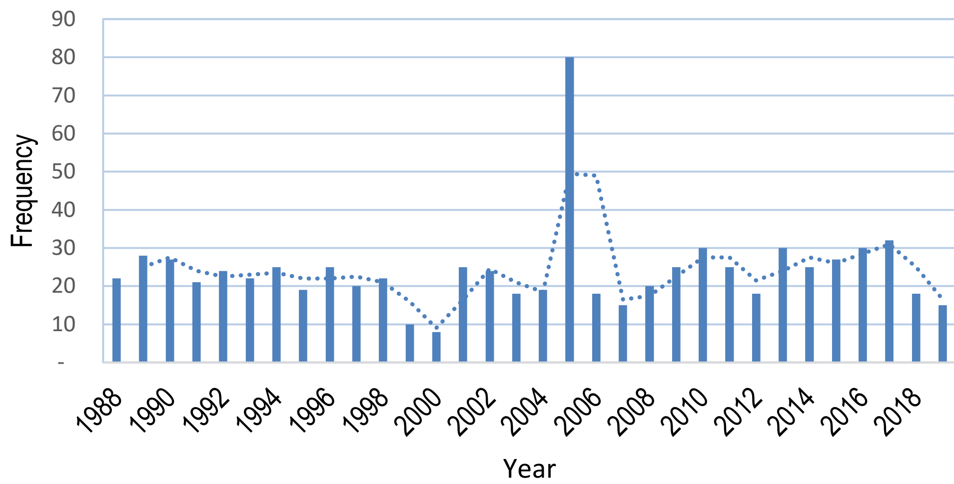

Figure 2: Mining fatalities in Zambia.

(Source: Mine Safety Department, 2020)

The Zambia daily newspaper on 25th July 2015, also released an article which stated that the main contributing factor to accidents in the copper mines is negligence and delay by government to implement the national laws on safety and health that were formulated at the convention C117 held in 1995 and 1999. According to the Zambia daily newspaper on 25th July 2015, the public complained of government's failure to discipline responsible inspectors of mines that fail to execute their duties. The weakness in implementation of safety laws in the mining industry has compelled mining companies not to invest in the safety of workers because severe penalties are not usually applied.

Kansumba (1995) also carried out a study to determine the contributing factors to mine accidents at Mufulira division of Zambia Consolidated Copper Mines (ZCCM). The author showed that mine accidents in developing nations are more than those happening in developed countries. However, international intervention has consistently failed to produce long term improvement. The study outlines reason for this failure as the inability to put in policy interventions. In Zambia, like many other developing countries, work related illnesses are not adequately recognized as problems and usually go undetected (WHO bulletin, 2001).

Figure 3 shows the summary of copper production figures against the total accidents reported for the entire copper mining industry in Zambia from the year 1988 to 2019.

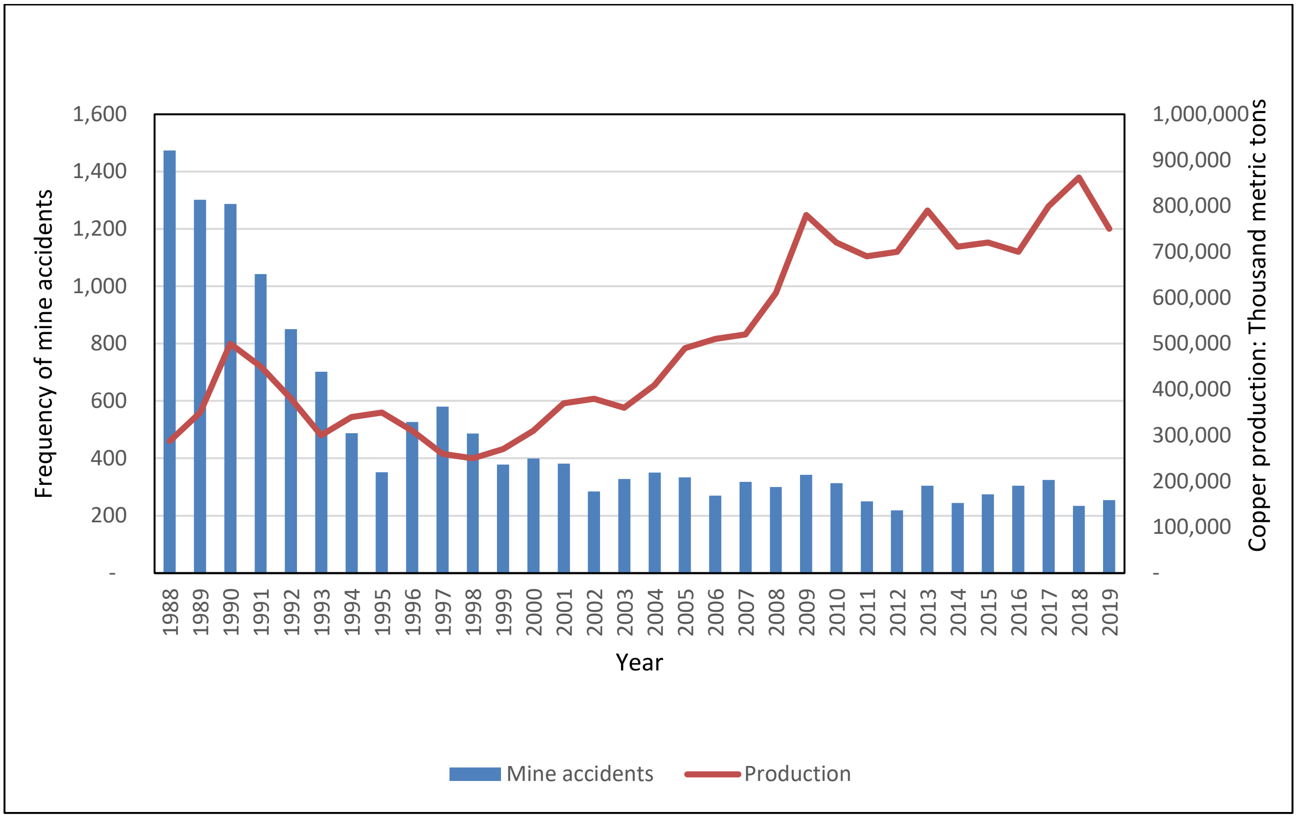

Figure 3: Copper production and reported mine accident from 1988 to 2019

(Data Source: Mine Safety Department, 2020)

The number of accidents and production figures in the mining industry in Zambia were very high especially from the year 1988 to 1990 whereas a decrease in production figures and accident rates is seen from 1990 to 1993 as shown in Figure 3. In the period 1990 to 1994, copper prices dropped on the international market which made Zambia Consolidated Copper Mines Plc (ZCCM) to shut most operations and led to the decrease in copper production. The shutting of operations also resulted in less manpower and decrease in accidents occurrence. In 1998, the mines were privatized, and a sharp increase in production is seen from 1998 to 2002. However, the number of accidents in this period were reduced due to safety measure that were introduced by the new mine investors. Such measures included improved technologies (mechanization of the mines), less exposure of workers to danger, improved safety measures, etc.

1.3 Aims and Specific Objectives

This study aims at determining the systemic factors contributing to accidents at one of the copper mining companies in Zambia. The results obtained are also compared with those of other local mines as well as mines from developed and developing countries. The approach in this study involves using the existing framework developed by Bonsu (2013). This framework was then applied to the accident reports that were collected from this copper mining company being investigated. The results obtained are vital in determining the effects of leadership, technology, personal, unsafe condition and acts with respect to safety.

The following are the main objectives: -

1. To apply the existing framework that was developed by Bonsu (2013) to analyse the causes of accidents at the copper mining company in Zambia used as case study.
2. To determine the distribution of human errors in the causes of accidents.
3. To determine the effect of personal and situational variables such as age, experience, time of day, status of employee, stress level, etc., on the propensity of mine workers to commit unsafe acts. It also involves establishing the links between upstream factors (workplace and systemic) and unsafe acts committed by workers at the mine.
4. To compare the results of two of the mine sites of the mining company being investigated in this study as well as with results obtained in other countries (developing and developed countries).
5. To make recommendations based on this study for the Zambian mining industry.

1.4 The Case Study of This Work

Zambia has several large mines which include Mopani Copper Mines Plc (MCM), Luanshya Copper Mines (LCM), Chambeshi Metals Plc, Non-Ferrous Metals (NFCA), Barrick Lumwana Copper Mine Plc, Chibuluma Mine Plc, Munali Nickel, Ndola Lime Company, Lafarge Cement, Zambezi Portland Cement and Konkola Copper Mines Plc (KCM). In addition, there are several small mines. This study is specifically focused on one of the mining companies in Zambia located in the Copperbelt province. The mining company that was investigated has various operations consisting of underground mines, open-pits, metallurgical plants, and general offices. One of the key motivations for choosing the mine site used as case study in this work is because a parallel study was done on one of the other sites of the company using the same accident analysis framework as used in this study. The framework was first developed by Bonsu (2013). The findings of this work and those of the parallel study are compared to understand the similarities and differences in terms of systemic factors affecting the two mine sites even though they are owned by the same company. Of the two mining sites, this study focuses on the site which has underground mines, open pits, metallurgical operation and other surface operations. In 2003, the company recorded a total of 169 injuries at one of its mine sites, which is the site used as case study in this thesis. Figure 4 shows that from 2003 to 2008, the company was recording more than 80 accidents per year. Figure 4 depicts the decrease in accident occurrences from the year 2010 to 2019. This decrease was because of some safety measures that the company implemented such as mandatory alcohol test for all employees.

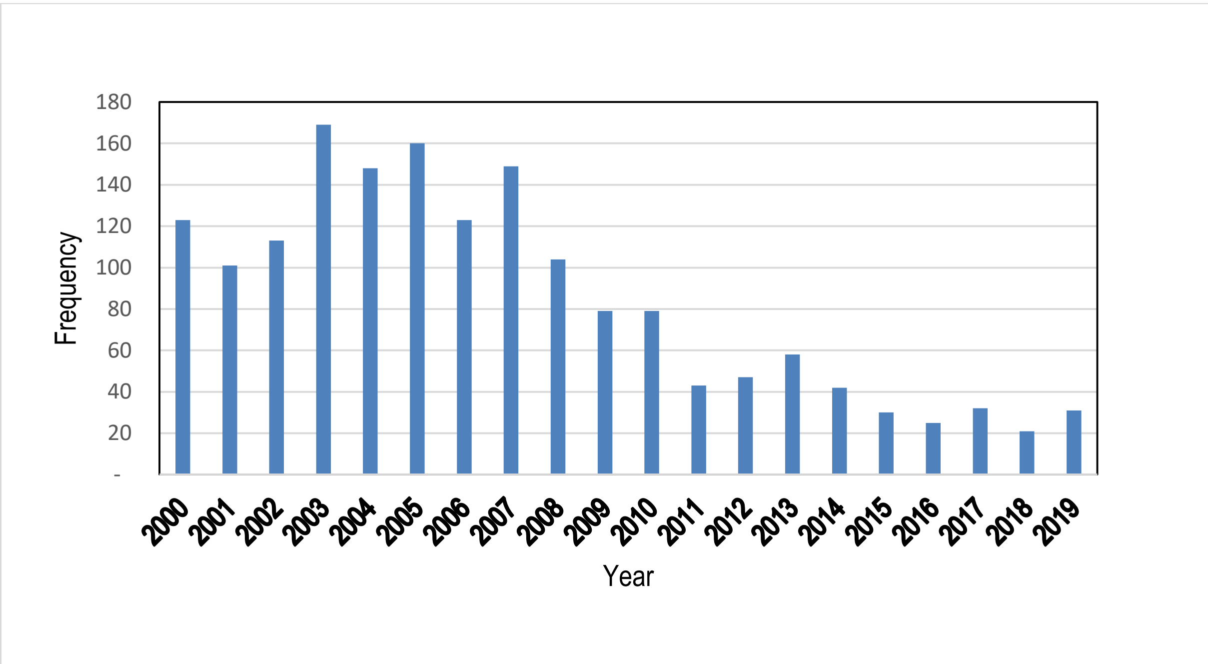

Figure 4: Mine site reported accidents.

(Data source: Mine Safety Department, 2020)

As earlier stated, one of the key motivations of this study is to establish how safety culture compares in two different mining sites owned by the same company. Hence a parallel study to the one done in this dissertation was carried out by Mwansa (2021) using the same framework developed by Bonsu (2013). The study of Mwansa (2021) analysed 101 accidents reported at the other mine site while this study analysed 100.

Based on the results obtained, comparisons have been made both internationally as well as locally on the safety cultures across different mines. Comparing the mine investigated in this study with that studied by Mwansa (2021), the site of this study has got more underground shafts while the other has only one underground mine. The underground shafts used for this study have different mining methods while the other mine site under Mwansa's (2021) study has only one mining method. In terms of processing plants or metallurgical processing, Mwansa's (2021) study has a lot more activities compared to the mine site of this study. Therefore, it can be concluded that the mine site of this study has more employees working underground compared to that of Mwansa (2021). However, one of the similarities between the study of Mwansa (2021) and this study is that both mine sites produce the same commodity (copper ore). The results obtained in this piece of work could also be compared with the results that would be obtained when the framework of Bonsu (2013) is applied to other mining commodities in Zambia so as to develop a holistic set of approaches to tackling mining accidents in Zambia and developing countries at large.

1.5 Scope

The scope of this study involves the use of an existing framework that was developed from the Swiss Cheese Model by Bonsu (2013). Few modifications were made to the existing framework in terms of terminologies and coding system used by the mining company that was investigated. A set of 100 accident reports from the year 2013 to 2014 were collected, and these accidents consisted of only fatalities, return to work and lost time injuries (LTI). The collected accident reports were then populated into the existing framework and results were obtained in each section of the framework.

A research questionnaire was also administered to the general workforce at the mine site for this study. The questionnaire on employee's monthly income for both the company staff and contractors was conducted to understand its effect on a worker to commit unsafe acts (see Appendix A for questionnaire for a sample of employees). Research questionnaires on the safety and health of the workers were also administered to the general workforce at the mine site for this study. This being a case study, the questionnaires were confined to only one mine site.

1.6 Structure of Dissertation

This section briefly describes an overview of the entire dissertation and is arranged as follows: -

Relevant literature considered in this study are presented in *Chapter Two*. Reviewed literature under this chapter comprises world major mine accidents, mining techniques, mine accident description, human error, accident modeling techniques, human error accident frameworks (taxonomies), systemic safety research and finally safety research in Zambia. These topics, which are covered under chapter two, are intended to explain the necessity of systemic study in the Zambian context.

Chapter Three elucidates comprehensively the techniques and methods engaged for this study. Topics covered under this chapter comprise the description of existing framework used in this study, data collection, coding system, tools used to analyse the results and typical examples describing the use of the existing framework.

Chapter Four presents detailed results of analysis achieved in the study. The initial section of the results presents accidents according to characterization. The second section presents accident in terms of the identified causal factors and linked to accident causality at various stage of the analysis. The third section focuses on the unsafe acts and linkages with accident characterizations. The fourth section is workplace factors and its linkage with direct causes to determine the distribution of accident in each level. The fifth section entails systemic factors which are also linked with the workplace factors in order to determine the distribution in each level of accident analysis.

Chapter Five discusses the results displayed in chapter four and is presented to form a foundation for conclusions of summarized results of chapter six.

In Chapter Six the findings, significance, challenges, and recommendations of this study are presented.

CHAPTER TWO: LITERATURE REVIEW

The important literature reviewed in this study are highlighted in this chapter. The chapter begins with discussion of the challenges the mining industry is facing globally in terms of safety. Various mining disasters in different mining countries are reviewed and put into perspective in this study for the purpose of comparison. The first section of this chapter reviews worldwide mine accidents that have occurred previously and why they occurred as documented in the literature. This helps to understand and develop the role of human error, organizational error, and violations in accident causation.

Other sections of this chapter include mining techniques, methods for establishing accident causality and terminologies used in human and organizational errors. Understanding of accident causality in this study also requires modeling techniques of accidents and its importance which is explained in detail. A systems approach is compared to other accident modeling approaches and justified as to why it is better than other methods; this is explained in detail and examples are also given. This chapter also explains the justification for selecting this organizational error model based on the concept of the Swiss Cheese Model and other systemic modelling techniques. At this stage, the literature review pays attention to describing the Swiss Cheese Model and other accident analysis models that are relevant to this study. This is done to consolidate research that has been done using these frameworks and compare their results. This chapter also discusses systemic studies on mining accident causality with emphasis on what conclusions can be drawn from them. The chapter wraps up with a review of studies that have been carried out on safety in Zambian mines and summary of the key learning points from the literature review.

2.1 Major Global Mine Accidents

There have been significant efforts in recent years to improve the working conditions for mine workers to create a safer environment. The advancement in the use of safer mining equipment and the introduction of strict safety legislation, has led to a significant decrease in the occurrence of accidents in the mining industry in recent years (Stemn, 2018). However, even with such efforts that have been put in place, there are still significant dangers associated with working in a mine. Globally, this is seen as a major challenge (Gyekye, 2006). Major accidents have occurred in various mining related industries around the globe which includes, the coal, gold, copper and tailing facility storage (see Table 2).

Although metalliferous mines such as copper, cobalt, gold and platinum haven't produced much fatalities compared to the coal mines, the accident rates in these mines are high. Examples of mine accidents include the Mufulira mine disaster in Zambia in 1970 (Neller et al, 1973) where about 89 people died, the BGRIMM explosion in Zambia which killed more than 50 people in 2005 (Chabala, 2006), the Harmony Gold disaster in South Africa in the year 2009 where more than 50 people died (Chamber of Mines South Africa, 2012), and Chengzihe Gold mine in China in the year 2002 where about 124 lives were lost. Other major mine disasters include the Crandall canyon disasters in the US (August 6, 2007), the Turkish's Zonguldak mine disaster which happened in May 2010 and the Chilean mine disaster which happened on the 5th of August 2010. Tailings storage facility (TSF) have also produced much catastrophic failures. The recent Brumadinho dam disaster which occurred on 25th of January 2019, claimed more than 259 fatalities (Phillip, 2020). Table 2 shows mining disasters around the world which have made the industry to be regarded as the most dangerous operation to work in (Phillip, 2020).

Table 2: World major recorded mine accidents.

Mine Name	Location	Date	Casualty	Commodity
Coalbrook	South Africa	21st January, 1960	427	Coal
Mitsui Miike	Omuta, Japan	9th November, 1963	438	Coal
Wankie	Zimbabwe	6th June, 1972	422	Coal
Mufulira Mine	Zambia	25th September,1970	89	Copper
Kinross Mine	South Africa	16th September, 1986	177	Gold
Dobmja Jug Mine	Bosnia	26th August, 1990	180	Coal
Sunjiawan Mine	China	14th February, 2005	214	Coal
Pasta de Conchos	Mexico	19th February, 2006	65	Gold
Taoshi Tailings	China	8th September, 2008	254	Iron
Ulyanovskaya Mine	Russia	19th March, 2009	108	Coal
Harmony Gold Mine	South Africa	27th November, 2009	60	Gold
Gyama Mine	China	29th March, 2013	83	Gold
Soma Mine	Soma, Turkey	13th May, 2014	301	coal
Brumadinho dam	Minas, Brazil	25th January, 2019	259	Iron
Hpakant Jade Mine	Myanmar, Canada	2nd July, 2020	113	Jade

(Source: Phillip, 2020)

Mining operations is hazardous in nature by considering the rate of accidents that had occurred in the past years. The study of Stanton (2003) also acknowledged the significant number of accidents recorded in mines compared to other industries.

The international labour organization (ILO) in 2010 also reported that workplace injuries were very high in the mining industry. However, mining companies across the world have embarked on safety programs which aim at eradicating accidents and other related problems that has to do with safety. There are a number of departments at the mines which are responsible for ensuring that safety is maintained in the mines. Such departments include geotechnical, mine planning and safety department. The United State Department of Labour under the Mine Safety and Health Administration in 2015 reported that every year from 2009 to 2015 over 30 fatalities and 4,000 non-lost time injuries were recorded in the mining industry alone (MSHA, 2015). The next section briefly describes the stages of copper processing from extraction to final product.

2.2 Copper Extraction Process

Figure 5 gives an overview of how copper ores are extracted from the earth's crust and converted to pure metal. Depending on the geological information of the orebody, the extraction can be either through open pit or underground mining (Hartman, 1987).

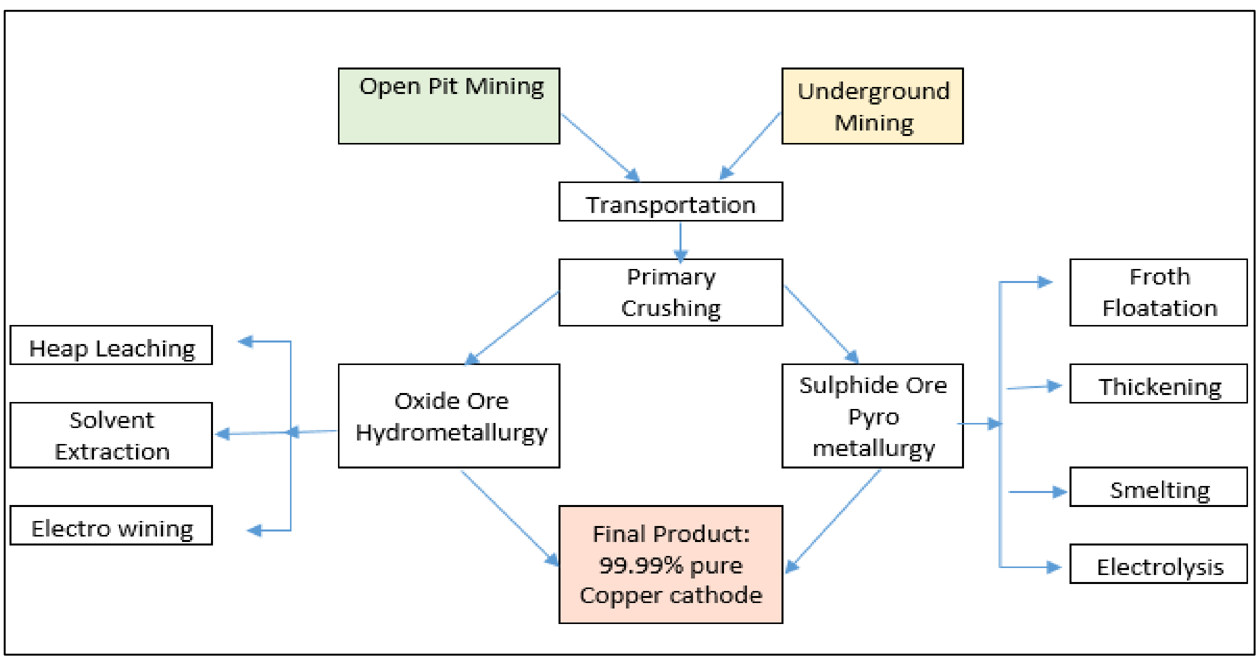

Figure 5: Copper extraction process from orebody to final product (Hartman, 1987).

Underground mining is used to extract ore from below the surface of the earth safely, economically and with as little waste as possible (Hartman, 1987). The entry from the surface to an underground mine may be through horizontal or vertical tunnel, known as an adit, shaft or decline (Hartman, 1987). There are different types of underground mining methods which include; sublevel caving (SLC), sublevel open stoping (SLOS), room and pillar, block caving, cut and fill, longwall mining, vertical crater retreat (VCR), shrinkage stoping method, and many other methods which are applied according to the geological formation of the orebody (Hartman, 1987). Surface mining involves extracting minerals near the surface of the earth. The three most common types of surface mining are open-pit mining, strip mining and quarrying (Hartman, 1987). Upon extraction, the ore is transported to the primary crusher for grinding (as shown in Figure 5). The ore that is extracted through surface operations contain oxides and are treated through the process called hydrometallurgy while the underground material contains sulphide and are treated through the process called pyro metallurgy operations. Hydrometallurgy extraction process involves, heap leaching, solvent extraction and electro winning to produce 99.99% pure copper (Hartman, 1987). Pyro metallurgy extraction process involves, froth flotation, thickening, smelting and electrolysis to produce a final metal product (Hartman, 1987).

The operations for the mine site used as a case study has both underground mining and metallurgical processing plants. However, the underground mine sites are more than metallurgical process plants. Underground mine sites have more employees compared to metallurgical processing plants for the site used as a case study.

2.3 Mine Accident Description

The mining industry high-risk can be seen from historical data (Gyekye, 2006). The way the term ''mine accident'' is defined in the United States of America mining industry is different from that of Australia. The Australian legislation defined a mine accident as an event where the person involved must be dead or admitted to hospital for injury treatment (Patterson and Shappell, 2010). Under the United States of America's legislation, mine accident is defined as an event where the individual involved dies at the mine or the injury sustained has the potential to cause death (Patterson and Shappell, 2010).

These definitions, i.e. those of the USA and Australia, are actually similar. However, these are supplied from different sources, where that of Australia originates from the Queensland Government's Coal Mining Safety and Health Act 1999 (CMSHA) and Mining and Quarrying Safety and Health Act 1999 (MQSHA) while that for the USA originates from the Mine Safety and Health Administration (MSHA). The difference is that the USA regulations identify an accident on a broader aspect and the phrase ‘high-potential incident’ is not included in the definition. High-potential incident is referred to as an “event, or a series of events, that cause or has the potential to cause a significant adverse effect on the safety and health of a worker”. The accident that causes injury to a person such that the person is absent from work for more than one day from the time of accident is referred to as lost time injury. In the Zambian context, accidents are categorized as Lost Time Injury (LTI), Return to Work Injury (RWI) and Fatal. LTI is an accident or incident in which the injured worker is absent from work for more than a day from the time the accident happened while RWI is an accident where the injured person returns to work within a day from the time an incident happened (Mine Safety Department, 2000). A fatal accident is an accident that results in the death of the victim within a day from the time the incident happened (Mine Safety Department, 2013).

2.4 Human Error

Human error is defined by Reason (1990) as the “failure of planned actions to achieve the desired result without the intervention of unforeseeable events”. Also, Rasmussen (1983) stated that human error is only judged based on the outcome of what the performer does when the error is committed. Human error is characterized regarding the level of reasoning involved (Rasmussen, 1983). Human behaviour is responsible for the errors which are committed by humans. Therefore, human behaviour can be grouped based on rule, knowledge and skill. Ruled-based are concerned with learned application of rules which include decision making processes in policies and procedures. In this category, an error happens when an incorrect or bad rule is applied. When past experience or knowledge is applied to perform a task, then the behaviour recorded is knowledge-based. An error in this category is likely to occur because of lack of training of the individual involved in a task. The tasks involved in this category usually require high thinking capacity and is likely to cause problems involving unusual emergency cases (Patterson and Shappell, 2010). The final category is the skilled-based behaviours; these are often automated in nature and take place at an unconscious level.

Reason (1990; 1997) also describes errors and violations as “unsafe acts” which an individual commits and leads to an undesired event. An error is categorized into two types. The first is when the planned activity is not executed according to plan, and this is referred to as slips and lapses. Slips and lapses in this case happen due to errors involved during execution. While slips are due to attention failures, lapses are due to memory failures hence the name memory lapses (Reason, 1990, 1997; Kletz, 2001). The second type of error is where the planned activity was not adequately executed according to plan (Patterson and Shappell, 2010). These types of errors generally arise from failures of intention and they are usually mistakes. Mistakes are further grouped based on the knowledge and skills involved. Mistakes that are knowledge-based happen in cases where an individual want to solve a problem without having sufficient knowledge of the problem. Lack of knowledge on experience to solve a problem will make the mind to develop a solution based on inaccurate knowledge. Reason's (1997) study stated that mistakes involving knowledge-based situation are usually subjected to personal biases. Mistakes involving rule-based situation is applicable to the case where an individual applies experience to solve a similar problem. Mistakes arise when a good rule is misapplied or failure to apply a good rule.

Patterson and Shappell (2010) defined violations as the deliberate action to ignore rules and regulations and are further classified as either routine or exceptional. According to Reason (1998), one other human behavioural pattern that leads to accident is violations, which can be described as the factor which has the potential to increase errors and can lead to accidents. Routine violations are violations that happen because of routine bending of rules that are overlooked by management within an organization whilst exceptional violations are isolated violations of the rules of an organization. Exceptional violations are not usually obvious in the behaviour of a person. Exceptional violations are situational specific, which happen on occasions where the operator sees the violation as the only option to get the job done. The potential to commit errors is within an individual's mental activity (Patterson and Shappell, 2010). The intention of an individual is very important when classifying errors. According to Reason (1990), it is important to distinguish between deliberate and unintended behaviour when categorizing human error.

The other important study on human error is that of Miller and Swain (1987) in which human error was categorized into omission, commission, or substitution type of errors. Omission errors occur when there is failure to perform a step in the assigned task. Commission errors happen when a person performs an action which should not have been performed. Substitution errors occur when an undesired action is performed in place of the desired action (Miller and Swain, 1987). There are a lot of studies on human error, with descriptions and categorizations in different ways. Despite the availability of different ways of categorizing human error, there is still some challenges in defining and coding errors according to criteria (O'Hare, 2000). This inconsistency is why industries across the world are unable to share and compare data regarding safety. Therefore, the percentage of accidents being considered due to human error has remained high for several decades (O'Hare, 2000).

2.5 Accident Modelling Techniques

Accident modelling is an empirical approach of describing an accident by the flow of events in an incident. A direct relationship between causes and effects with accident characteristics is provided in the concept of accident modelling. The accident modelling techniques considers the concepts of characterization, causes and effects of accident processes. Accident modelling techniques explain why an accident has happened. To analyse the causes of accident occurrences in the post hoc process, modelling tools can be used to help conduct risk assessments (Qureshi, 2007). During accident investigations, accident model imposes patterns on the accidents and influence both the data collected, and the factors identified as causative (Leveson, 2004). A key driver for the continued rise in analysis model and method numbers is the ever-increasing complexity of socio-technical systems (which are comprised of interacting human, technological and environmental components) and the resulting change in accident causation mechanisms (Underwood and Waterson, 2013).

There are two main types of accident modelling techniques that have been used across industries to analyze accidents. The techniques are sequential and systemic accident modelling. Sequential modelling techniques conceptualize accidents in a sequence or chain of events (Leveson, 2004). They assume that an undesired event, i.e., a 'root cause', initiates a sequence of events which lead to an accident and that the cause-effect relation between consecutive event is linear and deterministic (Underwood and Waterson, 2013). Based on this modelling approach, it can be concluded that accidents happen due to causes, therefore, if those causes are recognized and eliminated, then the same type of accidents will not recur. Some examples of the sequential approach are the failure modes (FM) and effects analysis (FMEA), fault tree analysis (FTA), event tree analysis (ETA), and cause-consequence analysis (Qureshi, 2007).

The Domino theory is one of the earliest models involving accident causation. It was suggested by Heinrich in the 1940's to describe an accident as a series of disconnected events occurring in a distinct temporal order (Qureshi, 2007). The Domino theory, which is classified under the sequential accident modelling techniques, led to the development of most accidents and risk assessment related models such as failure modes and effects analysis (FMEA), fault tress analysis (FTA), event tress analysis (ETA), and cause-consequence analysis (Leveson, 2011). One of the disadvantages of these models is the limited capacity to describe accident causality in more realistic ways (Hollnagel, 2008). Some of the most common root causes of accidents recognized with these modelling techniques are, energy build up, component failures and human error. The models also work well in relatively simple systems and have proved to be limited in the ability to provide clear illustrations for reasons of accident occurrence in complex systems (Qureshi, 2007).

The other type of accident modelling considered in this review is the system contextual approach for the occurrence of accidents. The theories behind these models are that they consider interactions of systems and do not specify a single causal variable. The study of Hollnagel (2008) for systemic models reveals that at a particular time and space, unexpectedly when various causal factors such as technical, human and environmental conditions interact with each other, an accident will occur. Accidents are seen in systemic models as occurrences due to the complexity in the relationships between system components that may lead to disturbance of the system which may ultimately result in an accident (Qureshi, 2007). The origin of systemic models is from systemic theories. The systemic theories include the regulations, ideologies, and models required to understand the complexity in the interactions, interrelationships, and interdependencies between components (human, technical, organizational and management). In the systemic models, it is stated that accidents are not created by a combination of latent and active failures; they are the result of humans and technology operating in ways that seem rational at a local level but unknowingly create unsafe conditions within the system that remain uncorrected (Underwood and Waterson, 2013). Some examples of the accident modelling theories are the Swiss Cheese Model (SCM) of Reason (1990), the AcciMap of Rasmussen (1997), the Systems-theoretic accident model and processes (STAMP) of Leveson (2004), and the human factor analysis and classification systems (HFACS) of Wiegmann and Shappell (2003).

2.6 Reason's Swiss-Cheese Model (SCM) of Accident Investigation

Reason (1990) developed the Swiss Cheese Model for accident investigation and depicts this as a sequence of five 'planes' lying one behind the other. The first plane represents the topmost decision markers, the second plane represents the managerial level, the third plane represents effective working conditions, the fourth plane represents production events while the last plane represents defense against common workplace hazards. The hierarchy of the planes is shown in Figure 6. To achieve effective production within a system, the right decision must be followed at each level (see Figure 6).

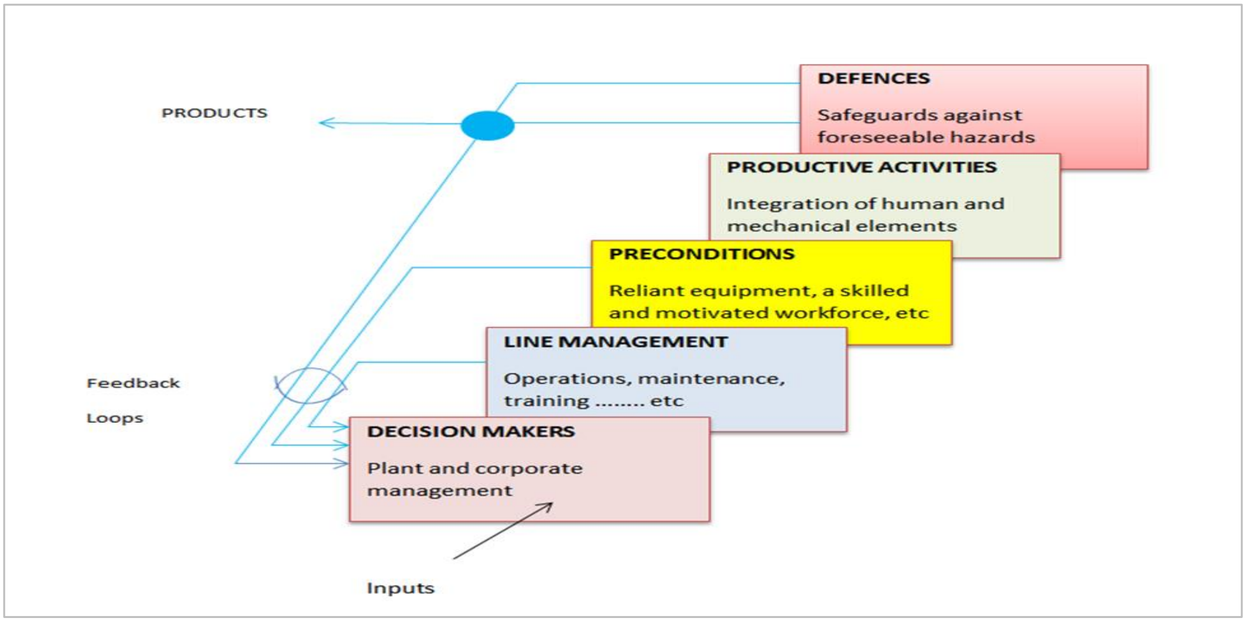

Figure 6: The important production system components (after Reason, 1990).

The progression of an accident begins when imperfect decisions that are taken at the management level filters via the different layers of operation of a system (see Figure 7). The judgements taken generate holes in the existing barriers to produce accidents.

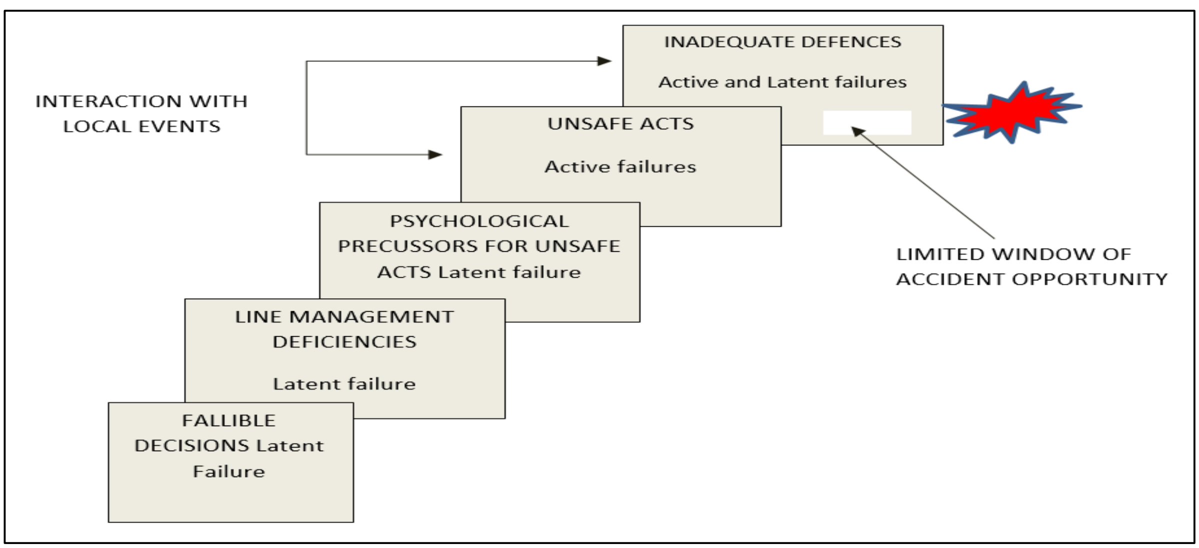

Figure 7: The Mark I version of the Swiss Cheese Model (after Reason, 1990)

Figure 8 describes how an accident is seen as the time when holes in the various safeguards line up for the accident trajectory passing through successive 'slices' (Reason et al, 2006). The accident trajectory was developed to describe dynamics in accident causation that arise when there are interactions between passive failures and a variety of local triggering events (Reason et al, 2006). The white slices represent organizational (managerial level), human failures (unsafe acts) and grey slices represents defense-in-depth (set of defenses ensuring system's integrity). Figure 8 shows that an accident occurs at the time when holes in different barriers are lined-up for the accident trajectory to be completed.

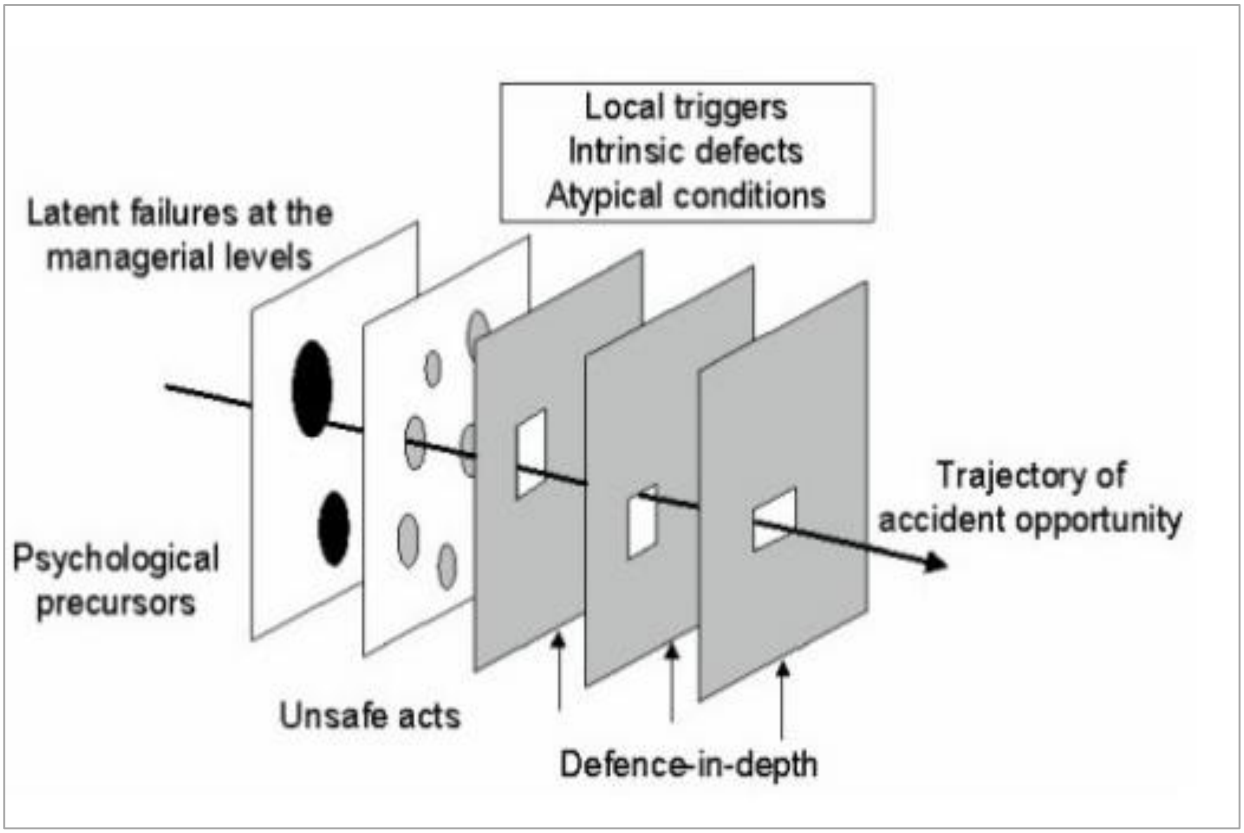

Figure 8: The accident trajectory (from Reason et al, 2006)

The second version of the SCM is the Mark II, in which the barrier factors have evolved from four in Mark I to three, namely, organization, workplace and person. The organization includes corporate culture, organizational processes and management decisions. In the Mark II version at the same time, the number of barriers has increased from one in Mark I to three, resulting in the prototype of the SCM (Reason et al, 2006).

A third version of the Swiss Cheese Model was also developed by Reason (1997) and is referred to as Mark III version of the SCM. In this model, all planes were removed and replaced with barriers, controls, defenses, and safeguards of the system (see Figure 9). The Mark III involves an explanation on how holes are generated in the system. The framework also has arrows to show the direction in which an accident occurs as well as the direction in which accident is investigated.

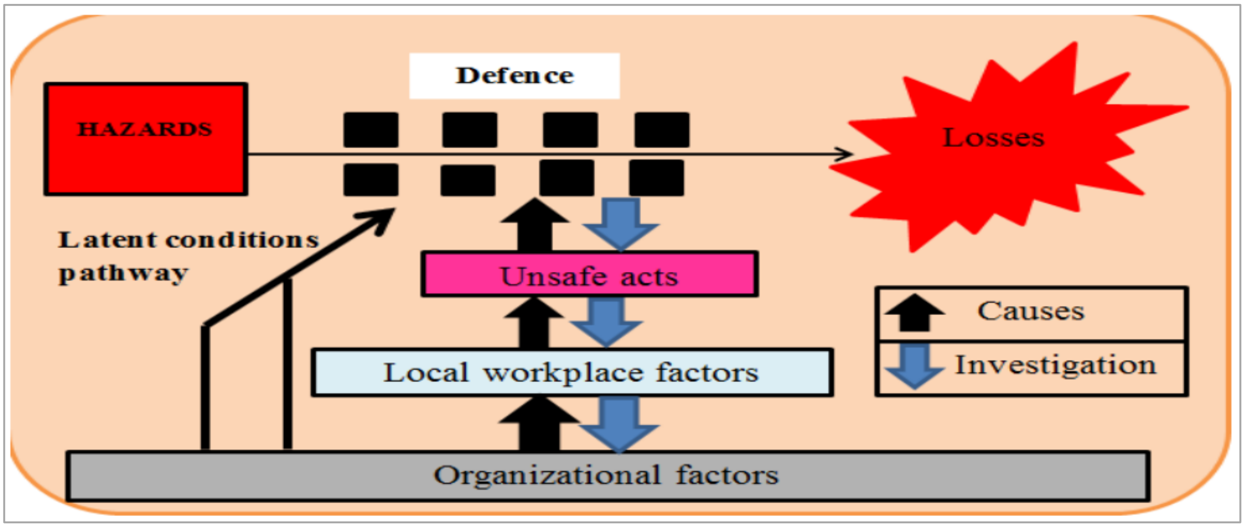

Figure 9: The Mark III version of the Swiss Cheese Model (Reason, 1997)

The Mark III version of the Swiss Cheese Model is described as a framework in which decisions made within the organization create holes that propagate into workplace factors and later turn or breeds into unsafe acts that are caused by front line operators (see Figure 9). The presence of unsafe acts within the system in the long run create holes in the defenses which can lead to accident occurrences (referred to as active failure situations). The Mark III version considers possibility of recording accidents where organization and workplace factors are involved (referred to as passive failure situations).

2.7 Human Error Accident Frameworks (Taxonomies)

Most accidents happen due to human error (Rasmussen, 1982). Human error continues to be implicated in most accidents. Most accident investigation and reporting systems are not currently designed around any theoretical framework of human error (Rasmussen, 1982). The discontinuity between classical theories of human error and the practical application of these theoretical approaches in accident investigation may be the reason for this (Rasmussen, 1982). The Swiss Cheese Model is generally accepted for depicting situations leading to accidents in production systems, however, there has been some criticisms which states that it lacks adequate details for practical applications (Shappell and Wiegmann, 2000). To address such criticisms, different analysis techniques have been developed based on the SCM. These techniques include ergonomic, cognitive, epidemiological and psychosocial (Rasmussen, 1982; Wickens and Flach, 1988; Edwards, 1988; Helmreich and Foushee, 1993). However, new models have also been developed which describe the occurrence of accidents as being a result of the interaction among the causes of the accidents. They focus on the system approach unlike a single element approach of accident causation. The systems and organizational methods of accident investigation are usually presented in human error models. Examples of human error models include the Human Factor Analysis and Classification System (HFACS), the Software, Hardware, Environment, Liveware (SHEL) Model, the Incident Cause and Analysis Model, the Wheel of Misfortune, the Behaviour Safety Method (Be Safety). These models are discussed in the next section.

2.7.1 Incident Cause Analysis Method (ICAM)

The Incident Cause Analysis Method (ICAM) was developed in Australia and officially launched in April 2000 by Broken Hill Property (BHP) Billiton mining company. Reason (2000) helped to facilitate the development of ICAM (as shown in Figure 10) together with the Australian Transport Safety Bureau and the Dedale Asia Pacific. The entire concept of the ICAM was based on Reason's (2000) study. The ICAM model is based on the principle of the acceptance of the inevitability of human error. The ICAM model recognizes and analyses accidents at four different levels, namely, organizational factors, task or environmental conditions, individual or team actions and absent or failed defences (see Figure 10).

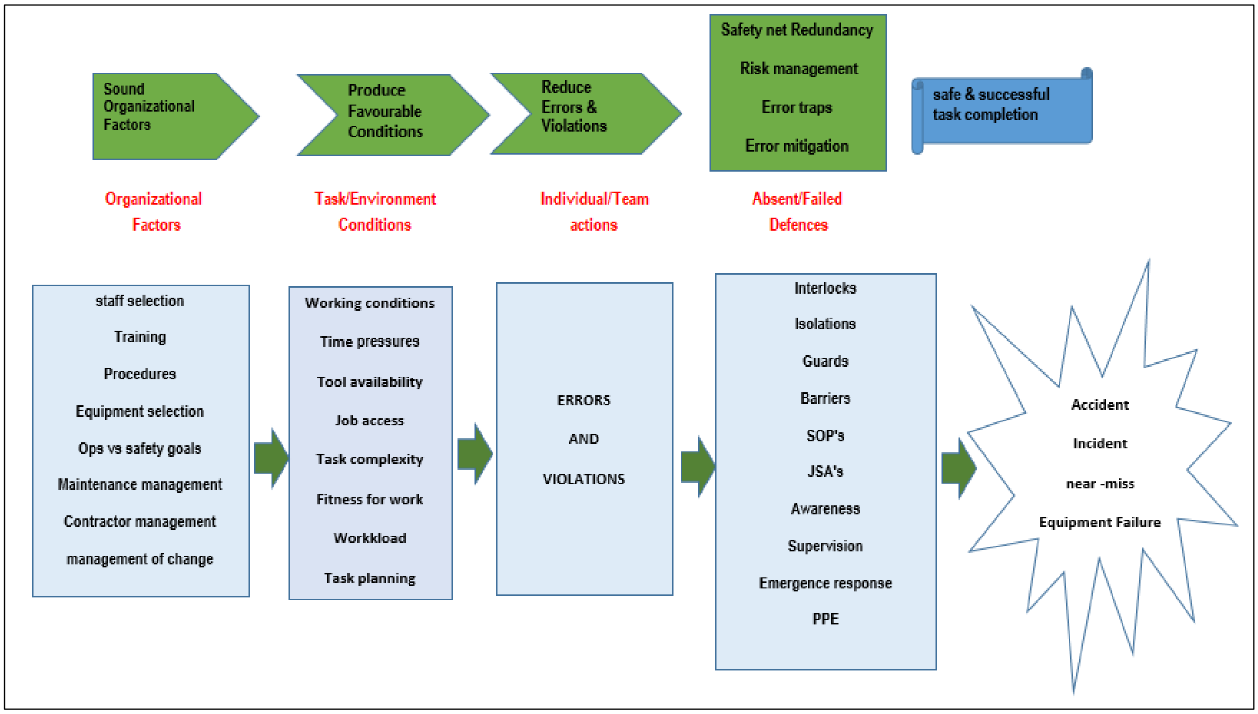

Figure 10: The ICAM model (from De Landre et al, 2006)

The aim of ICAM is to first recognize failed deficiencies in an organization. This is then followed by the development and implement recommendations to handle identified deficiencies. ICAM, together with the SCM, has been used across various industries to investigate the causes of accidents. De Landre et al (2006) explained the objectives of the ICAM accident investigating tool as being capable of establishing facts, identifying latent contributing factors, checking the effectiveness of available procedures and measures, finding results, offering active corrective recommendation, detecting organizational factors, and offering established key learning facts that can be distributed across the organization. The ICAM process of accident investigation is not structured on a blame or liability game but it intends to identify human error and offer remedial recommendation. These recommendations are based on the findings of failure in an organization. Figure 10 shows the four different levels of the Incident Cause Analysis Method.

Absence of defenses or failed defenses is the first level in the ICAM model. The ineffective, or absent, defenses that failed to recognize and safeguard the system against technical and human failures are identified in this first level. In the first level of the ICAM model, the roles of barriers include detection/warning, awareness, hazard identification, recovery and control, rescue/escape, and protection.

The second level in the ICAM model is individual/team actions (see Figure 10). This level is aimed at identifying errors and violations of frontline operators that led directly to the incident under investigation. Typical examples of such conditions include tools availability, time pressures, working conditions, etc.

Task and environmental conditions in the ICAM model is the third level. The pre-existing condition, prior to the occurrence of an incident, that led to a frontline operator's action is recognized in this third level of the model (De Landre et al, 2006).

The organizational factors is the final level of the ICAM model. This level aims at identifying the fundamental organization concerns which produces work conditions to affect the performance of the frontline operator. Instances involving organizational factors are hardware, training, communication, procedures, mismatched goals, design, risk management, maintenance management, change management, management of contractor, organizational culture, supervisory influence, and organizational learning (De Landre et al, 2006).

The ICAM model has been successfully used by many mining companies around the world to analyse mine accidents such as the BHP Billiton Company (De Landre et al, 2006). It is essential to state that the copper mine being investigated in this study also uses ICAM method to analyse mine accidents. However, one major problem identified with the ICAM is the failure to classify individual and team action level in the model.

2.7.2 SHEL Model

The SHEL (Software, Hardware, Environment, and Liveware) Model, presented by Edwards (1972), describes human machine interactions and can identify areas in a system where failure is likely to occur. In the SHEL model, four failures (see Figure 11) have been categorized as hardware, software, environment conditions and liveware. Hardware comprises physical resources such as equipment which are used in the design system. Software comprises the documents, procedures, standards, policies, and regulations on which the design system operates. Environmental factors comprise environmental conditions for the design system. Finally, it is the liveware that includes factors like teamwork, communication, leadership, and norms. Failure is likely to happen due to any component failure or misconnection of any component in the system. When considering the systems approach in the SHEL model, the focus of the model is man-machine interface (Patterson and Shappell, 2010).

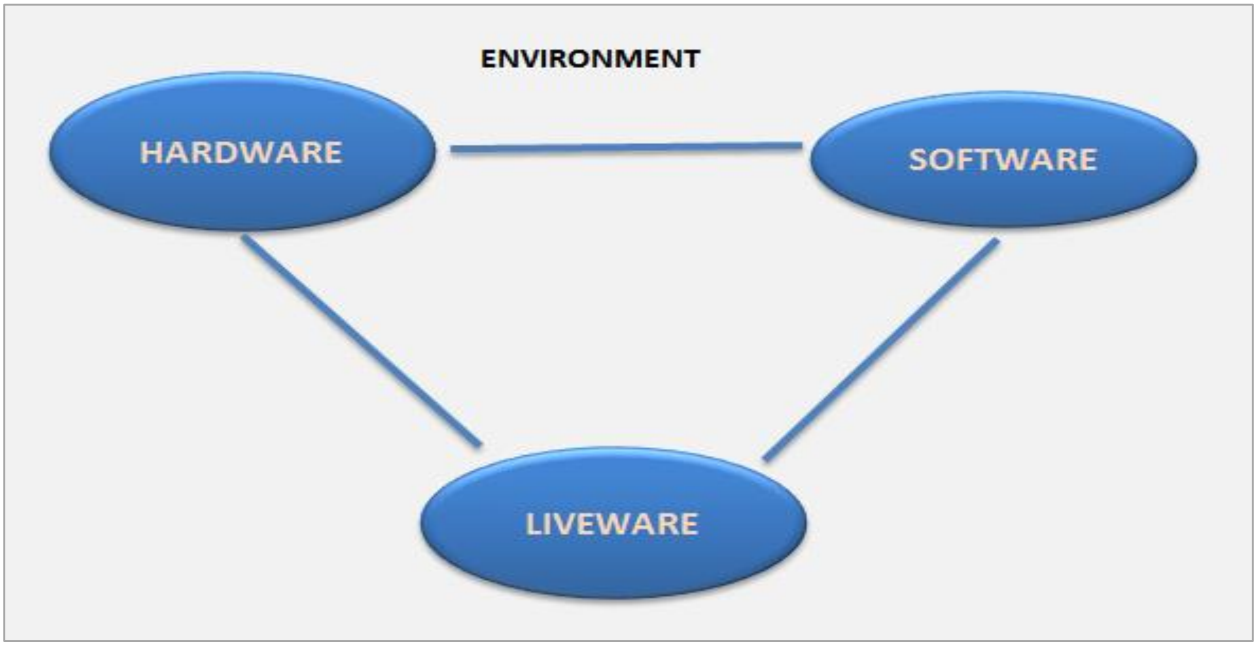

Figure 11: Software, Hardware, Environment and Liveware model (Edwards, 1972).

2.7.3 Wheel of Misfortune

This taxonomy was developed by O'Hare (2000) for analysing the role of human factors in accidents in the aviation industry as well as other complex design systems. The taxonomy of O'Hare draws on the works of Helmreich (1990) and Reason (1990). The structure of O'Hare (2000)'s taxonomy is comprised of three basic concentric spheres (see Figure 12) of which each represents the action of the front-line operators, local conditions, and conditions of an organization. The innermost of the spheres, "local action," represents the local actions which attempts to describe what happened. These include data such as information error, deduction error, goal error, strategy error, procedure error and action error. The middle sphere represents any condition which is likely to affect the operator's performance. The conditions under this second sphere are demand task, interface and resource. The outermost sphere represents reasons as to how policies, procedures and philosophies can lead to the condition of the operator performance. O'Hare (2000) also grouped the third sphere with regards to recognition and unrecognition of hazards.

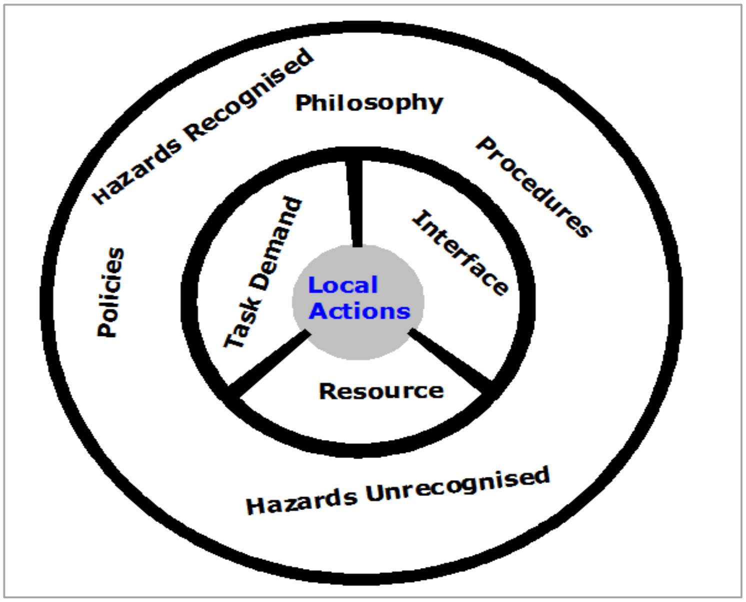

Figure 12: The Wheel of Misfortune (O' Hare, 2000)

2.7.4 BeSafe (Behavioural Safety) Method

The method was developed by ergonomists at the British coal industry as a technique for investigating accidents to identify their latent causes. Previously, the method had a name called potential human error audits (Simpson, 1994). Benedyk and Minister (1998) stated that the basic principle of the BeSafe method is entirely dependent on Reason's Swiss Cheese Model and it addresses latent failures in the system design. The BeSafe method can identify the areas that are prone to human errors using ergonomic tools such as checklists, task analysis and questionnaires (see Figure 13).

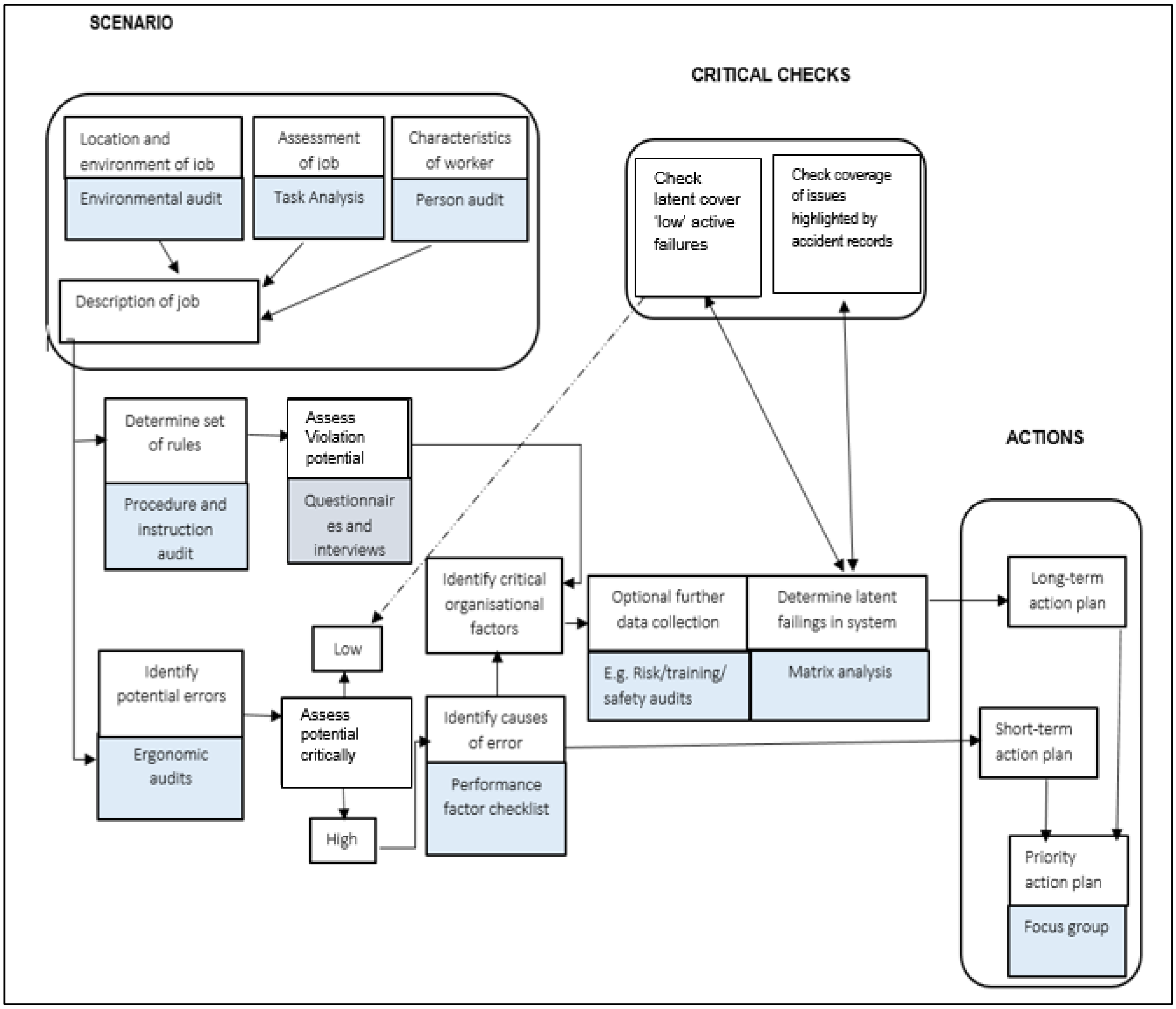

Figure 13: BeSafe Method (after Benedyk and Minister, 1998).

The analysis approach in the BeSafe method begins with the assessment of the environment or location where the task is likely to be carried out (referred to as environment audit) and the impact of it on the performance of the task. The next step is to assess the task requirement (job assessment) to know the type of skills required for the task. Finally, information about the person assigned to carry out the task is analyzed (personal audit) to identify potential strengths and weaknesses. The result of the analysis from these three analyses (environment, job, and personal audits) is used to detect how human factors will contribute to accidents. The procedures firstly allow the identification of human errors likely to cause accidents (active failures). This might be directly caused by the design of the task in hand, or indirectly caused by the worker violating a procedure. The BeSafe procedures then enable the identification of organizational factors which are likely to predispose active failures; following, these give the latent failure in the system. The other analyses that are carried out in the BeSafe method include a procedure and instructions audit (for the purpose of identifying violation inducing potential of a set of rules), the performance aspects checklist (to identify the causes of errors) and an ergonomic audit (to identify errors induced by nature of work systems design). The previous accident modelling techniques described (i.e., ICAM, HFACS) analyze accidents in a post-hoc manner, unlike the BeSafe method which analyses accidents in an ad hoc manner. The importance of this method is that errors are identified prior to occurrence of an accident which implies that the statistics can be used as a check in the system (Benedyk and Minister, 1998).

2.7.5 Human Factors Analysis and Classification System (HFACS)

Shappell and Wiegmann (2003) developed the Human Factor Analysis and Classification System (HFACS) for the US Navy for accident investigation. According to Shappell and Wiegmann (2003) the HFACS was developed to describe the passive and active failures that were identified in the Swiss Cheese Model of Reason (2006). Four structural levels of analysis are considered in the structural design of the HFACS framework (see Figure 14). The four levels include the unsafe acts, pre-condition for unsafe acts, unsafe supervisions, and organizational influences. The actions performed by a worker prior to the occurrence of an accident is referred to as unsafe acts. This model divides the unsafe acts into errors and violations. The errors are further divided into decision, skilled-based and perceptual, while violation is divided into routine and exceptional. The pre-condition level for unsafe acts considers three factors which are operator's condition, environmental and personal factors. The environmental conditions under the pre-condition for unsafe acts considers the physical and technological environment, whereas the operator's conditions tackle the adverse mental state, physiological state, fitness for duty and physical limits. Personal factors tackle the crew resource management and personal readiness. The third level of the HFACS is the unsafe supervisions and consists of inadequate supervision, planned inappropriate operations, failed to correct problems and supervisory violations. Organizational influence is the final level of the framework, which considers resource management, organizational climate, and organizational process. The HFACS was developed specifically to be used within the military aviation but because of its versatile nature, the framework has proved to be effective in other industries such as commercial aviation (Wiegmann and Shappell, 2003; Krulak, 2004), railway transport (Viale, 2006), (Hopkin, 1995), medical industry (ElBardissi et al., 2007) and remote pilot aircrafts (Tvaryanas et al, 2006). The HFACS framework is also an essential tool in academia especially in safety related studies.

According to Wiegmann and Shappell (2003) studies on HFACS show that the criterion used to develop the framework were very reliable, comprehensive, diagnostic, and usable. The HFACS uses kappa value as a means of testing inter-rater reliability in the model. The kappa value ranges from 0 to 1 and is used to indicate the degree of agreement of nominal assessments made by multiple appraisers (Cohen, 1960).). The higher the value, the stronger the degree of agreement (Cohen, 1960) The kappa value of 0.94 was achieved in the HFACS framework for the USA military aviation (Wiegmann and Shappell, 2003). The rating in the kappa are as follows; a fair value is anything below 0.60, a good value will range from 0.60 to 0.74 and an excellent value will be 0.75 or higher (Fleiss, 1981). The HFACS framework has also been used outside the military aviation and was able to get a classification rate of 0.75 which shows that the framework is also capable of giving good results outside the military aviation arena, although requires a slight modification of terminology. The HFACS framework can identify the breakdowns within the entire system that allowed an accident to occur. HFACS can be used to proactively analyse historical events to identify reoccurring trends in human performance and system deficiencies. HFACS can also be useful as a tool for guiding future accident investigations in the field and for developing better accident databases, both of which would improve the overall quality and accessibility of human factors accident database (Shappell and Wiegmann, 2003). The model's ability to recognize the interactions amongst the errors along with their causes is referred to as diagnosis. The study of Li and Harris (2008) recently proved the diagnosis of the HFACS framework for their works in the aviation industry.

The ability to transfer the theories and academic solution to the practical usage within the mining industry is referred to as usability (Patterson and Shappell, 2010). The practical usage of the HFACS framework has been successfully proven by the results obtained in the analysis and investigation of accidents in different industries such as the Federal Aviation Administration (Patterson and Shappell, 2010). However, the study of O'Hare (2000) identified one major problem with the HFACS framework not to have clear boundaries between higher levels for causal factors.

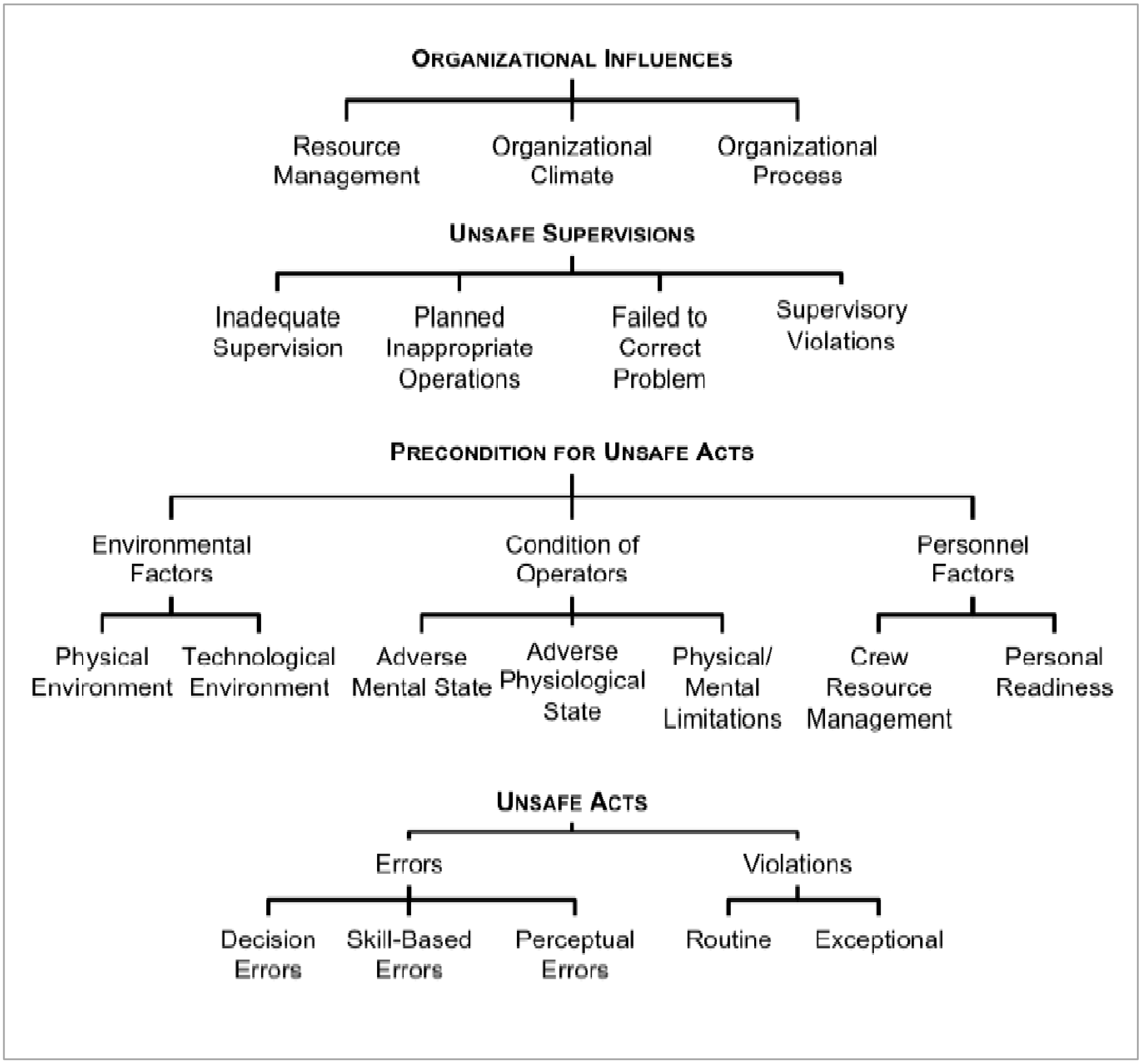

Figure 14: The HFACS framework (after Wiegmann et al, 2005)

2.8 Systemic Causes of Accidents

Different studies on mine accidents across the world have been successfully carried out using the Swiss Cheese Model and other related frameworks which originated from systemic theories of accident investigation. Patterson and Shappell (2010) carried out a study on the human factor trends and system deficiencies within the Australian mining industry using the HFCAS method. The accidents investigated in the study showed that unsafe acts were involved in most of the cases. The study of Patterson and Shappell (2010) from the Australian mines shows that most of the unsafe acts were because of skilled based errors and the variations were minor in different mines. Pre-condition for unsafe acts were standing at 81.9% of all the accidents investigated and analyzed. The accidents investigated showed that the most common pre-condition factor contributing to unsafe acts was workplace environment (mine environment). The problem of *leadership* was also significant at 36% while *organizational factor* was at 9.6% in all cases analysed. However, the study of Patterson and Shappell (2010) concluded that at each level of the organization, causal factors were identified in a hierarchical way and this represents a much more structured organizational analysis of incidents. These results attest to the fact that higher level factors are rarely involved in most accidents (Patterson and Shappell, 2010). The first reason for this may be due to a single deficiency of high organizational factor that has the potential to influence other factors down the line. The second reason is that it may be due to the focus of the accident investigation. The third reason might be found in the studies of Sanmiquel et al (2010) which stated that environmental problems were the most prominent causes of accidents whereas behavioural problems were usually reported as the final cause of most accidents. According to their studies, it was found that the causes of accidents were subdivided into precursors and contributing factors.

Under environmental problems, most of the events happened due to lack of preventive systems within an organization whereas problems involving behaviour were mostly due to skilled-based errors. Lack of training, unsafe workplaces and provision of inappropriate equipment were the most contributing factors identified to have been causing accidents in the Spanish mining industry. The study of Sanmiquel et al (2010) further analysis the reason why human behaviour is regarded as the root cause of most of the accidents. This confirms Reason's (1990, 1997) Swiss cheese model of accident modeling which explains that some factors are more of contributory in nature than causal. However, the study of Sanmiquel et al (2010) did not consider the link between accident (active and latent failures) pathogens and behavioural factors.

Cawley (2003) studied electrical related accidents in the mining industry in the USA. The study revealed that from the year 1990 to 1999, the fourth leading cause of accidents in the mines was electricity. The study of Cawley (2003) further stated that 93% of accidents were due to electricity related incidents. The study of Homce and Cawley (2008) from the mines in the USA also revealed that 25% of the fatal accidents recorded from all accident analysed were due to related electricity related incidents. Homce and Cawley (2008) further stated that the other causes are the involvedness of high reaching mobile equipment coming in close contact with supply overhead power while in transit in the haulages, or mine drives leading to the metal to produce the frame which becomes energized, and this may not have been noticed by operators. The study of Homce and Cawley (2008) from the USA further states that from 1980 to 1997, about 57% of all accident analysed were due to overhead power in which operators were not aware of the contact.

Groves et al (2007) studied the contribution of mining equipment to the fatalities in the USA from 1995 to 2004. This study reveals that of all accidents analysed, 77% had happened due to the use of mining equipment whilst 49% of the fatalities were due to the use of mobile equipment. Mining haulage trucks such as mobile trains, front end loaders, conveyors, dump trucks, and dozers were mostly cited in many of the accidents.

The study of Kecojevic et al (2007) in the US mining industry identified that the most common types of accidents that occurred had involved the mobile equipment colliding with pedestrians. The study also revealed that of all the incidents that occurred, 44% involved workers having less than 5 years' work experience. The most common root causes of accidents involving mobile equipment were mechanical faults, failure to obey warnings, non-existence of warning signs and non-existence of operating procedures (Kecojevic et al., 2007). Lack of training, poor roadways and poor workplace designs were the other contributing factors identified by the study to cause accidents.

Lenne et al (2011) conducted a study on the Australian mining industry to analyse the extent of association between high level organizational factors and operator performance using the HFACS method. The most prominent causes of unsafe acts identified in the study were skilled-based errors. The study also recognized adverse mental state and technological environment (level 1 factor) as contributors to the skilled-based errors whereas team resource management (level 2) was recognized in decision errors. The study also revealed that inappropriate planning and poor supervision (level 3) were the most common contributing factors to cases involved with crew resource management (level 2 factor). Physiological state, as well as adverse mental state, were the cause of supervisory violation and inadequate supervision respectively. Resource management and organizational climate were identified as the most prominent causes of poor supervision. This is very important to this study as it provides a constructive linkage between different levels of accident causes and therefore a demonstration of Reason's (1990) theory of accident trajectory in the mining accidents.

Laurence (2004) conducted an attitudinal survey at 33 mines in New South Wales (NSW) and Queensland provinces in Australia. The aim of the study on the mine site which involves 500 workers was to seek the opinion of the mining workforce on safety rules and regulations on a general basis, and how they apply to their specific jobs. The study of Laurence (2004) also investigated the level of awareness and understanding of mine rules and procedures such as manager's rules and safe work procedures. The study revealed results which suggest that mine management and regulators should not continue to produce more and more rules and regulations to cover every aspect of mining. The detailed prescriptive regulations, detailed safe work procedures, and voluminous safety management plans, will not connect with a miner (Laurence, 2004). This implies that achieving more effective rules and regulations is not the only answer to a safe workplace.

The analysis conducted by Bonsu (2013) at a platinum mine shows that most violations happened in the absence of supervisors and this was due to poor leadership. Standard operating procedures must be enforced by supervisors at the workplace to reduce accidents (Stemn, 2018). Bonsu (2013) further stated that humans were involved in executing most of the operations at the site, resulting in an increase in human errors in the system. According to Stemn (2018), there are differences between the types of human error occurring in mechanized mining compared to conventional mining. The unsafe acts that were identified by Bonsu (2013) were *slip and lapse* (30.8%), *routine violation* (45%), *mistakes* (43%) and *deviant violation* (2.2%). The study of Bonsu (2013) identified *leadership* (51.6%) as the most prominent systemic factor leading to accidents. However, measures to avoid mistakes were taken when dealing with cases involving falls of ground and the use of hand-held tools or equipment. The root cause of slip and lapses were recognized in temporal environmental conditions that were created by the work process. Based on Bonsu's (2013) study, it is worthwhile to state that a technique developed from the Swiss Cheese Model (Reason 1990, 1997) can be successfully used to analyse the causes of accidents in the mining industry.

2.9 Safety Research in Zambia

Studies on mine accidents have been conducted in different countries using different techniques. However, for this reason certain application maybe limited to this study. Mines are much more labour intensive in countries like Zambia and South Africa whereas in countries like the United States of America, Sweden, Australia, United Kingdom, Russia and Canada, the mines are mechanized (Hatting and Du Plessis, 2010). This is one major difference between mines in developing and developed countries. Although most of the mines in the Copperbelt province of Zambia are mechanized, there are still some mines which operate in the conventional state including the mine used as case study in this work.

Chabala (2006) analysed how safety laws in the Zambian mining industry conflict with each other as well as how such conflicts has led to some mining companies not taking responsibility over certain accidents. Lack of will on the part of the government to implement safety and health laws for mine workers was seen as a weakness.

According to the report by the Zambia Development Agency (ZDA) of 2013, there are more underground mines in the country compared to surface mines. Globally, it is known that most underground mines are labour intensive whereas surface mines are mechanized (Huang, 2011). This implies that humans are mostly involved in executing tasks in the conventional mines as opposed to mechanized mines. This is the reason why it is very important that human factors be considered in a quest to improve safety of the mines.

Kansumba (1995) also conducted a study to determine the factors contributing to accidents in Zambia's copper mines. The results showed that 62% of all the accidents analysed were due to negative attitude by workers in performing the assigned tasks. The author acknowledges the fact that most workers had knowledge about the standard operation procedures but rarely followed them when executing tasks. This led them to record more accidents at workplaces.

Chipere (2008) conducted a study on stress management and reduction in the copper mines in Zambia. The factors recognized in the study that contributed to stress were excess workload, unreasonable performance demand, long working hours, and low monthly income. Other factors recognized by Chipere (2008) that contributed to increased stress for the worker were physical environment, organization practices, interpersonal relationship, and management of change.

This systemic study which involves the identifying of human errors as contributing to accidents is the first of its kind in the Zambian context. This systemic study involving accident causality would be very important and useful for understanding and appreciating the dynamics of safety issues in the mining industry. The availability of such knowledge and information will assist relevant stakeholders to understand the significance of decision making regarding the worker's ability to commit unsafe acts that can lead to accidents. In summary, the literature reviewed under this chapter revealed that organizational error model or the Swiss Cheese Model states that Human and organizational factor (HOF) can lead to accidents in the mining industry, but at the same time HOF can also be used as a safety barrier to optimize the existing resources (Reason et al, 2006). The Swiss Cheese Model can be used to study an accident situation and can provide a better understanding of the system with respect to automatic and manual safety barriers. A significant number of large-scale disasters in various industries have occurred in the past with improved technology in place (NIOSH, 2006). The root causes of these accidents have been traced to latent failures and organizational errors arising in the upper echelons of the system in question (Reason et al, 2006). The organizational error model of the Swiss Cheese Model describes two interrelated causal sequences. The first causal sequence is the active failure pathway that originates in the top-level decisions and proceeds via error-producing and violation-promoting conditions in the various workplaces, to unsafe acts committed by those at the immediate human system interface. The second causal sequence is the latent failure pathway that runs directly from the organizational processes to deficiencies in the system's defenses. Another important outcome from the discussion of this chapter is that organizational errors increase the likelihood of operator's error through the active failure pathway and, at the same time, enhance the possibility of adverse effects through defensive weaknesses.

In this study, the existing systemic accident framework, which was developed by Bonsu (2013), for the analysis of accident reports at one of the platinum mines in South Africa, is used, with some modifications, to analyse the cause of accidents in one of the mine sites of a copper mining company in Zambia. The description of the existing framework, the reason behind its mode of development, as well as the modification done on the framework in this study, are explained in detail in the next chapter.

CHAPTER THREE: METHODOLOGY

The framework for accident analysis used in this study is based on a combination of the Swiss Cheese Model presented by Reason (1990, 2000), HFACS framework by Wiegmann and Shappell (2003), and other safety and management principles. The framework used is in this study, which was developed by Bonsu (2013), is described, and compared to other existing frameworks in this chapter. The framework of Bonsu (2013), who was a postgraduate student at the Department of Chemical Engineering, University of Cape Town, was used to analyse 91 accident reports from a platinum mine in South Africa, to understand the causes of accidents at the mine. However, the framework was slightly modified in this study to make it adaptable to the analyses of accident reports from the Zambian copper mining industry. This chapter also describes the following: data gathering method adopted, explanations of the terms used in the accident reports from the mine site used as case study, and the various sections that comprises the analysis framework used. This information is vital for this study as it guides the reader to understand the system of reporting accidents and what has been happening at the mine. Section 3.1 briefly introduces the sections of the existing framework from Bonsu's (2013) study. Section 3.2 explains data gathering at the mine site studied as well as background of the mine, and its incident reporting and investigation procedures. Section 3.3 explains the coding of the gathered data which is in accordance with the mine's safety standard and procedural documents. Section 3.4 involves detailed presentation of two of the accident reports used in this study for the purpose of illustrating and verifying the coding process approach adopted. The last section of this chapter, which is Section 3.5, provides a detailed incident and accident investigation system as well as the accident analysis of the data.

3.1 Description of Systemic Analysis Framework Used in This Study

The analysis framework developed by Bonsu (2013), with slight modifications that were done in this study, was used to analyse accident reports from a copper mining site in the Zambia's Copperbelt province. The framework, which is easy and simple to apply to determine accident causation in mining operations, has three major sections. The sections, which were developed in Microsoft 2010 Excel spread sheet, comprises agency (causal analysis), metadata, and barrier analysis sections. The causal section comprises proximal causes, workplace, and systemic factors.

3.1.1 Causal analysis

This portion of the framework is designed for the analysis of accident causality. The accident causality portion of the framework is designed and described in the same way as the Mark III version of the SCM. The causal analysis is further divided into three sub-sections namely: proximal causes, workplace factors and systemic factors (Appendix B for causal section).

3.1.1.1 Proximal factors

The proximal factor is one that aims at identifying events or actions which are directly related to an accident (as shown in Appendix B 1). The proximal factor is further subdivided into non-human causes and unsafe acts. The action or activity that is performed by an operator to accomplish assigned task but leads to an accident is referred to as unsafe acts. This happens because the operator's action had failed to achieve the proposed or required objectives. Slips and lapses, mistakes, routine violations and exceptional or deviant violations are the subdivisions of the unsafe acts. These subdivisions consider all the way human behaviour or actions can cause accidents.

Slips and lapses. The framework under this category uses slips and lapses to represent actual behaviour in which the planned task had failed to meet its anticipated results because of memory failure or wrong action from the initial plan. Slips and lapses can also be errors highly associated with routine activities that are usually carried out in an autopilot mode. Slips are due to the loss of attentiveness while lapses are because of memory failure. Reason (1990) classified slips and lapses separately but this study combines the two in the same way as done by Bonsu (2013) where both words have the same psychological process which is as a result of skilled based activities (Berry, 1993). The HFACS and HFACS-MI framework describes slips and lapses in a similar manner as the Wheel of Misfortune framework.

Mistake: The framework of Bonsu (2013) describes mistake as a situation where the plan to be executed proved to be deficient for the task. This usually happens due to wrong judgment because of inadequate information or data to understand a particular problem. Diagnosis and procedure errors are further classified and are also used in this case. The Wheel of Misfortune (O'Hare, 2000) presented diagnosis error. However, in the framework developed by Bonsu (2013) this diagnosis error was not considered to be essential for the study. Details involving such can only be seen to be essential, when dealing with research works that consider different types of mistakes (Bonsu, 2013). Bonsu (2013) from his study further noted that due to the nature of reporting at the mine site which the author used as a case study, it was impossible to extract such details.

This is similar with the reports for the mine site used in this study which also did not contain such information. Hence it is inappropriate to include it in the existing framework.

Violation or non-compliance: This is a situation where laid down procedures, rules and standards are not followed diligently in accomplishing assigned tasks. Under this category in the framework, violation is categorized as routine and exceptional.

Routine violations: Violations comprised of situations where rules are broken for purposes of conserving time, energy and other unknown reasons. These violations are usually noticed by management, but no steps are taken to curb them instead they are ignored because they do not usually directly result in accidents. A typical example of routine violation considered in this study is a situation involving a worker's failure to follow the laid down company procedure on barring down. Another example could involve situations when an employee performs a task without following the standard operating procedure of the whole process, and such actions may result in an accident.

Deviant violations: These types of violation happen unexpectedly and they are very difficult to predict and control. These violations usually happen when workers have no other method to perform a task. Other causes of deviant violations are due to issues of meeting personal goals of the operator involved. In terms of rate of occurrence, routine violations are more common compared to deviant violations.

Non-human causes: The analysis framework included this category to consider cases where human error was not directly involved in the cause of an accident. Underground rock formation and earthquakes can cause geological or structural failure, resulting in accidents which are non-human causes.

3.1.1.2 Workplace factors

Workplace factor is the category in the framework which describes the factors at the working place that can cause accidents. Workplace factors can also be defined as latent conditions that produce what has been termed as the proximal causes of accidents. Four essential workplace factors in the existing framework were taken from the Nertney Wheel Model of accident analysis (Bullock, 1979) which is shown in Figure 15. These workplace factors are the work practices, working environmental condition, fit-for purpose equipment and competent people which can affect the worker to perform tasks. The existing framework of Bonsu (2013) identified lapses and deficiencies in any of the four components (work practices, competent people, fit for purpose equipment and controlled work environment) as ways in which workplace factors can contribute to accident occurrence or affect the performance of a worker.

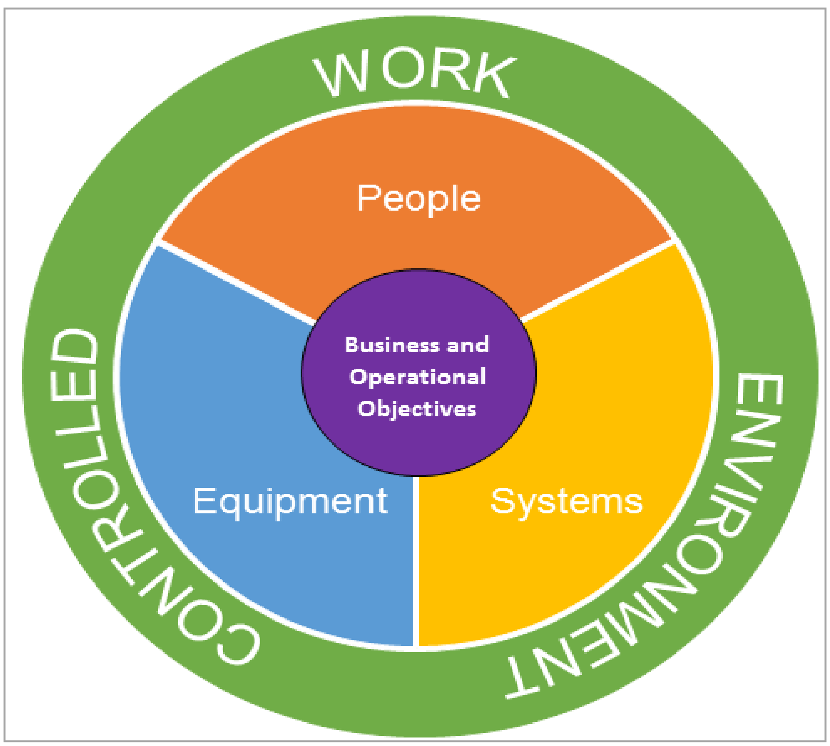

Figure 15: The Nertney Wheel Model (Bullock, 1979)

Competent people

Competence of people that is being used for a specific job at a workplace is very important and critical for the organization to achieve its intended objectives successfully. The mining industry is a very complex and hazardous industry; hence its process requires the use of competent man power. The term competence is attributed to a task performed successfully by the worker at the place of work. Competence is based on a technical know-how as in ensuring that the personnel assigned to do a task is trained for that particular task. Competence also involves ensuring that the training process is adequate for the task assigned or ensuring that an operator has an operating permit to perform specified tasks. In this category, all situations with respect to the operator's ability to achieve assigned tasks successfully are described accordingly. Employees in an organization who have physical and medical problems to achieve assigned tasks are also classified under this category. Substandard condition operator in the HFACS-MI is classified in the same way as competent people. In the framework used in this study, the situation involving the enthusiasm of an individual to perform a task as used in the HFACS and suitability for duty as used in HFACS-MI (Patterson and Shappell, 2010) are incorporated under competent people. This is a reflection that enthusiasm can affect an operator's competence to perform assigned tasks.

Fit-for purpose equipment

This is a very important factor for any effective and productive system of an organization. This category in the framework is included to cater for situations in which the quality of equipment being used affects operator's behaviour which in turn gives ineffective results for assigned tasks. This includes amongst others, defective equipment, poor design of the equipment and non-availability of any operating manual for equipment. The other example of non-availability of fit-for-purpose equipment include cases involving lack of personal protective equipment (PPE), malfunctioning machines, faulty vehicular breaking systems and faulty equipment operating system. This fit-for purpose equipment category corresponds to the category 'resources and interfaces' in the Wheel of Misfortune whereas in the HFACS-MI and HFACS it corresponds to 'environmental technical conditions'.

Unsafe work practices

For every production process of an organization, a safe working environment is critical and is always important to the well-being of all stakeholders involved. The unsafe work practices class is encompassed in the framework of this study for circumstances where the working environment exposes personnel to various hazards when performing assigned tasks (Bonsu, 2013). Typical examples of situations involving unsafe work practices include non-existence of standard operation procedures on how to perform certain critical tasks, or the inadequacy of the methods described in the procedures for safe accomplishment of tasks.

Controlled work environment

The controlled work environment refers to both physical and supervisory control in the work process (Bullock, 1979). All the processes occur in some environment where conditions such as lighting, ventilation, traffic control, ground control, etc., affect safety and health in the process (physical). Supervisory control refers to need for the work process to be defined, directed and checked (behaviour). This category explains the conditions in which the quality of working environment affects the performance of the worker to achieve assigned task. The controlled work environment is therefore divided into physical and behavioural environments.

Physical environment comprises situations such as noisy environment, poor lighting, poor/bad ventilation especially in underground mines, slippery floors, bad/loose hangings in the roof and sidewall of excavations especially in underground mines, lack of signage and inadequate barricades in working places. All these situations are known to contribute to poor performance of employees in the mining environment. HFACS and HFACS-MI frameworks, as well as the Wheel of Misfortune framework, similarly describe physical environment in the same way. Behavioural environment are conditions where unsafe behaviours are either ignored or not glowered upon. Some of the cases to be considered under behavioural environment are conditions where an employee discovers him/herself in a work group where breaking of working procedures are not glowered upon. Therefore, behavioural environment in this study is similar to problems involved with poor communication or lack of coordination in the HFACS-MI framework (combined as poor coordination and poor leadership). It has also been proved from research that safety behavioural cultures are improved upon when social support group is present (Paul and Maiti, 2008).

3.1.1.3 Systemic factors

The fundamental phrase of Reason's (1990, 1997) model of accident causality is that an accident will happen when certain components within the organization stop behaving in a safe way. This portion of the existing framework considers the manner in which the hierarchy within the organization behaves in an unsafe way (see Appendix C 3). Safety management systems are the most influential components in this section of the framework. The factors considered in this section are like that of De Landre et al (2006) in the ICAM model discussed in chapter two.

Training and competence**:** This category include situations where the particular training that was presented did not assist the employee to perform the assigned task in a safer manner. Other scenarios are where an employee has not been exposed to all required training before being assigned to perform a task. This type of training is not only limited to usual training of performing a job but also job safety and hazard identification trainings. The other condition is where unqualified employees are assigned to perform a task in an organization.

Design: This section of the framework epitomizes conditions where equipment is poorly designed or poor design of the work environment tends to compromise the quality of physical environment of the working place. Poor designs can lead to bad roadways, flooding of the workplace, premature collapse of structures, and instability of surface/underground structures. Therefore, poor design is also perceived as the focal causes of the workplace factor under physical environment. Improper excavation designs in underground mines can lead to accidents such as fall of ground which could be avoided in the initial stage of planning if at all rock engineering principles were considered.

Contractor management: This is a situation where a company contracts certain jobs to be done by a contractor. It is the responsibility of the company to ensure that employees of the contractors undergo necessary training to observe and follow the organization’s existing standard operating procedures. This also encompasses updating contractors on safety programs and conducting onsite trainings for them when executing tasks.

Management of change: The attitude of introducing changes in an organization has high chances of causing additional risks in the organization. Under this group, management may not fully recognize the full risk that may arise due to the introduction of new machine, task, and project which can lead to an accident. The framework under management of change tackles cases where management fails to appreciate the risks involved in the system and this may also serve as a root cause of an accident.

Hazard identification: This portion is referred to as the process of identifying potential hazards which are likely to cause accidents. Controls are designed in which to identify hazards so as to protect workers from accidents. Hazards are grouped according to the type of work and tasks performed at the workplace.

Therefore, the framework highlights situations where an organization lacks hazard identification control measures to prevent accident recurrence.

Monitoring and auditing: Maintaining a safe environment should be a priority of any productive organization, therefore the design of the system should be in a manner where the existing control measures are able to prevent accidents from happening. To ensure that safety is in place and improved in an organization, control measures should be developed and implemented in order to minimize or prevent deviation in the working environment. This portion in the existing framework critically highlights cases where the organization lacks monitoring and auditing control measures to prevent accidents.

Maintenance management: The framework under this category highlights cases where the maintenance of structures and equipment is compromised, or poor, which can lead to accidents in an organization. A culture which encourages poor maintenance of equipment at a workplace may cause the equipment to function poorly, which can lead to the operator to make mistakes and affect his/her performance. This can lead to the operator to record accidents. This is also a main root cause of the existence of unfit for purpose equipment under this category. Poor maintenance of the workplace can lead to instability problems, poor sanitation, poor ventilation, poor lighting systems, and collapse of buildings and structures.

Resource provision: This is a situation where management is unable to provide adequate or necessary resources for an organization to accomplish assigned tasks which in turn can lead to accidents. This category highlights situations where management fails to provide personal protective equipment, right tools, and other resources, hence leading to accidents as attributed to some accident investigation systems at workplaces.

Strategic planning: This category of the framework represents situations where decision making conflicts with goals of the organization. Certain management decisions such as reducing labour force, increasing working hours, and other decisions create an unbalanced state between safety and production which can even lead to conditions that create accident proneness. Under this group, it is difficult to effortlessly identify such issues when investigating the cause of accidents from reports.

Risk management: Managing risks is a challenging constraint of every organization and it needs proper action plans to be successful. Failure to identify and manage risks in an organization is a sign of problems and this also serves as a root cause of accidents.

Leadership: Poor leadership affects the performance of workers in an organization and this cannot be overestimated in a workplace. The description of safety climate should involve how conscious a leader should be regarding the safety of employees working under him/her. In the mining industry, most accidents happen due to a worker's unwillingness to follow the laid down company standard operating procedures (Kecojevic et al, 2007). Therefore, it is very important for the leader to frequently be conducting visible felt leadership (VFL) to enforce the laid down company standard operating procedures to the workers. The framework under this category highlights situations such as ineffective supervision, supervisor's failure to take control measures in preventing accidents, and inactive supervisors failing to make wise decisions in preventing accidents.

***Work scheduling*:** This is a very critical stage in the planning process, and it helps an organization to ensure safety of employees and associated risks at the workplace. Under this category, situations such as long working hours (more than 8 hours), overtimes, continuous night shifts and over working without breaks, increases the chances of accidents at the workplace. In some cases, work schedules tend to coincide with unforeseen situations such as bad weather which increases the risk employees are exposed to at the workplace. This category is described under systemic factors.

Emergency response: This can be defined as serious or unforeseen dangerous event that requires immediate action to alleviate the situation. To protect employees, property or environment, immediate action is required when emergencies occur at the workplace. It is the responsibility of the mine management to ensure that employees are trained on how to respond to emergencies and should provide right tools to use during an emergency response. This category in the framework considers poor emergency procedures and tools as the root cause of accidents.

3.1.1.4 Existing framework compared with other frameworks

This section compares the causal analysis section of the framework of Bonsu (2013) with other frameworks of accident analysis such as the HFACS, HFACS-MI, the Wheel of Misfortune and the ICAM. These frameworks are popular and mostly used in accident analysis. The mine site investigated in this study uses the ICAM framework to analyse accidents. One observed difference between the framework of Bonsu (2013) used in this study and the HFACS model is the type of levels that must be considered to recognize accident causality. Three levels of accident causality were recognized in Bonsu's (2013) existing framework (like the mark III version of the SCM) while four levels were recognized in the HFACS (like mark I version of SCM). The inclusion of a separate level on the effect of leadership on accidents that is created in the HFACS method (also exist in the Mark I version of the SCM) is the difference that arises with Bonsu's (2013) framework. This extra level was ignored in the framework of Bonsu (2013) because it was not necessary because in most organizations, the responsibility of supervision is to ensure that the structures in the system are working properly. However, it is worthwhile to state that organizational factors usually can place a constraint on the leader to perform the role effectively or ineffectively. Good supervision is part of the systemic or organizational factors and tend to constrain the lower-level factors such as proximal and workplace factors. The three layers of accident causality used in the existing framework can be found in the Wheel of Misfortune and ICAM frameworks (Bonsu, 2013). The nonexistence of human error category in the ICAM method as discussed in section 2.7.1 is the main difference between the framework of Bonsu (2013) and the ICAM. However, due to the nonexistence of such clarifications, no further comparisons were done with the ICAM model. The categories of proximal and workplace factors in the framework of Bonsu (2013) are shared with the Wheel of Misfortune and the HFACS models.

3.1.2 Agency and barrier analysis

This section was aimed by Bonsu (2013) to capture data on the safety barriers broken and accident-causing agents in the accident report (see Appendix B for agency and barrier analysis). The agency and barrier analysis are included with the belief that the results produced under this section gives more meaning to the results that were produced in the causal section (Bonsu, 2013). In the framework of Bonsu (2013) as used in this study, safety barriers are recorded as failures during the process of an accident. These safety layers or barriers of protection act as physical or non-physical means that can control and alleviate accidents' occurrence (Hollnagel, 2008). The section under this category in the framework is where the safety barriers breached are analysed. The knowledge is about the type of safety barriers that were breached, why and how they were breached. This will provide a level of information about the causes of accidents. The ICAM model of accident analysis also has a barrier analysis section. In the ICAM model, information involving the agencies in each accident analysed are recorded. The aspect of recording every hazard in the system will help to provide data on the energy causing harm whereas the agencies will provide data on the material carrying the energy. The framework under this category was classified and chosen in such a way that it can be compared to the previous and future studies regarding the causes of accidents. The accident classification codes employed and used in this study is in accordance with the Zambian safety report standards under the Mine Safety Department (MSD) and the safety standards of the mine site being investigated. Some of these codes include fall of ground (FOG), transportation of equipment, machinery tool handling, electricity or heat burns, fire and explosives, caving, etc. The nature of the mine investigated in this study, and types of accidents prevailing at the mine site necessitates a slight modification in the use of agencies. The agencies used in this study may be different from those used by the mining industries in other countries.

3.1.3 Metadata

Metadata is simply defined as data about data or data describing data (see Appendix A 2 for the metadata section). The purpose of metadata is to offer explanations on different factors that influences the happening of accidents at the copper mine investigated in this study. In addition to data on accident-causing agencies and safety barriers, the existing framework was designed to capture specific metadata about the accidents analysed (Bonsu, 2013). Bonsu (2013) also indicated that even if the studies of Patterson and Shappell (2010) integrated some situational data, based on Reason (1990, 1997), the metadata has never been officially incorporated into any of the previous frameworks. The most important point is that metadata will help understand why most specific unsafe acts are happening at the same place, or the same work shift or time. The variables under the metadata are time of accident, date of accident, place of accident, accident type, activity involved which resulted in an accident, task schedule of an accident, age and work experience of victim involved in an accident, company where employee works, and job title of worker. Considering each of this data separately during accident investigation might not seem meaningful, but when considered holistically, it has proven to be very useful.

3.2 Collection of Data

The data used for this study involved the incidents that happened at a particular copper mining site in Zambia. Data was only obtained from one mine site which has underground mines, surface operations, process plants and general offices. Despite obtaining data from only one site, the information was enough for the analysis and to make the study of value to the mining industry as the mine site has vast operating departments. The author of this study is also mindful of the fact that the use of such information from one site has the demerit of limiting the applicability of the results obtained in this study. Data was only obtained from one mine site with the fact that, the site has so many facilities which can produce meaningful results after analysis. The data obtained also has a great deal of contextual information and thereby making the analysis relevant. The summarized accident reports from the Mine Safety Department (MSD) do not contain enough information for each incident. Therefore, the use of such data disadvantages the analysis due to lack of necessary information to populate into the framework. However, the accident reports from the mine were detailed and very useful. The reason for choosing this commodity (copper mining) is because this industry contributes much to the GDP of the country. The company has also invested a lot in trying to improve on the safety of employees at their workplaces.

3.2.1 Background of the mine used as case study

The mine site used in this study has underground mine shafts, an open pit, general offices and surface process operations. Accidents were reported in accordance with the Safety Health Environment Company's department ethics and format of reporting accidents. The accident reports contain data about casualty such as date and time of incident, job title of the victim, working experience of the victim, age of the victim, and place of incident. Also, each accident report is accompanied by description of the incident as well as snapshot, analysis of the event and some remedial action taken. The accident reports used in this study were from the year 2013 to 2014 and these accidents were only fatal, return to work and lost time injuries in nature.

The model that the mine uses to analyse accidents is the ICAM model, but this study adopts an existing framework that was developed from Reason (1990) by Bonsu (2013). The study of Bonsu (2013) had considered 91 accidents reports for the analysis to give meaningful results whereas this study considered 100 accident reports from the year 2013 to 2014. The type of accidents considered during data collection consisted of six fatalities and a combination of ninety-four lost time and return to work injuries. These incident categories are clearly defined in the section below.

3.2.2 Current state of incident reporting and investigation at the mine site

The company has a document in which all incidents and accidents investigation processes are followed. This document was developed by the manager of Safety, Health and Environment section of the company. The purpose of establishing the document was to create a uniform method of accurately documenting and investigating work injuries, property damage accidents, near-miss events and industrial diseases.

The objective of incident and accident investigation are; to take a pro-active approach in preventing damage and loss by systematically investigating actual and potential incidents which occur at the mine site, to establish the cause of incidents and implement appropriate corrective and preventive action aimed at preventing recurrence, to ensure that workers understand and know their roles and responsibilities regarding reporting and investigating incidents, taking action to mitigate the potential impacts and for establishing corrective, preventive actions and finally to ensure compliance with relevance to Zambian legislation and the mine corporate reporting requirements.

Procedure statements

The prime objective of accident investigation is prevention. Finding the causes of an accident and taking steps to control or eliminate it can help prevent similar accidents from happening in the future (ILO, 2010). Therefore, the company's procedure statement includes investigating all incidents to prevent a recurrence and facilitate internal and regulatory reporting where applicable. Also, it involves workers having to be tested for alcohol after involvement in the following incidents: all life-threatening incidents, all incidents involving plant, machinery and vehicles, and high potential near-miss events.

Collection of relevant data at the mine site

After an accident has happened at the mine site, the first phase of investigation is to collect relevant facts. The collection of data is divided into four main elements: people, environment, procedures, and organization. Conditions, actions, or errors in each of the element are identified, which could be the contributing factors to the subsequent incident. To ensure that all facts are uncovered, the following broad questions are asked: who, what, when, where, why and how?

Document archival

Investigative data and reports are archived in accordance with corporate and regulatory guidelines for the mine site for this study.

3.3 Coding

The author of this study comprehensively used the coding in accordance with the mine site's safety standard and procedure document. This was done in to understand and analyse the collected data according to the terminology used at the mine site. Throughout the period of coding, and where it was problematic to understand what code to adopt, some mining terminologies used in the accident reports were clearly explained by the safety superintendent on site.

However, coding used in this study is in line with the terminology used in all accident reports by the Health, Safety, and Environment department of the company which is also in line with the Zambian safety standard legislation under the mine safety department (MSD) of the ministry of mines. Accidents were reported and then information is inputted in the framework. The description of an accident, photographs, stated causes, remedial actions and recommendations within the reports were used to recognize situations involving violations, slips and lapses, physical environment, behavioural environment, mistakes, etc.

A category which includes mistakes and physical environment were sometimes counted more than once as a root cause of an accident. This counting was a suggestion for the existence or nonexistence of a given category for each incident. The need for this was to avoid over presentation of a single incident. The most important point noted was that mistake, slip, lapses, and violation were rarely mentioned in the accident reports. Nevertheless, rigorous statements of unsafe acts committed by the worker were usually presented in accident reports (e.g., failure to conduct mid-shift barring down, poor supervision, etc.). To determine what kind of unsafe acts are committed by the workers, the company's standard and procedures document were also used for close checking purposes. The rule broken by the victim is a distinctive factor between unsafe acts (mistake, slips and lapses) and violations. Routine and deviant violations are distinguished based on the specific kind of violation whilst the distinctive aspect between slips and lapses and mistakes was intention.

3.3.1. Coding of direct causes of accidents

Direct causes of accidents were centered on the data captured under the immediate causes section of the accident reports. The reports have no provision of categorizing accident information on violations, mistakes, slips and lapses; however, the unsafe acts performed by the victim is recorded in an accident report (e.g., did not do risk assessment). Standards and procedure of the company in terms of safety was thoroughly followed and used in this study. The distinguishing element between violations and other unsafe acts (mistakes, slips and lapses) was whether a rule was broken by the victim. Frequency of a particular type of violation is the distinctive element between routine and deviant violations. Intention is the distinctive element between slips and lapses and mistakes. Making the area safe in an underground environment in this study is referred to as barring down. The barring down term is used in the underground mining environment as the process of removing loose hangings or rocks in the excavation either in the supported area or unsupported area to prevent falls of grounds (FOG). Barring down is the process which should be done before the start of the shift and during the shift. The process of barring is important in underground operations because it helps to prevent falls of ground in the working areas.

3.3.2. Coding of systemic and workplace factors

The details of the accident report contain important information on the type of accident, extent of damage, victim involved, brief root cause and remedial action. This reported data helps to identify whether the accident happened because of a workplace factor or systemic factor. However, the sub-categories used in the framework of Bonsu (2013) were not directly presented in the accident reports. The decision on classifying an accident that happened because of a workplace or systemic factor was made from information contained in the accident reports such as, failure by team leader to observe mid-barring down in the workplace and this was identified as workplace factor. The following case studies are presented for purpose of illustration.

3.4 Case Studies

To verify the coding into the Bonsu (2013) framework, two of the accident reports were taken and set as examples to show how the accident analysis in this study was done.

3.4.1 Illustration 1: Falls of ground (FOG) incident causing a Lost Time Injury (LTI)

The following paragraph highlights the information of an incident that happened: The incident happened on Wednesday 18th September 2013, at about 12:50 am. The worker was in the stopping position working on the drill rig boomer machine when a seismic event (rock bumping) occurred and subsequently a rock failed from the roof of the excavation, hit on top of the boom, fragmented, and finally struck on the employee causing the lost time injury (LTI). According to the investigations from the safety department, the possible cause of this accident was due to some loose rock in the excavation, which was not barred down or removed, the area was seismically active, the geological ground condition in the area was poor, and rock mechanics recommendation was issued but was not followed.

Throughout the coding of the above reported accident, the unsafe act acknowledged in this description was the worker who performed the job. The worker did not observe the area and failed to bar down the loose rocks in the area. However, this was indicated as routine violation in the framework because it was not the first time it was happening (more than two cases of similar incidents have been encountered). The identified workplace factor, due to the substandard nature of underground roof support, was designated as physical environment in coding of the framework. Failure to follow rock mechanics recommendation was coded as behavioural environment. The systemic factor coded in this instance was leadership failure which was due to poor management of risks.

3.4.2. Example 2: An accident leading to a fatality of the worker

This passage highlights the information of an incident that happened on Friday 6 November 2013, at about 8:00 pm: The worker was working on the bottom deck of the sinking stage. It was alleged that while standing *on the compressed air and water hoses that were stacked next to the kibble path, the man looked down over the kibble path screen barrier to the shaft bottom. The kibble on the southern side that was coming down the shaft struck him on the back of the neck and part of his head on the opening on the kibble path screen barrier and he died from sustained injuries.*

The investigation in this accident by the safety department was that the main cause was failure by the worker to observe the work environment, poor communication, and inadequate supervision. Throughout the process of coding, two unsafe acts were recognized in this report, namely routine violation and slips and lapses. The victim observing the moving of the kibble in the shaft being a restricted area was categorized as routine violation (with the notion that it was not the first time this was happening) whereas not observing movement of the kibble and sound was classified as a slip. The worker did not follow the right safety procedure which has to start with stop, look, assess, and manage (SLAM) prior to commencement of any task. This was designated as routine violation in the framework because this was not the first it was happening. The workplace factors identified in this report, which must have contributed to the unsafe acts, were competent people and behavioural environment. Failure to communicate (behavioural environment) must have been the motivation why he chose to stand in an unsanctioned area, and lack of necessary training (affecting his competence) might have contributed to lack of technical know-how on the movement of the kibbles. Lack of training was identified as a direct effect of poor communication. Lack of training is coded under contractor management since the man was not trained.

3.5 Analyzing the Data

This section includes an explanation of the tools used in analyzing and representation of the data in this study. In the Microsoft Excel 2010, the pivot table and chart tools were used to classify and summarize results of accident analysis. Results of analysis were generated in charts and presented in three categories in the framework. Accident characterization diagrams were the first category of charts generated (Figures 16 to Figure 21 in Chapter Four). Some of these accident characterization charts contain information obtained from the metadata such as place of incident, task performed, job title, task schedule and type of employee. Other accident characterization charts were generated from the causal analysis section in the framework such as the agencies and barrier analysis (as explained in section 4.2 of chapter four). The information presented under this section in the framework is very important as it can help to specifically identify which of the activities or places are more susceptible to accidents. For instance, considering the accident characterization according to shift of the day can give a rough idea of which shift is more prone to accidents.

The second category in the framework of characterization generated from the charts relates to the information in the causal section (Figures 22, 28 and 34 in Chapter Four). This section of causal analysis consists of three categories which are direct causes, systemic factors, and workplace factors. The charts presented in the section were also generated using the pivot chart tools.

The specific data generated includes information pertaining to systemic factors, human errors and workplace factors identified in the analysed accidents. The linkages between different kinds of variables were also generated in the framework and are shown in Figures 23 to 27, 29 to 33 and 35 to 40 in Chapter four. These charts help to determine the effects of variables on each other. The effects of work shift on the unsafe acts committed were presented under this group. The connection between unsafe acts, systemic and workplace factors, were also determined and presented using the pivot chart tools. In conclusion, various sections of this chapter that have been presented and employed in the method of this study and existing framework has been elucidated with some comparison with other frameworks such as the ICAM model, Wheel of Misfortune, HFACS and the HFACS-MI.

The results of accident analysis obtained in this study have also been compared with other studies from developing and developed countries. The fundamental principle on how the data was implemented in the existing framework has been illustrated in section 3.4.1 and 3.4.2. Chapter four explains the results obtained from the methods described in this chapter.

CHAPTER FOUR: RESULTS

This chapter presents the results obtained from the analysis of 100 accident reports obtained from one of the mine sites of one of the copper mining companies in Zambia. The first form of results is presented in the form of accident characterization as shown in section 4.1 of this chapter. The purpose of displaying these characterizations of accidents is to get a picture of the nature of activities at the mine site. The causes of accidents on the mine site are closely linked to the nature of operations being undertaken and this sets the foundation for analysis of causal results. Therefore, section 4.2 of this chapter presents the causal analysis of each case from the accident reports. The causal analysis results are summarized (see Table 3) with frequency and percentages of the findings. Then further analyses of the results are presented according to unsafe acts (section 4.3), workplace factors (section 4.4) and systemic factors (section 4.5).

The results from the metadata section in this chapter are also presented according to each accident case, targeting the possible effects of variables such as place of incident, particular time of an incident, task, victim's age, victim's experience, work shift, job title, etc. Under the unsafe acts, the possible causes were identified in terms of most and less common factors and followed with a detailed explanation of what is pertaining on the ground.

4.1 Accident Characterization

The accident characteristics consists of information obtained from the metadata such as *place of incident*, *task performed*, *job title, shift involved, type of employee, nature of agency and barriers broken.*

4.1.1. Place of incident

The accident characterization according to place of incident (as shown Figure 16) was done to offer indication of the level of accidents in different locations of the mine site such as underground, surface, concentrator, shaft sinking, open pit and general offices. Underground mine sites are presented with reference to mechanization of the mining methods as well as depth below surface. Figure 16 shows that underground mine site 5, 2 and 1 had the highest frequency rate of accidents in the year 2013 to 2014 in terms of injuries and fatalities. Underground mine site 3 and 4 (UG 3 and UG 4) had less frequency rate of accidents in the year 2013 and 2014 with regards to injuries and fatalities. Surface 1 and surface 2 had the highest frequency rate of accidents than other surface operations (surface 3, 4 and 5) in the year 2013 to 2014. Considering depth of underground mines with respect to the highest accidents, *UG 1* and *UG 2* are deeper with more than 1.5km and 1.0k m, respectively. The assertion can be because as the mine goes deeper, it becomes difficult to provide ventilation to the working areas which makes the environment not conducive for the workers to execute their duties (Huang, 2011). As the mining depth increases, the temperature of the rock increases, and the heat damage caused by the underground temperatures and other factors is amplified (Huang, 2011). The increase in temperature can lead to poor ventilation in the working environment as seen in high accident frequency rates with deep shafts (as shown in Figure 16). Shaft sinking is also a very sensitive/high risk project and it needs a lot of consideration in terms of operations, this is evidenced with the high rate of accidents recorded in the year 2013 to 2014 during a shaft sinking project. The primary consideration regarding shaft sinking is gravity, which determine that objects will fall and, from a sinking perspective, can fall onto persons below their point of dislodgement. This presents a significant risk to those working in the shaft bottom (Simeons, 1978). This risk is exacerbated by the increasing use of machines and the interaction between persons and kibbles at the shaft bottom (Simeons, 1978). The incidents recorded for Surface 2 and Surface 1 were higher than other surface work places. This shows that there are more risks and hazards associated with metallurgical processes than other surface operations.

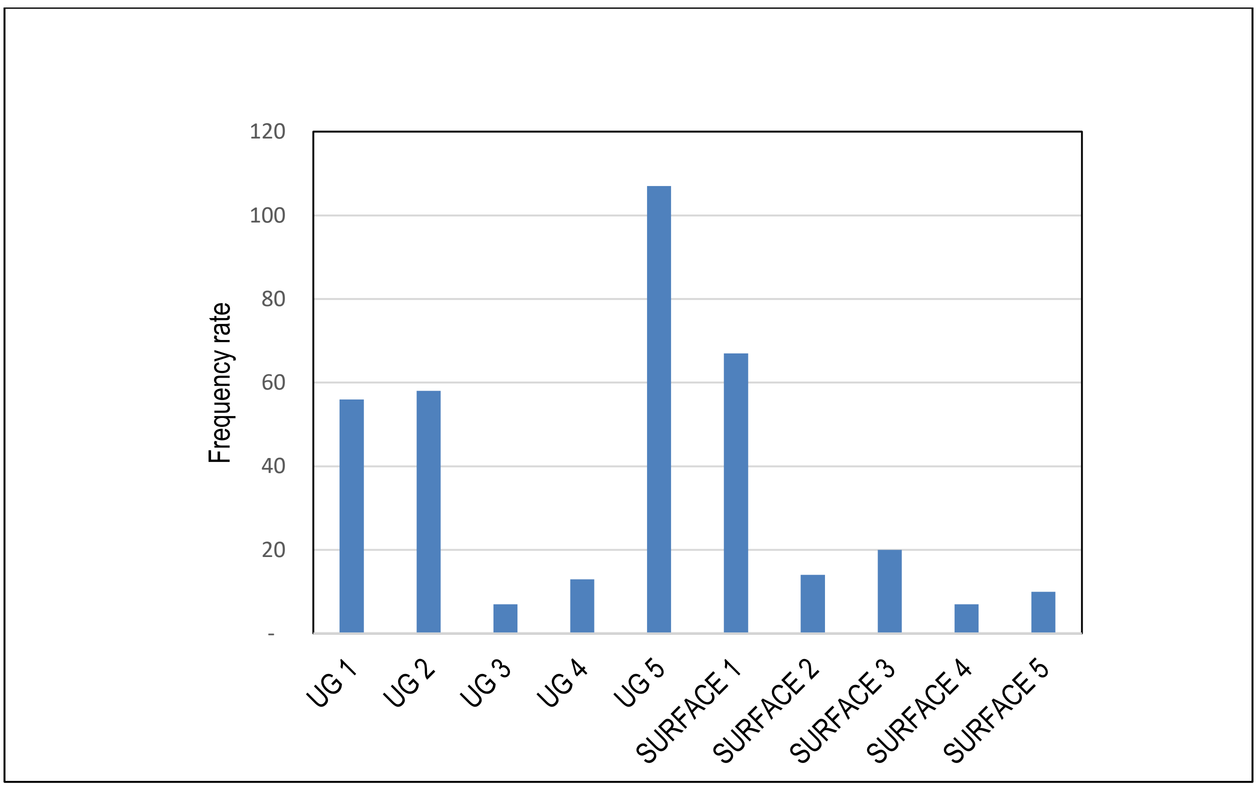

Figure 16: Accident distribution according to place of incident (year 2013 to 2014)

The study of Bonsu (2013) from the South African platinum mine was only conducted for a single underground mine site while this study has multiplicity of operations. However, the results are also compared to a parallel study of Mwansa (2021) from another mine site of the same company which also has multiplicity of operations. The study of Mwansa (2021) had also recorded high frequency rate of accidents for underground operations compared to surface operations. The study of Mwansa (2021) involved only one underground mine while five underground mines were involved in this study. Though Mwansa's (2021) study had fewer underground operations, the number of accidents in the mining department are still high as evidenced by the high frequency rate of accidents which can be attributed to the fact that these mines are facing the same challenges with regards to improving the safety of mining operations. Figure 17 shows that accidents in underground mining operations (66.7%) were still high for the study of Mwansa (2021). This may suggest that there are some common safety cultures in the two mine sites of the same company.

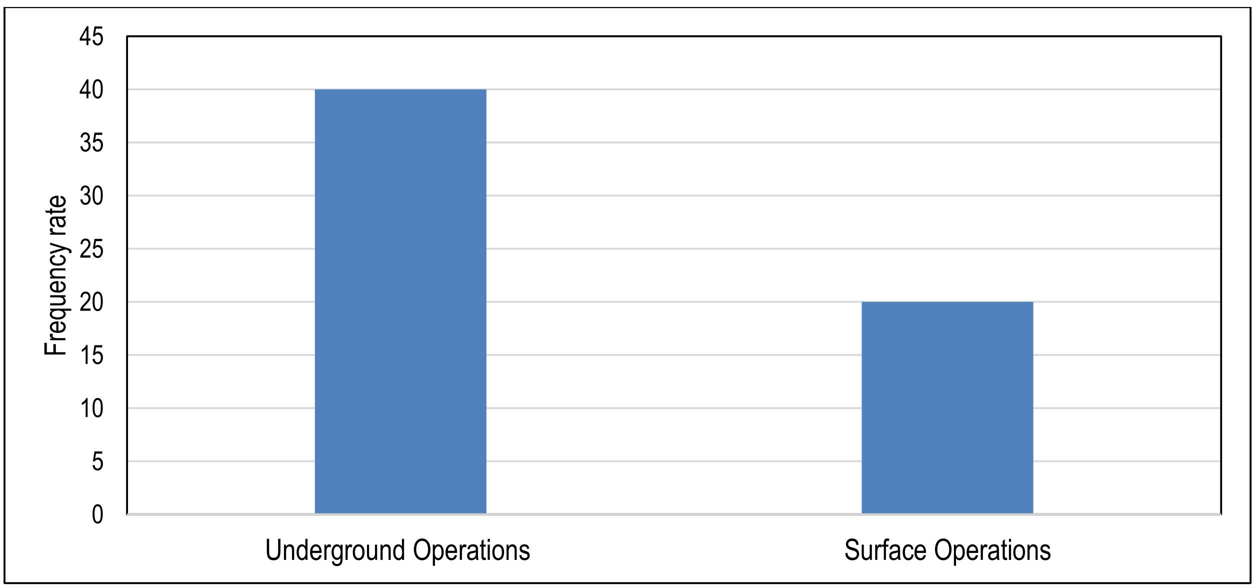

Figure 16: Accident distribution according to area of operation from the year 2013 to 2014 (Source: Mwansa, 2021)

4.1.2. Task Performed

The accident characterization according to tasks performed (as shown in Figure 18) was done in order to describe the level of mechanization employed to execute duties at this copper mining company. The information presented under this section is in accordance with the form of coding in the safety documents and accident reporting systems of the company.

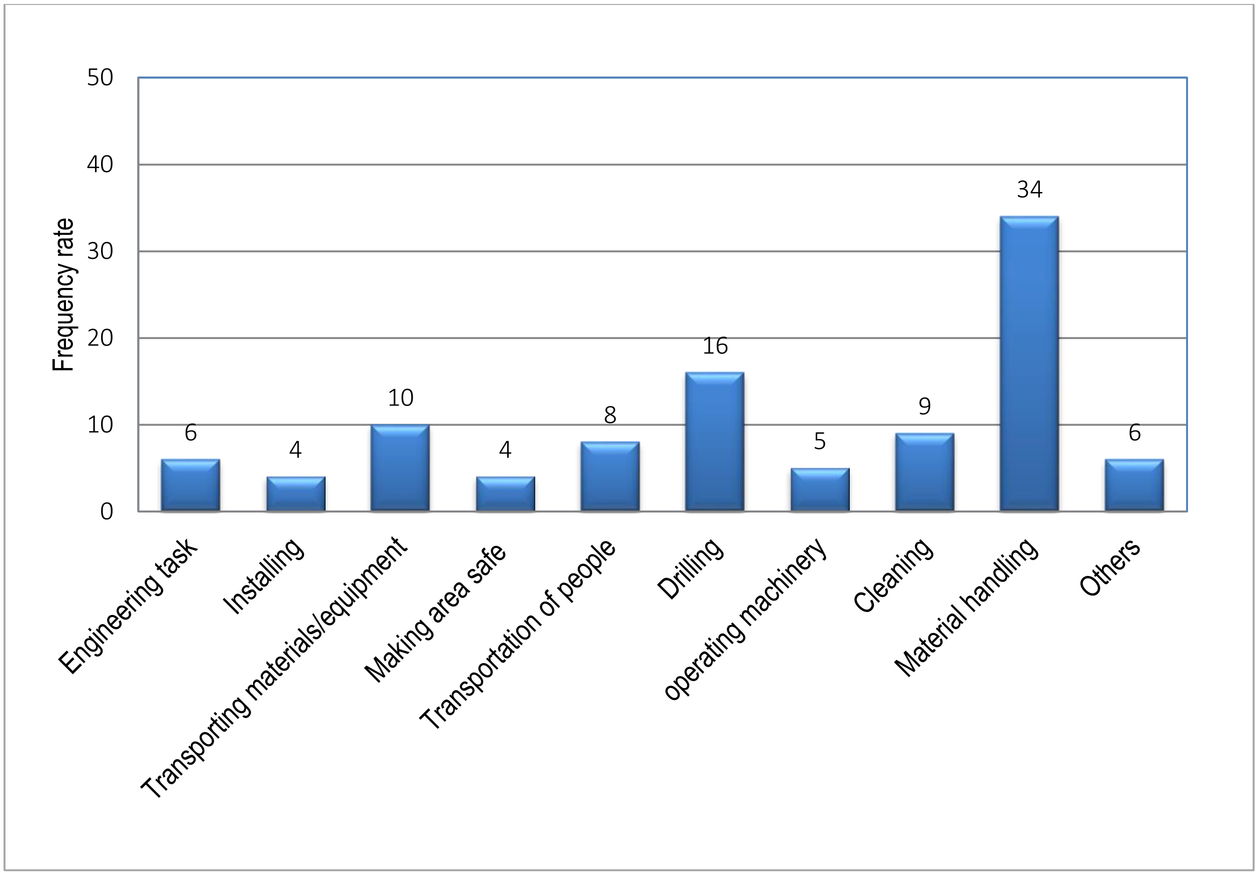

Figure 17: Accident characterization by performed task (year 2013 to 2014).

The most accident-prone tasks were *material handling, drilling, transporting material/equipment, cleaning and transportation of people and engineering tasks* (see Figure 18). Material handling thus caused more accidents than other work activities at this copper mining company. The term *material handling* involves "short-distance movement that usually takes place within the confines of a building such as a plant, underground or a warehouse and between a building and a transportation agency (Kulwiec, 1985).

The manual transfer of materials caused most of the material transfer accidents at this mining site and mechanical transfer caused most of the serious *material handling* accidents. Typical examples used in this study for hazards involved in material handling tasks include the worker being hit by materials, then caught between them or in pinch points, exceeding load limit and falling that are caused by improper stored materials, poorly maintained lifting devices, etc. *Material handling* is a prime example of the inherent risks at this mine site. The term *drilling* in this study refers to the process of using drilling machines such as conventional Jack Hammers or mechanized drill jumbos (drill rig machine) for mining the excavation or other drilling tasks. There are several factors that can lead to the task of drilling recording the highest accidents and these ranges from poor *physical environment, behavioural environment*, *unsafe work practices* and *non-human cause*. Non-human cause includes situations such as drilling in poor ground condition which is not adequately supported, in poor ventilated areas, or drilling task being performed by untrained operators, etc.

Transportation of people/equipment tasks involve individual-transportation conditions (e.g., walking, travelling along the way and descending) and *transportation of people* by equipment. Most of the accidents under this category occur because of *poor housekeeping* or due to *physical environment*. *Cleaning tasks* in this study is referring to situations of removing unwanted material from the working area to make the area safe. An example of cleaning is lashing/removing of ground surface materials in preparation for charging/inserting of explosives. During the cleaning task, the down holes (these holes are called lifters) at the base of the face are to be exposed by removing fallen ground during drilling and this process is referred to as cleaning.

The results under task performed were compared to the study of Bonsu (2013) for the platinum mine in South Africa in which *drilling, engineering task* and *material handling* were the most accident-prone tasks. The accident coding in the study of Bonsu (2013) was according to the South African Mines Reportable Accidents Statistical System (SAMRASS) code book (Bonsu, 2013). The study of Ashworth and Peake (1994) from the gold and platinum industries also identified *drilling* and *engineering tasks* as most accident-prone tasks. Although their study identified certain tasks differently, it is important to state that most of these activities were engineering related tasks.

The results obtained in this section (see Figure 18) were also compared with those of Mwansa (2021) from the other mine site of the same company investigated in this study. Similar results were obtained in Mwansa's (2021) study, in which *material handling*, *transportation of material/equipment and engineering task* were recognized as the most frequent causes of accidents. This indicates that the causes of accidents at this copper mine were similar in the two different mine sites. Although this study does not identify engineering task to have frequent causes of accidents, most of the cases to do with *material handling* were involved in the *engineering task*. This study identified *drilling* tasks (16%) to have been involved in most of the accidents whereas in Mwansa's (2021), the incidents related to drilling tasks (6%) were minor. The reason is that the study of Mwansa (2021) involved only a single underground mine operation whereas this study site had five different underground mines. *Installing* tasks were also noticed to be low in the two mine sites, which signifies that there are few accidents which results from installation related tasks.

4.1.3. Characterization by agencies

The accident characterization according to agencies was done to find the agencies which were common in the accidents analyzed. Figure 19 revealed that the most prominent agencies recognized in the accident characterization by agencies were falls of ground (ground strata failure), fall of material, handling material and moving machinery. An explanation on how these agencies were involved is as follows in the next few paragraphs.

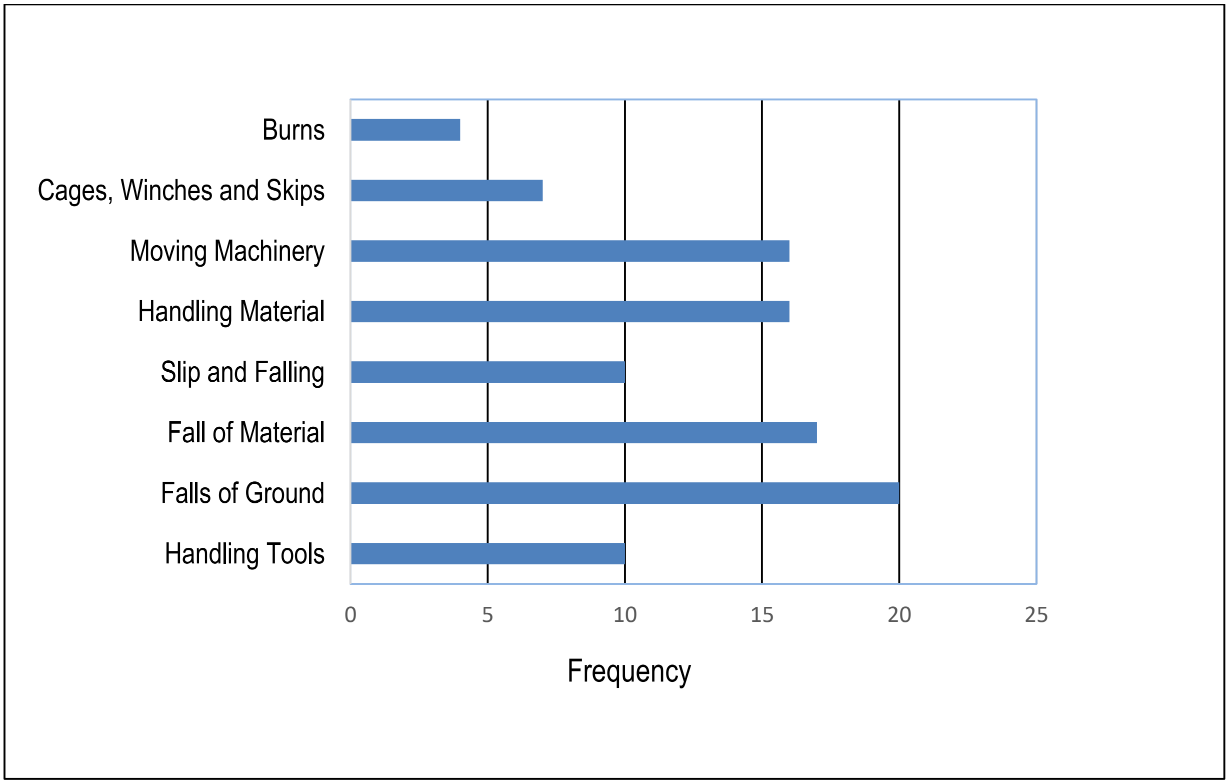

Figure 18: Accident characterization according to agencies (year 2013 to 2014)

The accident characterization according to agency is consistent with characterization according to task performed as well as with job title (see Figure 18). The typical analysis of this is to consider a workman (referred to as a grouter) who is usually involved in the *material handling* task. The grouter is involved in the installation of support in an underground environment, and most of these works are executed by contractors. These categories of workers are most of the time exposed to rock fall hazards, hence they are prone to falls of ground agencies.

Fall of ground was the most prominent accident-causing agency and this is consistent with accident characterization according to tasks involved where drilling was prominent. The explanation behind this is that drilling tasks were performed in an environment where the major hazards are loose rocks (see Figures 18 and 19). Accident characterization according to *job title* is also consistent with accident-causing agencies. This is because rock drillers were involved in a lot of accidents in the accident characterization according to tasks. Rock drillers are normally found underground during drilling, so they are exposed to various hazards, especially to loose rocks.

The agency involving *handling material* being the most prominent accident-causing agency coincides with the fact that tasks involving material handling and drilling were significant when accident characterization were linked to tasks performed (see Figure 18). Most of the accidents involving *material handling* incorporate a wide range of manual, semi-automated and automated equipment and systems that were supporting logistics. Drilling, cleaning, and making area safe are direct root cause of *fall of ground*. During drilling, rock drillers are at high risk to falls of ground; also, workmen when trying to make the area safe or when cleaning were also at risk to *falls of ground* related accidents.

Accidents involving *moving machinery* happen due to the machinery movement in the way and then hits a person for not following the standards and procedures. Examples of moving machinery are mine trucks such as front-end loaders, dump trucks and underground locomotive trains. There were few cases recorded in this study for accident which happened due to electrical burns, chemical burns, heat burns from underground high temperature. There were also few occasions of accidents happening due to shaft cages and winches. Situations involving shaft sinking in which a moving bucket strikes a victim after encountering it and this was classified as *moving machinery.*

Most instances of slip and fall incidents happened during self-transportation of the worker in activities such as walking and running which is because of poor housekeeping. Other examples are situations such as falling from heights which happen because of not using proper protective equipment (PPE).

Accident characterization by agency results as shown in Figure 19 were compared with earlier results obtained by Ashworth and Peake (1994), Sanmiquel (2010), Cawley (2003), Lenne et al (2011), Bonsu (2013) and the results obtained by Mwansa (2021). The studies of Ashworth and Peake (1994) and Bonsu (2013), which were conducted for South African mines, identified similar results in which falls of ground and slipping and falling were very significant to the causes of mine accidents. Mwansa (2021), who studied the causes of accidents from the other mine site, also identified *fall of ground* or *ground strata failure*, and *slipping and falling* as most occurring agency to have been causing accidents. This demonstrates that accidents due to *falls of ground*, *slip* and *fall* are very common in both mine sites for the underground operations.

The earlier study of Sanmiquel et al (2010) from the spanish mines revealed that the most prominent accidents reported were due to failing and collapsing of underground excavations and then victims getting trapped. These events are similar to *falls of ground* or *ground strata failure* and *fall of material* recognized in this study as the most prominent agencies. The study of Kecojevic and Radomsky (2004) from the United States of America also revealed that annual mine fatal injuries changing from 37% to 88% were attributed to mobile machinery (e.g. front end loaders, conveyor belts, assorted equipment, haul trucks). This can be attributed to the fact that mines in developed countries are mechanized. The study of Cawley (2003) from the United States also showed that electrical related incidents represent the fourth most prominent cause of accidents in the mining industry. The earlier study of Lenne et al (2011) from the Australian mines also identified electrical incidents as major cause of most accidents, which is the opposite to the findings of this study in which electrical incidents were less identified. Electrical incidents in the developed countries were most recurring agency identified as the root cause of most accidents while in the developing countries were less commonly identified. This makes a big difference between accidents in the developed and developing nations, meaning that mines in developed countries are more mechanized compared to developing countries. The other difference between mines in developed and developing countries is the high rate of *falls of ground* incidents in the developing countries. The improvement in technology and mechanization of the mines in the developed countries has helped to reduce exposure of people to dangers, hence reduce a number of mine accidnets (Hermanus, 2007). *Falls of ground* happen due to poor installation of ground support (roof bolts, mesh and shotcrete), poor mine design, lack of discipline amongst employees, pillar failure, etc (Barton, 2002).

Similar results were obtained in the study of Mwansa (2021) which identified *energy isolation* (in this study coded as burns) under the accident characterization according to agencies, as the least common agency contributing to accidents. The occurrence of this agency as being the for developing countries highlights a key difference in safety of the mines in developed and developing countries. However, the most important safety concern in both developed and developing nations maybe how to deal with identified hazards at the workplace. Zambian mines are still confronted with challenges of elliminating hazards with regard to conventional mining operations.

4.1.4. Shift of the day

The characterization of accidents according to shift of the day (see Figure 20) was done to give an indication of unsafe acts during the working hours of the day. The information presented under this section is to help understand which shift is the most accident prone so that a solution can be developed to reduce the accidents. The detailed explanation of this part is presented in section 4.3.6 under unsafe acts linked to time of the day. However, the most identified factors attributed to this trend is day shift (06:00am to 15:00pm) and afternoon shift (15:01pm to 22:00pm). These two shifts have a lot of contractors, service jobs are done during these shifts, production pressure by supervisors is usually during these shifts, and excessive overtime were common in the day/afternoon shifts which made workers to be fatigued leading to accidents.

The analysis under this category were compared to the earlier study of Bonsu (2013) from the platinum mine of South Africa. Similar results were obtained in Bonsu's (2013) study in which day shift was recognized to have recorded more accidents compared to other shifts. The study identified day shift (09:00-11:59 and 12:00-14:59) as the most dominant accident-prone shift and this can be attributed to the fact that during the day shift operations, there are some production pressures on the workers from line managers, although this was not stated in the accident reports.

The accident characterization according to shift of the day were also compared to the study of Mwansa (2021) from the other mine site of the same company with this study. Similar results were obtained by Mwansa's (2021) study where the day shift recorded more accidents than other shifts. Day and afternoon shifts had high frequency rate of accidents.

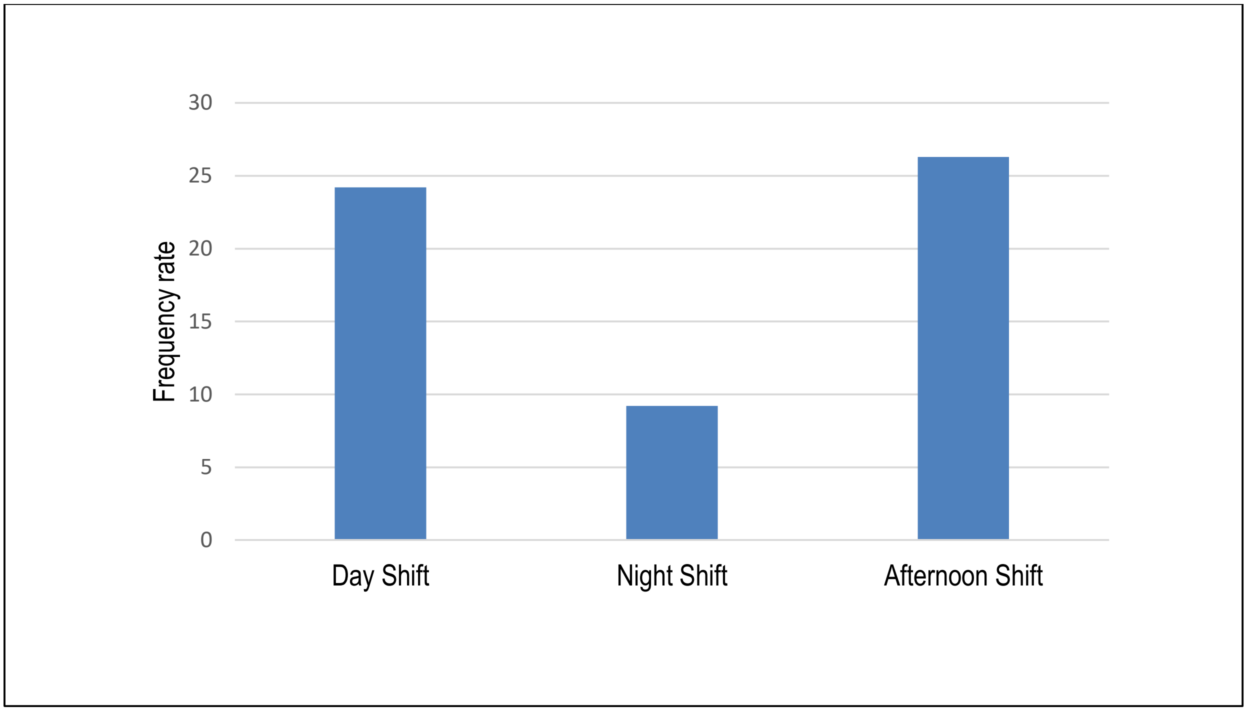

Figure 19: Accident characterization by shift of the day (year 2013 to 2014)

The afternoon shift is from 15:01pm hours to 22:00pm hours, and there is also a significant number of accidents happening during this shift. The afternoon shift recorded about 44.1% of all accidents analysed. The possible causes are fatigue due to overtimes and production pressures.

However, the results of Mwansa (2021) from the other mine site shows afternoon (15:01pm hours to 22:00pm) to have low frequent accident rate. This can be attributed to the fact that there are few cases to do with overtimes during this shift.

4.1.5. Job title

The accident characterization by Job title as shown in Figure 21 was done to determine the types of employees that are normally susceptible to mine accidents. This accident characterization by job title assists in establishing whether employees executing the works were trained or not.

Accident characterization by job title as shown in Figure 21 revealed that the most prominent job titles that were involved in accidents were rock drillers, workmen, machinery operators, personal in charge (PIC) and artisans.

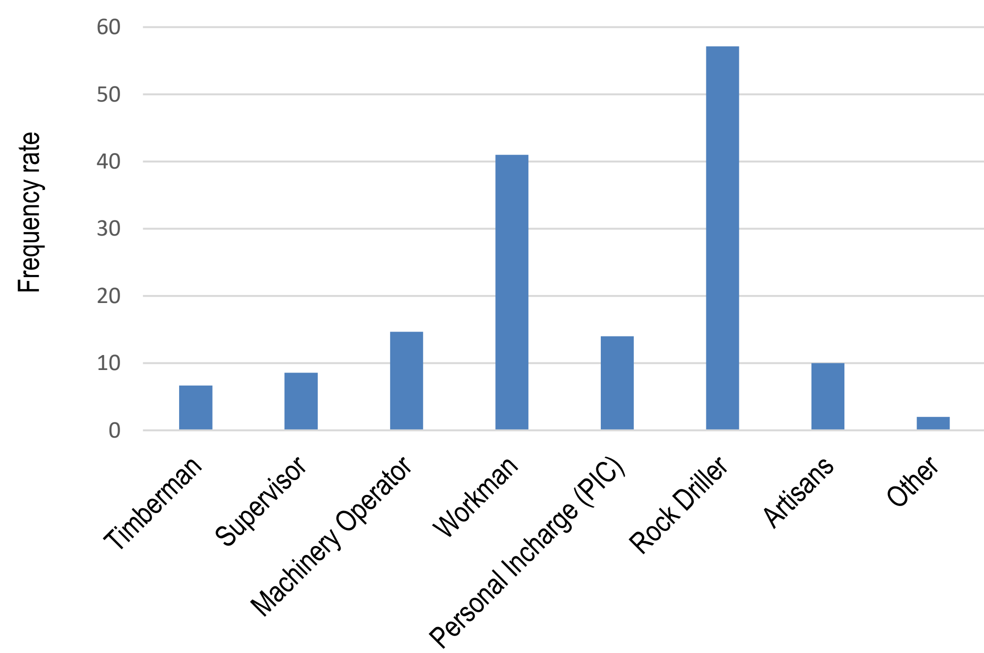

Figure 20: Accident distribution according to job title (year 2013 to 2014)

The job title workman is applicable to jobs such as grouters, helpers, material chasers and those are jobs without proper specialization or defined skills. The job title artisan is applicable to jobs such as boiler makers, electricians, and those workers with craft certificates. The job title machine operator is specifically referred to workers operating moving machinery such as front-end loaders, dump trucks, underground locomotives, and other moving machinery both on surface as well as underground.

This characterization is consistent with earlier analysis of characterization of accident according to task (see Figure 18) which shows that material handling, drilling and transportation of material/equipment were the most identified tasks prone to accidents. This shows that workmen were involved in most tasks to do with handling of materials whereas rock drillers were also involved in drilling tasks. The job titles with artisan and machinery operators were involved in material handling and transportation of equipment tasks respectively (see Figure 19).

The results under this section of accident characterization according to job title were compared to Mwansa's (2021) study from the other mine site of the same company with this study. Similar results were revealed in the study in which job titles such as workmen, operators and artisans were involved in most accidents. Job titles that were recognized in Mwansa's (2021) study were security guards and drivers. This study did not recognize any job title as security guard or drivers to have been involved in an accident. However, drivers for front end loaders and dump trucks were referred to as machinery operator in this study. Motor vehicle drivers were not identified in this study, which signifies that the study of Mwansa (2021) from the other mine site involves a lot of surface operations.

4.1.6. Accident characterization according to employee type

Accident characterization according to employee type as shown in Figure 22, revealed that the incidents involving contractor employee (76.3%) were higher than company employee (23.7%). There are various factors contributing to the increase in frequency rate of accident for contractors such as having a lot of contractor employees involved in several tasks compared to the company employees.

The other factor is the fact that most critical tasks at the mine site have been sub contracted, hence it is expected that contractors will be more involved in accidents. The most prominent task identified under accident characterization according to task performed was drilling. This was also noted in accident characterization by employee type, in which contractor employee had recorded more accidents than company employee. Tasks involving drilling activities were executed by contractors; this made workers more susceptible to accidents at this mine. Probably, lack of motivation among contractor employees could have been attributed to the low-income earnings which might have affected their zeal to perform efficiently and effectively. This is demonstrated by comparing contractor and company employee in terms of incomes and accident records (Appendix 6). The results showed that employees with less income were involved in accidents compared to those with high income earnings. However, this is a different picture from the other mine site (Mwansa, 2021) in which it is the other way round. The study of Mwansa (2021) revealed that company employees had significantly recorded more accidents compared to contractor employees. This is attributed to the fact that company employees execute most of the metallurgical surface operations; hence majority of the company employees are expected to be involved in more accidents. The other important point to consider is that the entire company has subcontracted all the underground mining operations (drilling operations). Therefore, it is obvious for this study to have more accidents on the contractor employee and less on company employee.

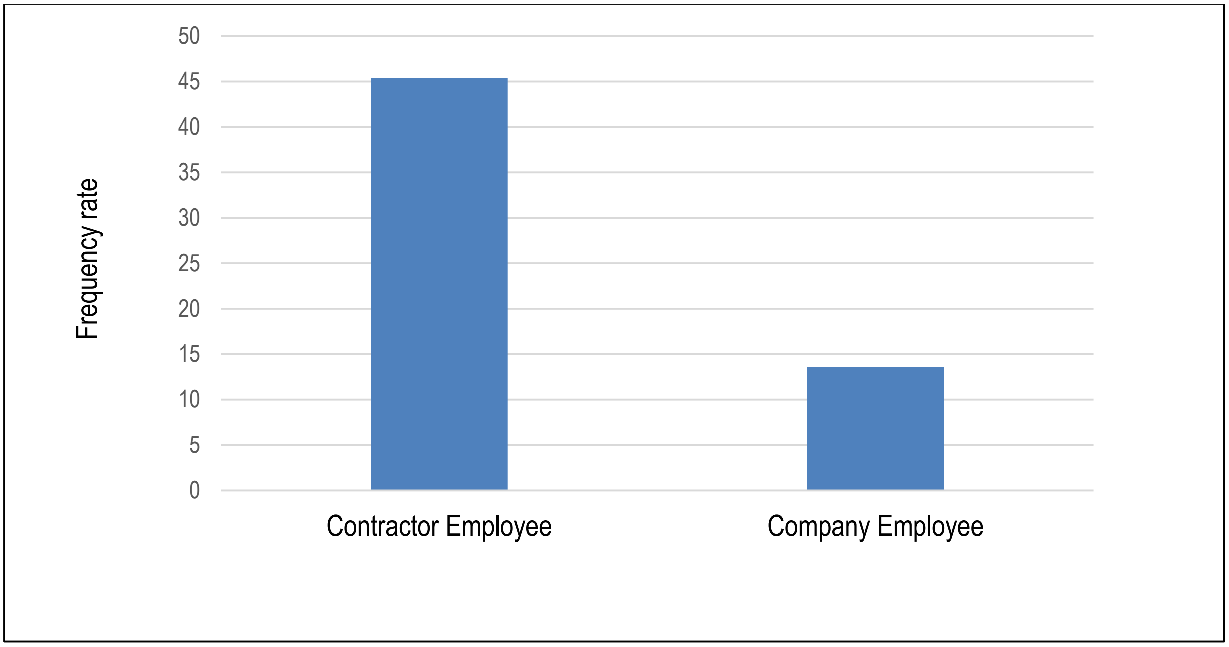

Figure 21: Accident characterization according to employee type (year 2013 to 2014)

4.1.7. Characterization by broken barriers

The *characterization of accident* according to *barriers broken* when executing a task is shown in Figure 23. This accident characterisation provides a signal in terms of effectiveness and nature of defense designed by the mining company to alleviate the impact of energy released from hazards. Figure 23, which illustrates *accident characterization* according to barriers broken, shows that the most prominent safety barriers breached were *standards and procedures*, *supervision*, *training and inductions, risk assessment, job safety analysis* and *safety equipment* as shown in Figure 23. This demonstrates the need to ensure the effectiveness of preventative controls, such as supervision, that are in place to ensure that workers follow *standards and procedures*. The other broken barriers identified were communication, warning systems and personal protective equipment.

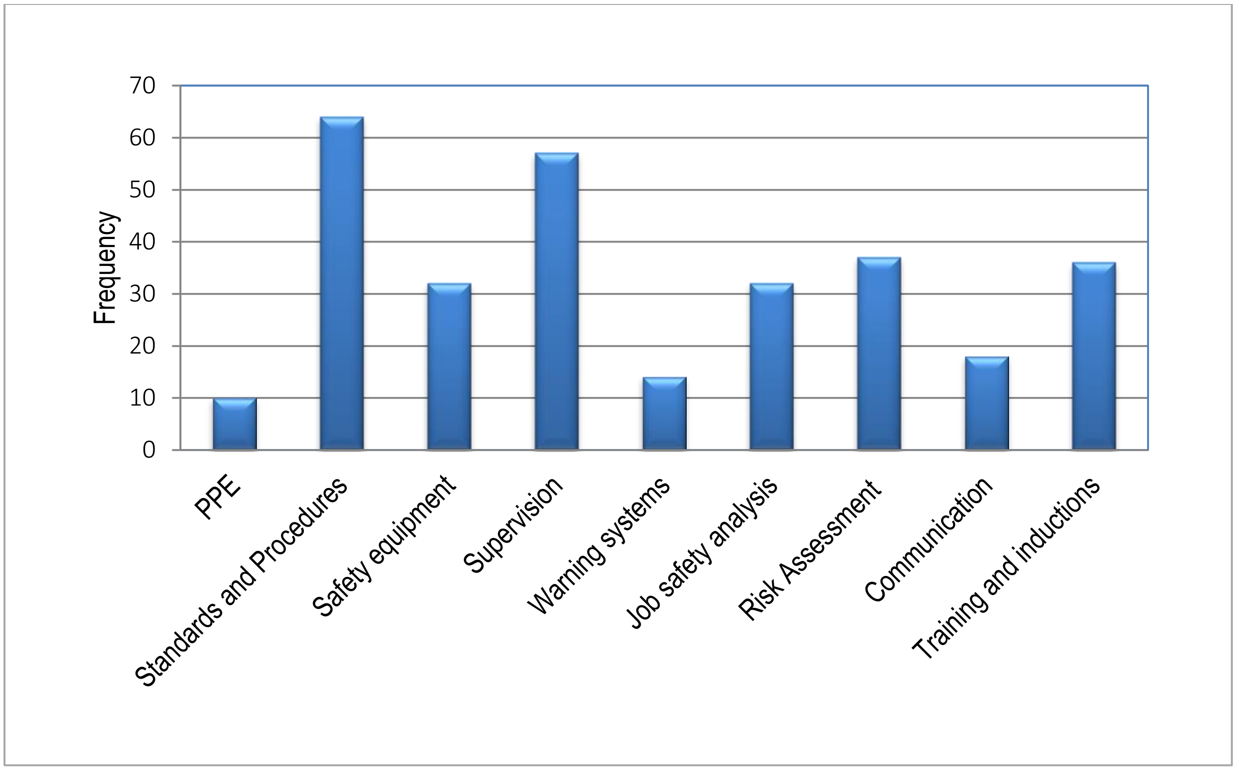

Figure 22: Accident characterization according to broken barriers (year 2013 to 2014).

The most important point to note in this section is the fact that most barriers broken involve two or more barriers in most accident analyzed (more than two accident reports).

The results under this section were compared to the earlier study of Bonsu (2013) for the South African platinum mine which shows that *supervision, risk assessment*, and *standards and procedures* were the most broken barriers. However, similar results were obtained in this study in which *standards and procedures, supervision*, and *risk assessment* were recognized as the most broken barriers contributing to accident at this copper mine investigated in this study. The other broken barriers identified in this study, which are similar to that of Bonsu (2013) with low frequent rate of accidents, were *communication*, use of *PPE*, and *warning system*. The broken barrier involving *job safety analysis*, and *training and inductions* for the case study copper mine were slightly high compared to the platinum mine in South Africa studied by Bonsu (2013) which shows significantly low frequency.

The results under this section is also compared to the study of Mwansa (2021) for the other copper mine site, and it shows that *standards and procedures*, *job safety analysis*, use of *PPE* and *supervision* were the most broken barriers. These results from the two mine sites signify that the accidents are due to human errors which are because of managerial problems (leadership). Failure to follow *standards and procedures* is due to poor leadership. Failure to conduct job safety *analysis (JSA)* prior to execution of any task is also because of poor leadership. Management's failure to provide necessary *PPE* can also lead to a worker being involved in an accident at the workplace. The barrier beached in the aspect of equipment *safety* was identified in a situation where the worker was allowed to perform a task using an unsafe equipment with a mechanical problem. Supervisors must be exposed to supervisory training courses; management must ensure that standard operating procedures (SOPs) are developed for all tasks. Furthermore, supervisors must ensure that planned task observations (PTOs) are carried out on every task while also showing visible felt leadership (VFL).

4.2 Causal Analysis

The section under causal analysis has three categories which include causes (direct), systemic and workplace factors. The causal analysis results have been summarized accordingly as shown in Table 3. Frequency is only for 100 accidents that were analysed and is also presented in percentage form in the last column of Table 3.

Table 3: Accident analysis in the framework categories for the 100 accidents cases

Systemic Factors	***Frequency***	***Percentage***
Leadership	52	22.6%
Hazard Identification	50	21.7%
Training and Competence	27	11.7%
Design	26	11.3%
Risk Management	19	8.3%
Contractor Management	16	7.0%
Resource Provision	10	4.3%
Housekeeping	9	3.9%
Management of Change	7	3.0%
Monitoring and Auditing	6	2.6%
Work Scheduling	3	1.3%
Maintenance Management	3	1.3%
Strategic Decision	1	0.4%
Emergency Response	1	0.4%
Total	**230**	**100%**
Work Place Factors		
Behavioural Environment	33	25.8%
Physical Environment	30	23.4%
Unsafe Work Practices	24	18.8%
Fit for Purpose Equipment	21	16.4%
Competent People	20	15.6%
Total	**128**	**100%**
Direct Causes		
Routine Violation	38	38%
Slip and lapses	30	30%
Mistakes	21	21%
Exceptional Violation	9	9%
Non-Human Cause	2	2%
Total	**100**	**100%**

The accident characterizations under direct causes were identified in the accident reports analysed. Unsafe acts were identified in 98% of all accidents analysed in the reports. This is like the study of Bonsu (2013) from the platinum mine of South African showing unsafe acts at 98.9%, which can be attributed to the fact that these are labour intensive mines (in developing countries).

The most prominent type of unsafe acts recognized were *routine violation* (recognized in 38% of all the accident analysed), closely followed by *slips and lapses* (identified in 30% of all cases) and then followed by *mistakes* (21% of the accidents analysed). *Exceptional violation* and *non-human* cause were the lowest at 9% and 2% respectively. Systemic and workplace factors were involved in 78.2% of the accident reports that were analysed. The most prominent workplace factor recognized was *behavioural environment* (25.8% of all cases analysed), closely followed by *physical environment* (23.4% of all cases analysed), then *unsafe work practices* (18.8% of the accidents analysed), then *fit for purpose equipment* (16.4% of the accidents analysed) and finally very close is *competent people* (15.6% of the accidents analysed).

In general, under the category of accident analysis on workplace factors, all the five factors were contributing to the causes of accidents in the site of the copper mine that was investigated as demonstrated by the closeness in percentages.

Behavioural environment was identified as a major contributing factor to most accidents analysed in the mining site, which was not a surprise. Systemic factors such as *emergency response, strategic decision, maintenance management,* and *work scheduling* were not so significant or were not found in some of the systemic factors in this study (see Table 3). This is like results obtained by Lenne et al (2011) in the Australian mines in which systemic approach to accident causation identified *behavioural environment/organization process* (at 65% of accident analysed) followed by physical *environment* (at 56%).

The working conditions such as disorder at the work-place, noise, high temperature, poor ventilation, and poor lighting can influence the employee indirectly thereby causing accidents (Fridlund, 1987). These are the conditions which contribute to *physical environment* (significantly high in this study). This is also consistent with the study of Sanmiquel et al (2010) for the Spanish energetic mining where 56% was identified for *physical environment*. *Behavioral environment* in this study was the most significant contributor to workplace factors which is due to workload and the pressure received from the supervisors in the process of having work done. Kansumba (1995) conducted a study to determine factors contributing to mine accidents in Zambia, in which lack of education was highlighted as one of the causes of accidents (see Table 4). Table

4 shows that many of the employees 31 (52%) who were involved in the mine accidents had gone up to secondary school level. The level of education, therefore, does not seem to effectively equip the mine employees with behaviours that would prevent them from being accident prone. Lack of education in the mining industry among workers may have a direct effect on the *behavioural environment* on the workplace factors and this was high in this study with 26.0%. The author of this study is of the view that maybe majority of the employees considered in the study of Kansumba (1995) had secondary school education, henceforth expected to have been involved in most accidents. However, this study did not consider the lack of access to education among workers as contributing to accidents at the copper mining company investigated. The level of education was not disclosed in any of the accident reports obtained from the mine site.

Table 4: Level of education in the mining industry Kansumba (1995)

Level of Education	***Involvement in Accidents***	
	Yes	No
Primary	2 (3%)	1 (2%)
Secondary	31 (52%)	18 (30%)
College	4 (7%)	4 (7%)
Total	37 (62%)	23 (39%)

(Source: Kansumba, 1995)

The most identified factor in this study under systemic factors was *leadership.* The other factors identified were *hazard identification*, *training and competence*, *design*, *risk management*, *contractor management* and *provision of resources*.

The less commonly identified factors under systemic factors were *housekeeping, management of change, monitoring and auditing, work schedule, maintenance management, strategic decision, and emergency response*.

The results in this section are compared to the work of Patterson and Shappell (2010) and Lenne et al (2011) from the Australian mines, Bonsu (2013) from a platinum mine in South Africa and the parallel study of Mwansa (2021) from the other mine site of same company with this study.

The level of involvement of systemic factors contributing to accidents in this study, and those of Mwansa (2021) and Bonsu (2013), were higher than the works of Patterson and Shappell (2010) and Lenné et al (2011) both being conducted for surface and underground operations. Both this study and Mwansa's (2021) identified *leadership* as the most contributing systemic factors leading to accidents at the copper mining company in Zambia. Similar results were obtained by Bonsu (2013), in which the most prevailing systemic factor contributing to accidents from the platinum mine was *leadership*. The studies of Patterson and Shappell (2010) and Lenné et al (2011) from the Australian mines identified organizational factors as contributing to most accidents which is like *leadership* in this study. The HFACS identified *leadership in* a separate level as the most prevailing organizational factor contributing to accidents.

The rate of accidents recorded in the causal factors as presented in the causal section of Table 3 (direct causes, workplace, and systemic factors) of the existing framework were more than 100 frequencies. This is attributed to the fact that in most situations two or more these factors were recognized as contributor to the causes of the same accident under the same level of the existing framework. A typical example under workplace factors is a situation where a worker is conducting barring down using a wrong tool/pinch bar (*fit for purpose equipment*) in the environment with poor housekeeping (*physical environment*), then in the process flipped and fell. This study also recognized non-human cause as a factor contributing to accidents at the case study mine site.

4.3 Unsafe Acts

This portion of the framework identifies unsafe acts according to the analysed accidents as *routine violations*, *mistakes, slips and lapses,* and *exceptional violations* as shown in Table 3. The unsafe acts are also analysed in more detail according to agencies, employee type, age, time of day and experience as presented in the following sections.

4.3.1 Overall distribution of unsafe acts

This portion presents the overall results of unsafe acts that were recognized in this study. The unsafe acts were presented as routine violation, mistakes, slips and lapses, exceptional violation, and non-human cause (see Figure 24).

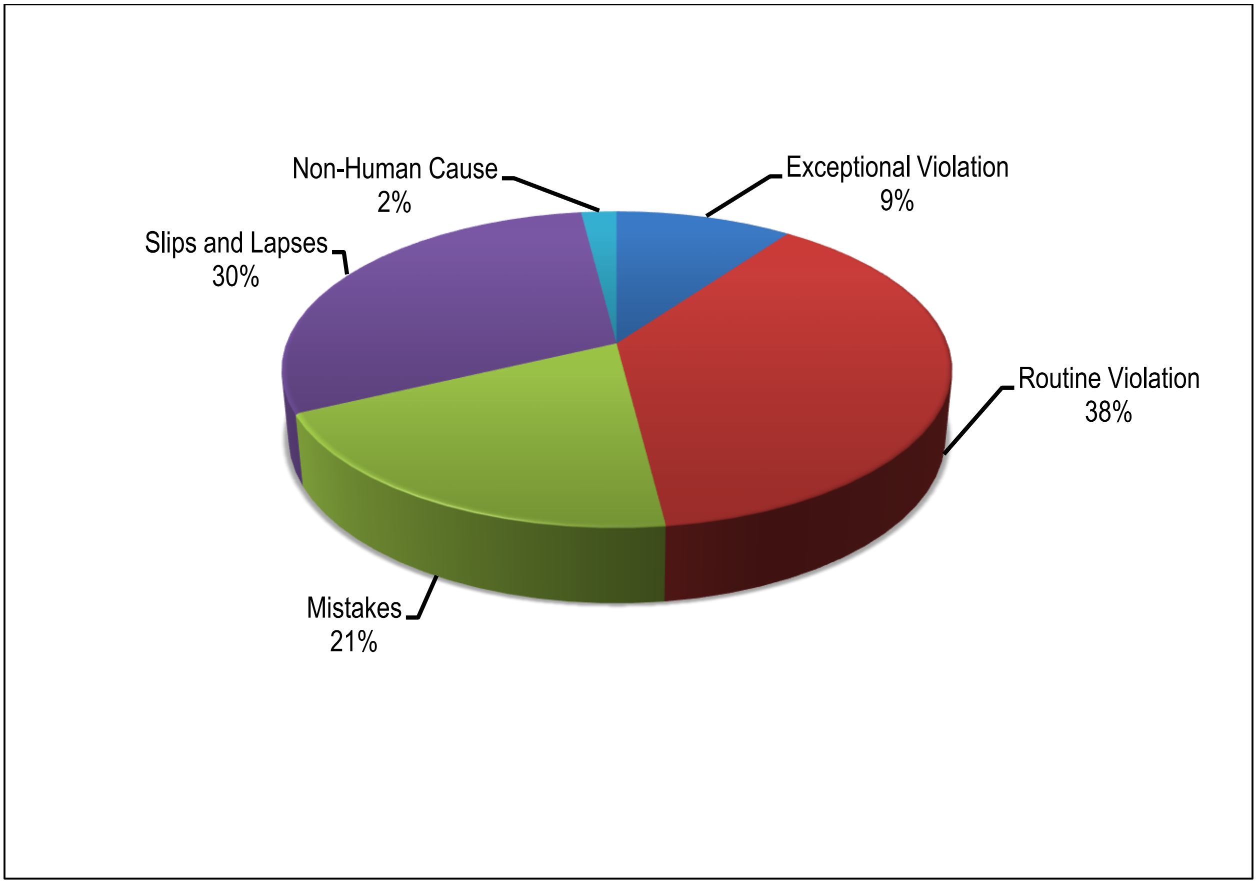

Figure 23: Overall distribution of unsafe acts (year 2013 to 2014).

Figure 24 shows that violations (*repetitive violations* at 38%) are the most common *unsafe acts*, then followed by *slips and lapses* (30%), *mistakes* (21%), *exceptional violation* (9%) and finally *non-human causes (2%)*. Most instance of *routine violations* involved situations such as failure by a worker to follow the laid down rules, procedure and standard, for barring down using the right tool, failure to follow the laid down standard operating procedure when installing ground support and failure by a worker to conduct a risk assessment prior to commencement of any task.

The instance of unsafe acts due to *slips and lapses* for this study is considered in situations where the planned task had failed to meet its intended results because of memory failure. Slips were common in instances where a worker losses attentiveness when performing a task. Lapses were common in situation where a worker is performing a task and in the process losses memory. Slips and lapses will make the worker not to escape from the hazards. The incidents of slips and lapses are so common in an underground environment. This is because an underground environment has very complex conditions (i.e., poor ventilation) which workers are exposed to as well as the long working hours in such conditions (NIOSH, 2006).

Instances of unsafe acts involving mistakes identified in this study include situations where a worker is assigned to perform a task such as barring down using the 3.4m long pinch bar (barring down tool). However, the worker uses a 1.5m long pinch bar (barring down tool) which is not meant for the task assigned, and in the process makes a mistake which then resulted in an accident. The other typical example of unsafe acts involving mistakes were identified in instances of poor communication amongst workers during task execution. Inadequate risk assessment normally led to conditions where workers chose to perform a task in the wrong position, chose to use a wrong equipment and exposure to existing hazards. However, hazards in an underground environment are unforeseeable, making it difficult for workers to distinguish safe working conditions from non-safe ones.

The most common cases of *non-human* cause were naturally driven such as premature failure of the component from the equipment causing an accident. The preventive measures must be taken to ensure daily routine checks are conducted to inspect the condition of an equipment prior to commencement of any task.

The results under this study were compared to the work of Mwansa (2021) to determine unsafe acts affecting the two mine sites. Similar results were obtained in the parallel the study of Mwansa (2021), in which *routine violation* (36%) was identified to have been the most common causes of unsafe acts, narrowly followed by *slips and lapses* (34%) and then *mistakes* (27%). *Exceptional violation* was identified in both studies to have low frequency cause of accidents.

The nature of accidents produced at the mine site of this study demonstrates the type of human errors that cause accidents at this copper mining company in Zambia. The next section describes the effect of unsafe acts on agencies that caused accidents at this mine site.

4.3.2 Unsafe acts distribution according to agencies

Figure 25 below shows the results of unsafe acts distribution according to specific agency. The information analysed is very vital in developing exact strategies of the kind of agencies causing accidents. Typically, to specify the kind of violation that can lead to certain accidents such as *fall of ground*, then this will help to understand specific measures that can be put across to address the cause. This method of linking unsafe acts to agencies is better than using a general solution strategy to address different type of violations.

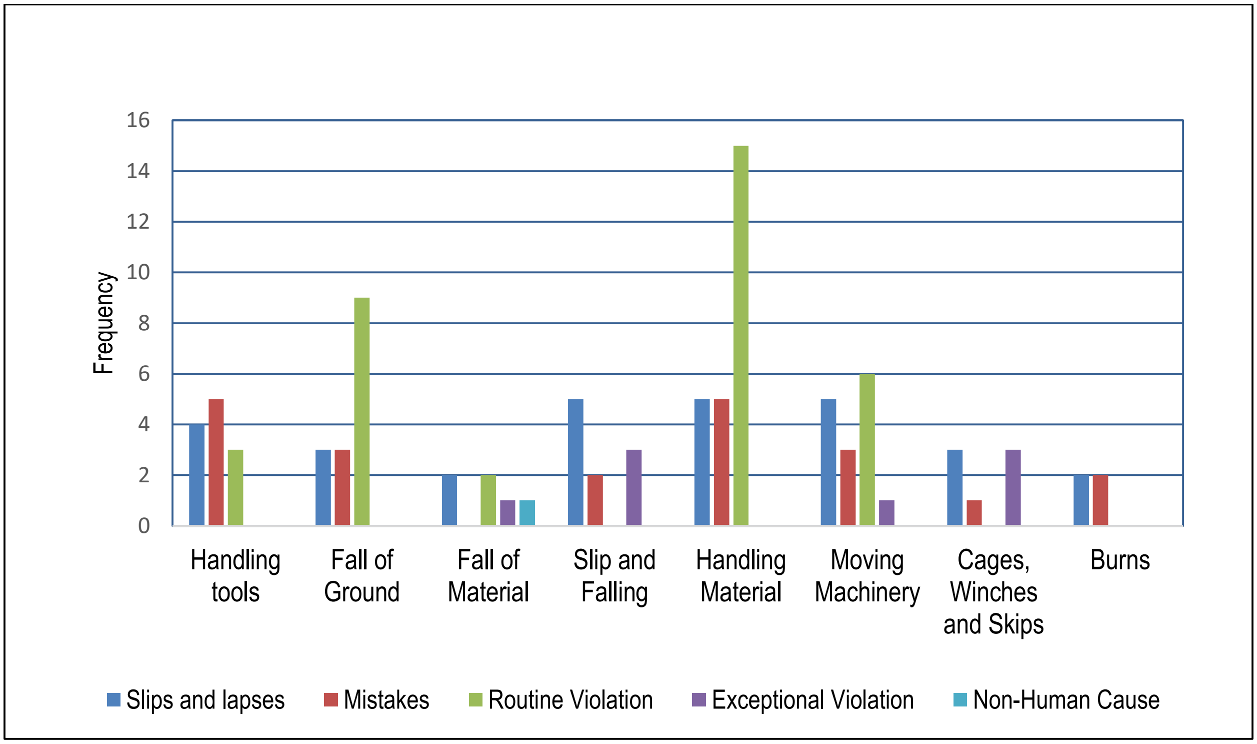

Figure 24: Unsafe acts distribution according to agencies (year 2013 to 2014).

The results in Figure 25 revealed that *routine violation* was the most common unsafe acts identified in the causing accident agencies such as the *handling materials*, *fall of ground, moving machinery, handling tools* and *fall of material*. This shows that the human errors are deeply involved in these accident-causing agencies. However, unsafe acts such as *mistakes* were identified in *handling tools*, *handling materials*, *moving machinery*, *fall of ground* and *burns* agencies. The unsafe acts involving *slips and lapses* were identified to be common in accident-causing agencies such as *slip and falling*, *handling material*, *moving machinery* and *handling tools*. The unsafe acts involving exceptional violations were only identified in *cages, winches, and skips, slip and failing*, *moving machinery* and *fall of material*. *Exceptional violation* in *moving machinery* agency was identified in instances involving an incompetent worker operating an equipment. Another example is where an operator violated the regulation by operating a piece of equipment that was not authorized to use. *Exceptional violations* are difficult to correct because they are unpredictable due to their departure from normal behaviour (Shappell and Wiegmann, 2003).

The results in Figure 25 further reveals that various types of human errors were involved in the agencies analysed. The truth about this is that deeper analysis of unsafe acts linked to agencies is required to have a better understanding of the problems in the operations. The *falls of ground* or ground strata failure related accidents can be prevented in underground mines by means of ensuring that the working area and travelling ways are supported to standard with the right ground support material and by competent personnel. The other method of preventing falls of ground related accidents is by ensuring that loose rocks are barred down to solid in the roof and sidewalls of underground excavations. During underground *drilling*, workers performing a task must be under the cover of safety net. This will help prevent falls of ground accidents. Failure to obey and follow these highlighted procedures and rules were the most prominent forms of violations recognized as prominent to occurrences of rock fall accidents. The use of incorrect tool for barring down was the other predominant violation identified under this agency. The most common mistakes identified were instance of not barring down the working areas due to lack of competent person to perform the task or lack of proper tool. The other common mistake that was identified in this study was insufficient risk assessment on the maintaining the safest distance to stand when performing barring down activity.

The typical example of the instance of *slips and lapses* recognized in this study are cases where an employee lacks the required knowledge and is allowed to work in an environment which is poorly supported. Due to lack of necessary knowledge, the employee is expected to be exposed to hazards that can lead to accident occurrence. The accident cases due to mobile equipment or *moving machinery* were identified in situations where a worker is standing in an unsanctioned area and then being hit by a moving equipment or moving machinery. The cases involving *slips and lapses* recognized in this study were instances where a worker was unintentionally standing in the roadway of a *moving machinery* and then being hit by the equipment. The most common cases of *routine violation* recognized in this study in agencies involving *cages, winches and scrapers* include situations when an employee works on an equipment in motion, uses the wrong tool or uses an incomplete PPE.

The agency involving *material handling* identified *routine violation* in cases where inadequate lifting tools/techniques or improper PPE were used to perform tasks of handling material. The other common violation identified in this study in *material handling was* communication failure among the workers. Loss of concentration among employees during task execution was the most common instances of *slips and lapses* that was identified with material handling. Most *slip and fall* accidents happened in situations where a worker is walking in the travelling way, then tries to flee from a hazard, in the process slips, and falls. The availability of tripping hazards along the travelling ways in an underground environment makes the worker more susceptible to slip and fall related accidents. To eliminate these tripping hazards at the workplace, it is important to conduct good and adequate risk assessments prior to commencement of any works. Poor housekeeping in travelling ways can make a worker to stand at the tripping hazard causing a slip and fall accident.

4.3.3 Unsafe acts distribution according to type of employee

An accident characterization result of unsafe acts by type of employee is shown in Figure 26, in which significant number of incidents involved contractor employees. This section was done to investigate which employees were more prone to unsafe acts at the mining site studied.

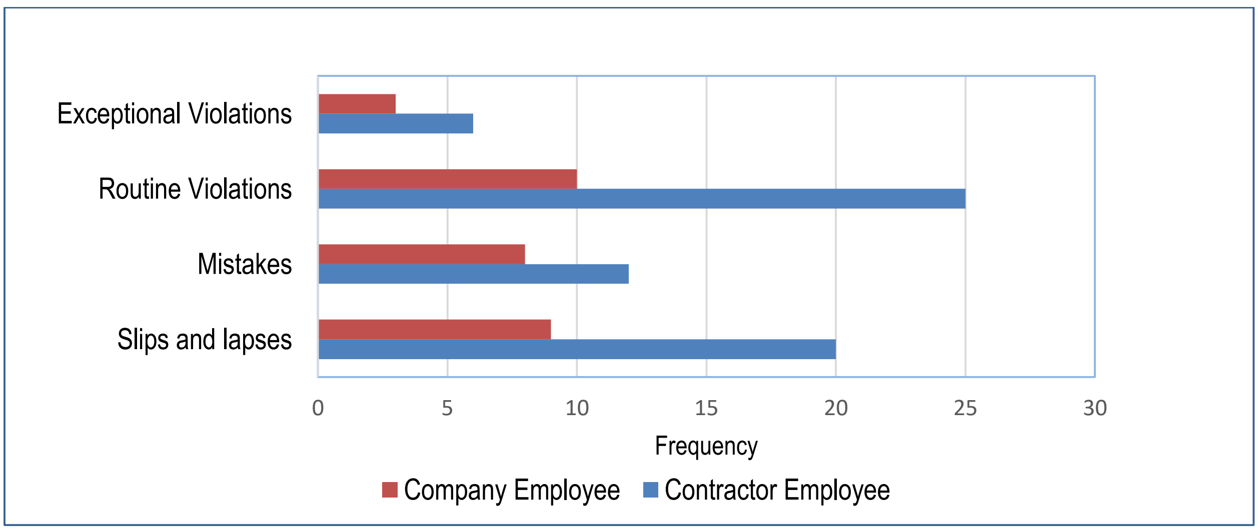

Figure 25: Unsafe acts distribution by employee type (year 2013 to 2014).

The results presented in Figure 26 show that *routine violations* and *slips and lapses* were the prevailing form of unsafe acts amongst both kinds of employees. The results, which also signify common trend among company and contractor employees, support the fact that mining company may have to concentrate on the level of competence among contractor employees that are appointed to perform certain tasks. *Non-human* cause was present among contractor employees. *Non-human causes* refer to situations involving premature failure of a component from an equipment that led to the occurrence of an accident. Premature component failure was common in drill rig equipment during drilling task activities.

The results in this section of this study were compared to the work of Mwansa (2021) and it was found that the results are similar. The unsafe acts for the contractor employees in the study of Mwansa (2021) showed that *routine violation* was the highest, followed by *slips and lapses* and then *mistakes,* whereas the lowest unsafe act was *exceptional violation*. Similar results for unsafe acts for company employees showed that *routine violation* was prominent, then *slips and lapses*, and then followed by *mistakes* whereas, *exceptional violation* was the lowest. However, *non-human cause* was not identified in the study of Mwansa (2021). Most accidents involving non-human causes happened during underground mining operations as previously stated.

4.3.4 Unsafe acts distribution according to worker experience

The unsafe acts distribution according to experience aims to determine the effect of the worker's experience on unsafe acts *(slips and lapses, violations,* and *mistakes*). The results of unsafe acts distribution according to experience revealed that both *violations* and *mistakes* were reducing with increase in worker's experience (see Figure 27).

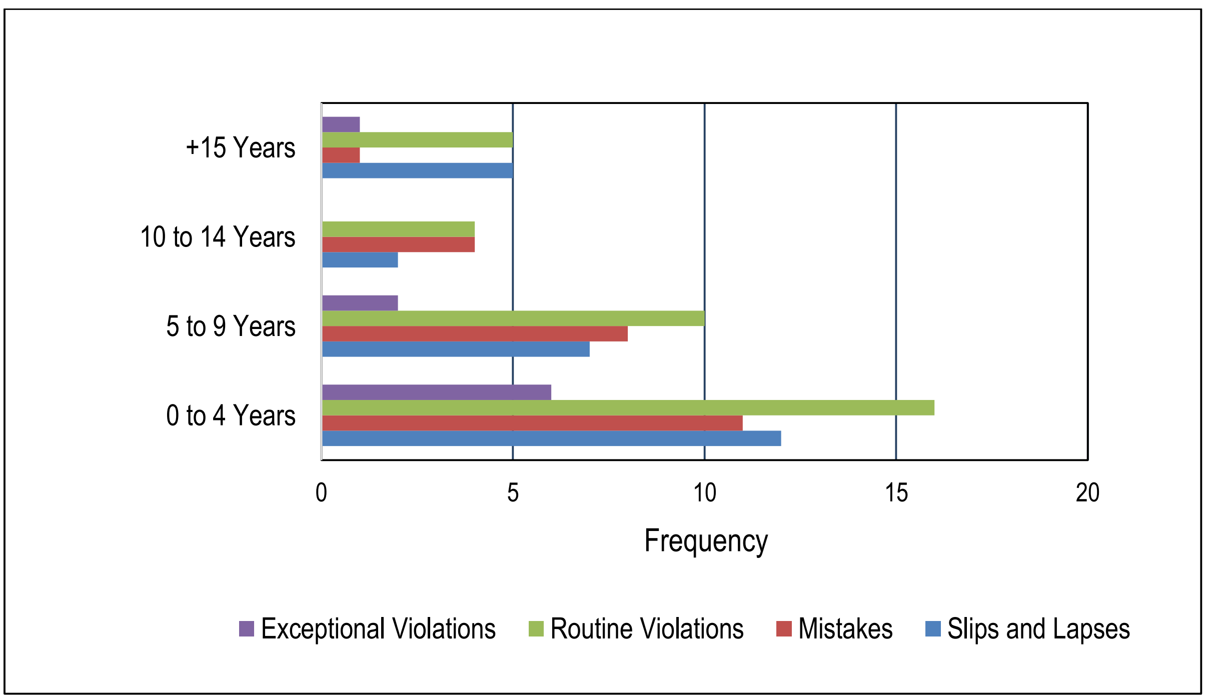

Figure 26: Unsafe acts distribution by experience (year 2013 to 2014)

However, *Slips and lapses* did not follow such trends. This can be explained by the psychological process behind slips and lapses which differs from *violations* and *mistakes*. A slip materializes because of a loss of concentration and this is not affected by the level of a worker's experience.

The results in Figure 27 showed that employees with less experience (less than 9 years) were implicated in most of the unsafe acts. Similar results were also obtained by the earlier study of Kecojevic et al (2007), the works of Sanmiquel et al (2010) and Bonsu (2013) and the parallel study by Mwansa (2021). The study of Kecojevic et al (2007), which was conducted in the United States for mining machinery accidents, revealed that employees with experience of 5 years and below were implicated in most accidents with machinery. The study of Sanmiquel et al (2010) for Spanish mining accidents also reported that more than 43% of victims involved in accidents had less than 5 years' experience. The results under this section were compared to the studies of Bonsu (2013), from the platinum mine in South Africa, and Mwansa (2021), from the other mine site of the same company with this study. The study of Bonsu (2013) revealed that *mista*kes, *routine violation,* and *slips and lapses* were the most common unsafe acts amongst the workers with less experience (0 to 4 years and 5 to 9 years). Similar results were also identified amongst the experienced workers in the study of Bonsu (2013). The experienced workers were identified with few unsafe acts (10 to 14 years and +15 years). However, *exceptional violation* was not stated in the study of Bonsu (2013) and an explanation was not given as to why it was omitted. Similar results were obtained from the study of Mwansa (2021) from the other mine site where *routine violation, slips and lapses,* and *mistakes* were the most common unsafe acts for the least experienced workers from 0 to 4 years. Also, for the group with experience spanning 5 to 9 years, the most unsafe acts were *slips and lapses, routine violations,* and *mistakes*. The other similar results were for the experienced group having 10 to 14 years and +15 years. In both studies, for the experienced group 10 to 14 years, *mistakes* and *routine violation* were the most common unsafe acts identified whereas for the +15 years of experience, the most common unsafe acts identified were *slips and lapses,* and *routine violation* (see Figure 28).

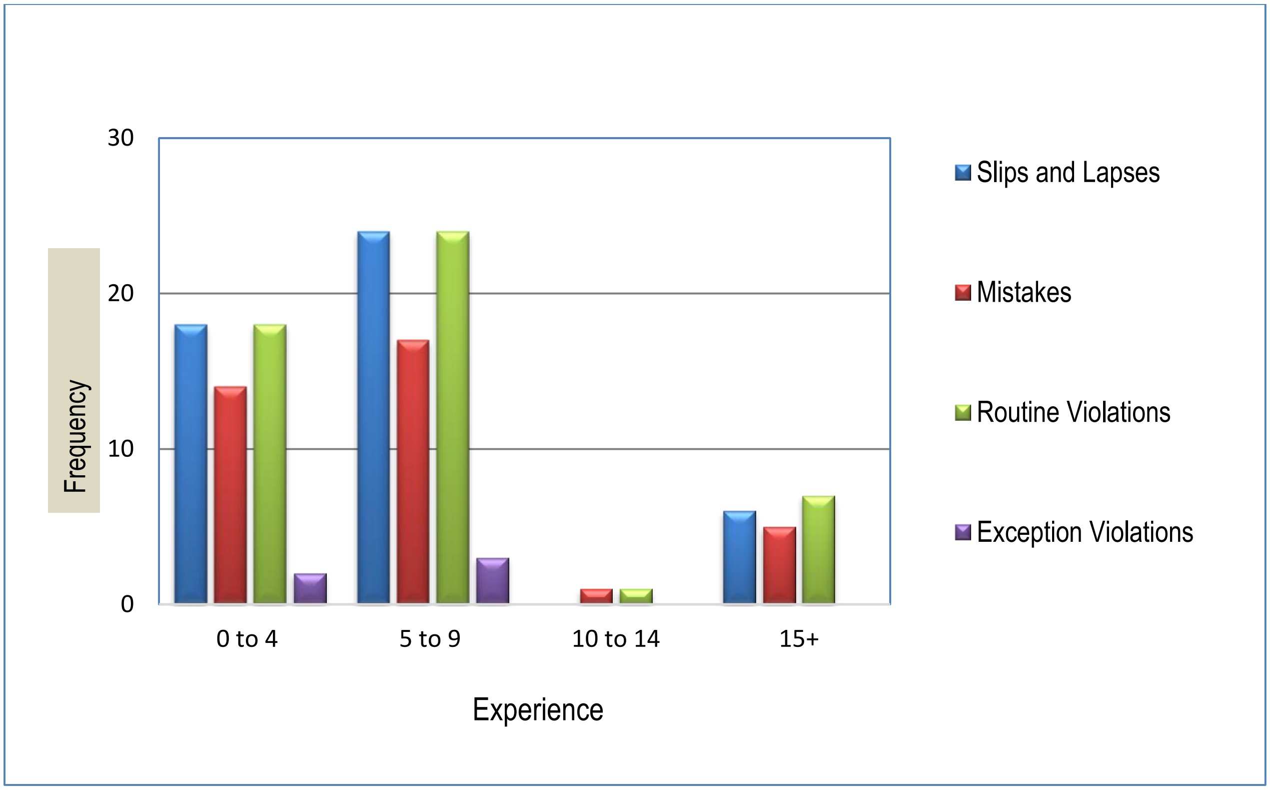

Figure 27: Unsafe acts distribution by experience (Source: Mwansa, 2021)

These results seem to suggest that experienced workers are less prone to *violations* and *mistakes* (Berkeley, 2000). This maybe due to the competence and maturity that the worker gains with experience in performing tasks. The author of this study also acknowledges the fact that unsafe acts were identiffied to be low amongst the workers with greater experience and this may be because of the maturity and experience the worker gains. The other important point that cannot be overlooked is that majority of workers at the mining company were of lower experience.

4.3.5 Unsafe acts distribution according to age

The distribution of unsafe acts by age is shown in Figure 29. The results of the analysis for unsafe acts distributed according to age displayed an increase in the unsafe acts from the age of 21 to 40 and a decrease in unsafe acts from the age above 41.

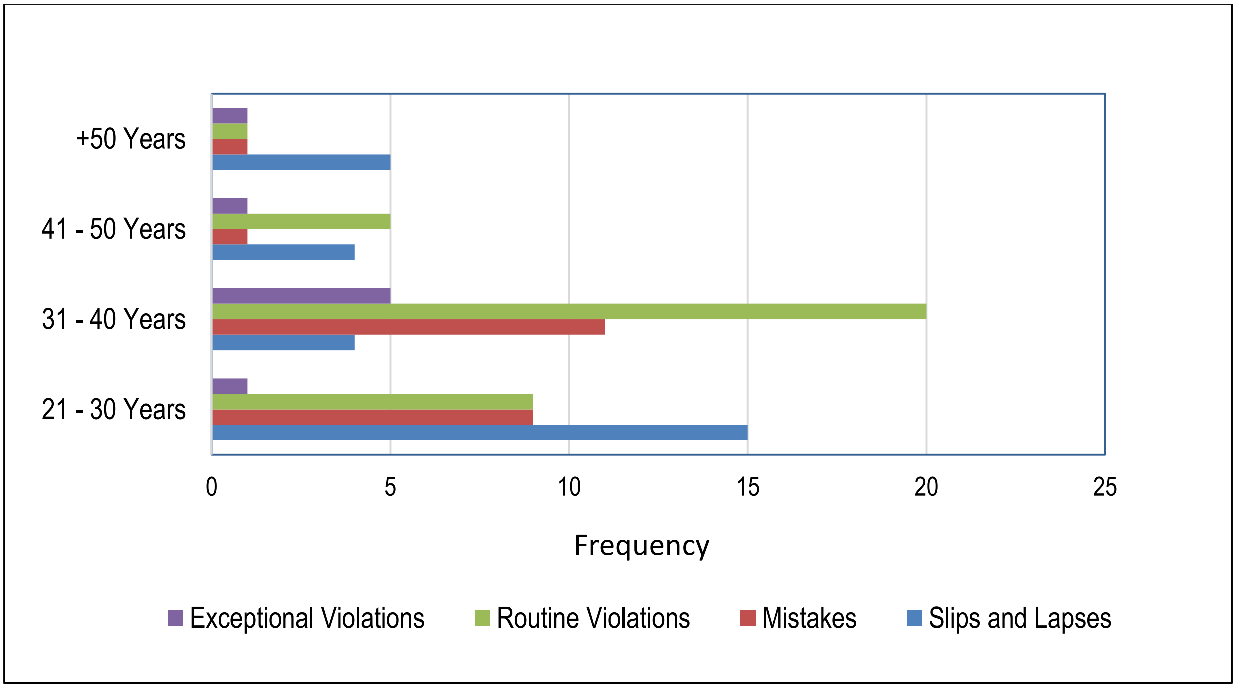

Figure 28: Unsafe acts distribution by age of perpetrators (Year 2013 to 2014)

Figure 29 reveals that human errors are more common in the age group from 31 to 40 which recorded more accidents which are a result of unsafe acts compared to the other age groups. The unsafe acts involving mistakes were very common for the lower age group (21 to 40), while slips and lapses were more significant for the higher age group comparatively (41 to 50+).

Violations were also significant for the age group 31 to 40. This seems to suggest that while the lower age group (young workers) have problems with decisions when performing a task, higher age group (older workers) have problems with compliance when performing a task. The results under this section were compared to the earlier studies of Sanmiquel et al (2010) in the United States, Bonsu (2013) for platinum mine in South Africa and the parallel study of Mwansa (2021) from the other mine site of the same company with this study. The study of Sanmiquel et al (2010) recorded that of all accidents analysed, the ages 30 to 39 recorded 26.6% while the ages 45 to 54 recorded 26.4%. The study of Bonsu (2013) also identified the younger workers (31 to 40 years) to have a significant number of unsafe acts (*violation*s, *mistakes and slips and lapses* at 44%). Similar results were obtained by Mwansa (2021), having the lower age group from 31 to 40 years with more human errors. This seems to suggest that workers within the age group from 31 to 40 (in the study of Sanmiquel et al (2010) is approximately from 30 to 39) were most vulnerable to accidents at the work place in either developing or developed countries. The author of this study acknowledges the fact that high rate of unsafe acts within the lower age group could have been because most of the workforce belonged to the lower age at this mine site. Therefore, the true reflection can only be identified if the age distribution among the workers was considered.

4.3.6 Unsafe acts by working hours

Figure 30 shows unsafe acts distribution by various time of the day. The unsafe acts distribution according to time of the working shift was done at this mine site to investigate the specific time of the shifts which is more vulnerable to record unsafe acts due to human errors amongst the workers. The mine investigated operates with three main production shifts of the day namely the day shift (06:00am to 15:00pm), afternoon shift (15:01pm to 22:00pm) and night shift (22:01pm to 05:59am). Time of day was distributed into 7 groups in which four groups were having 02:59 hours each and three groups were having 03:59 hours each (see Figure 30). This timing was adopted to synchronize with the shifts run by the mine used as case study. Each shift of the day has 8 hours of working time. However, the category for 02:59 hours were (10:00am – 12:59pm), (00:00am to 02:59am), (13:00pm – 15:59pm), and (03:00am – 05:59am). The category with periods of 03:59 hours were (06:00am – 09:59am), (20:00pm – 23:59pm) and (16:00pm to 19:59pm).

The explanation for having two different sets of categories (02:59 hours) and (03:59 hours) is to accommodate the changeover period of the shift.

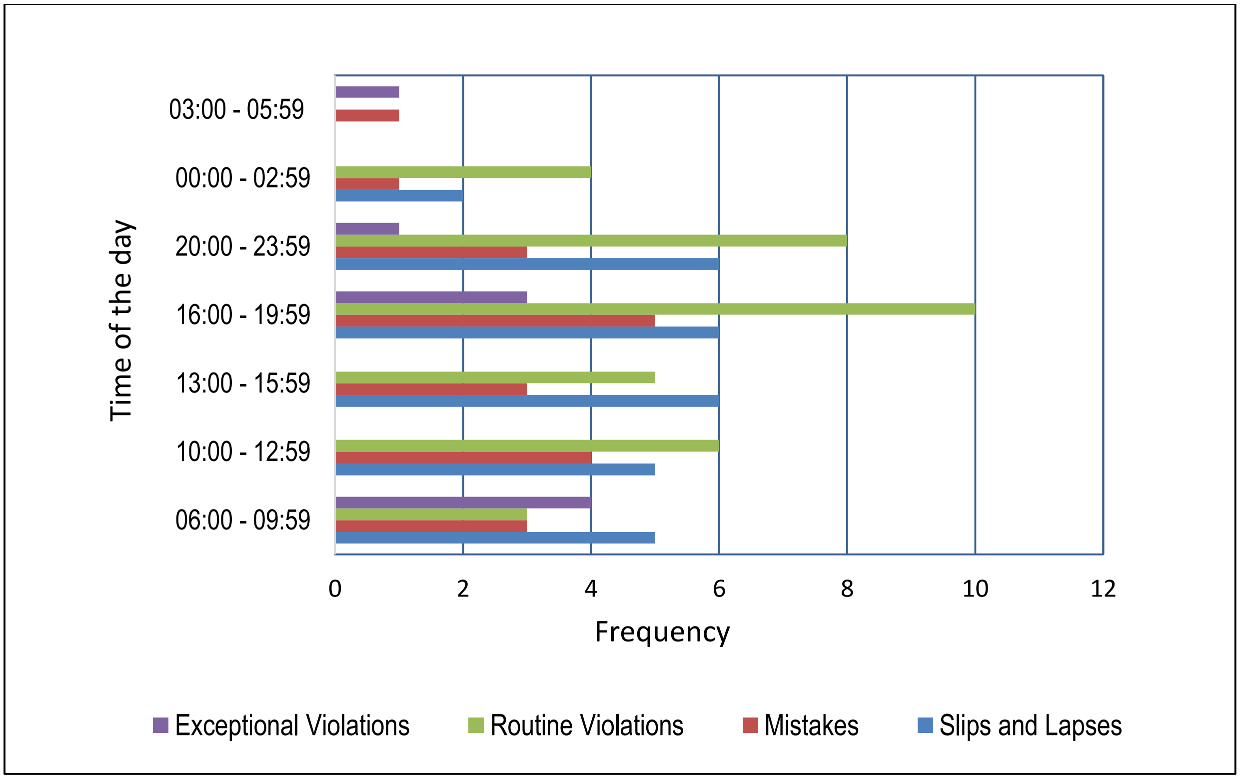

Figure 29: Unsafe acts distribution by time of day (year 2013 to 2014).

The sudden increase in the unsafe acts was observed in the late hours of the early day shift (10:00 to 12:59), mid-afternoon shift of afternoon (15:59pm to 16:00pm), and in the late shift of afternoon (20:00pm to 23:00pm). This is partially due to the fact that most of the works are done in the morning and there is a probability of extension of these jobs to the afternoon shift. Probably there are issues of overtimes in the morning shifts as evidence from the increase in unsafe acts between late hours of morning shift and early afternoon shifts. The results show that in the early hours of the morning shift (06:00am – 09:59am), *slips and lapses* was the most common unsafe act, followed by exceptional violation, then *mistakes* and finally *routine violation*. The emphasis on the less frequency of *routine violation* in the early morning shift can be attributed to improved supervision in this period. In the early hours of the morning shifts, workers are believed to be following standards and procedures due to availability of supervisors when executing tasks. In the middle of the morning shift (10:00am - 12:59am), the most common unsafe acts were *routine violation*, and *slip and lapses*. This is probably due to the amount of work pressure that increases with time. During this period, supervisors usually are also not present when workers are executing their tasks.

In the late hours of the morning shift (after 13:00pm), the most common unsafe acts were *slips and lapses*, *routine violation* and then *mistakes*. As previously explained, *slips and lapses* were caused by failure of thoughtfulness or memory. Employees were more susceptible to this type of errors because they get exhausted as time progresses when executing their tasks. *Routine violations* were caused by an individual's wrong thoughtful decisions which were not right whereas *mistakes* were caused by error in judgement. Poor supervision is the major contributing factor leading to unsafe acts involving violations and mistakes. This is due to the fact that inspections and planned task observations (PTO) which are supposed to be done by supervisors and leaders, are normally done at the start of the shift. Hence, an increase in unsafe acts involving mistakes and violations during the middle of the shift. Failure to perform mid-shift barring down was cited as the most common example of mistakes identified in this study. This is the reason for high level of violations recorded from 10:00am to 15:50pm (i.e. middle of the shift).

During the middle of the afternoon (16:00pm – 19:59pm), the most common unsafe act was *routine violation*. Also in the early shift of the night (after 23:59pm), the most common unsafe act was routine violation. This assertion can be attributed to the fact that there is lack of supervision during this period (middle of the afternoon and early of the night shifts) when workers are performing their tasks. However, low frequency of unsafe acts were observed during the period from 00:00am to 05:59am. This is because in the night shift, there are scarce operations (service works do not usually happen).

The results under this section were compared to the study of Bonsu (2013) and the parallel study of Mwansa (2021) from the other mine site of the same company with this study. Similar results were obtained in the study of Bonsu (2013) for the early of the morning shift (06:00am – 08:59am), in which the unsafe acts were less and dominated by *slips and lapses, routine violation* and *mistakes*. The results from Bonsu (2013) also revealed that during the middle of the morning shift (09:00am – 12:00am), mistakes were identified as the most common unsafe acts, then routine violation and slips and lapses. The most frequent unsafe acts were recorded during the mid-day shift that is from 09:00am to 12:pm. Failure to conduct mid-shift barring down was the common example of routine violation identified in the study of Bonsu (2013). The assertion by Bonsu (2013) regarding this was that there is lack of inspections and planned task observation in this period by supervisors. However, inspections and PTO's are done at the start and end of shifts. The study of Bonsu (2013) for the night shift (00:00am – 02:59am) identified *routine violation* and *mistakes* as the most common unsafe acts. Despite having some accidents in the night shift, Bonsu's (2013) study for the night shift identified lower frequency in unsafe acts. However, the study of Bonsu (2013) did not record any accident from the

15:00pm to 17:59pm. This is because the mine site Bonsu (2013) used as a case study had only two shitfs (Day and Night shifts) and considered this period as a change over period. Therefore, no activity was taking place during this period.

Different results were obtained in the study of Mwansa (2021) for the early of the morning shift (06:00am – 08:59am), in which the most common unsafe acts were *routine violations*, *slips and lapses*, and *mistakes*. In this same period, the study of Mwansa (2021) identified *exceptional violation* to have less frequency. This seems to suggests that there is supervision problems in the early hours of the morning shift for this other site. Similar results were obtained for the middle of the night shift (00:00am – 02:59am), in which the most common unsafe acts were *routine violations, slips and lapses* and *mistakes*. Although on a large scale, both studies identified the night shift (00:00am – 05:59am) to have lower frequency in terms of unsafe acts. This seems to suggest that there are few operations around this period for both sites. Similar results were also obtained in the study of Mwansa (2021) for the early hours of the afternoon shift (15:00pm – 17:59pm), in which the most common unsafe acts were *slips and lapses*, and *routine violations*. The results presented in the early hours of morning shift (09:00am – 11:59am) in the study of Mwansa (2021), identifed the *routine violations*, *mistakes* and *slips and lapses* as the most common unsafe acts. Both studies identified *exceptional violations* to have low frequency for the middle of afternoon shift (18:00pm – 20:59pm). This shows that human error was highly involved in most accidents that occured at this copper mining company as evidenced by outcome of the results presented in both studies.

4.4 Workplace Factors

The workplace factors consist of *behavioural* and *physical environments*, *competent people*, fit for purpose equipment and unsafe work practices. This section distributes workplace factors according to unsafe acts as shown in Figure 31.

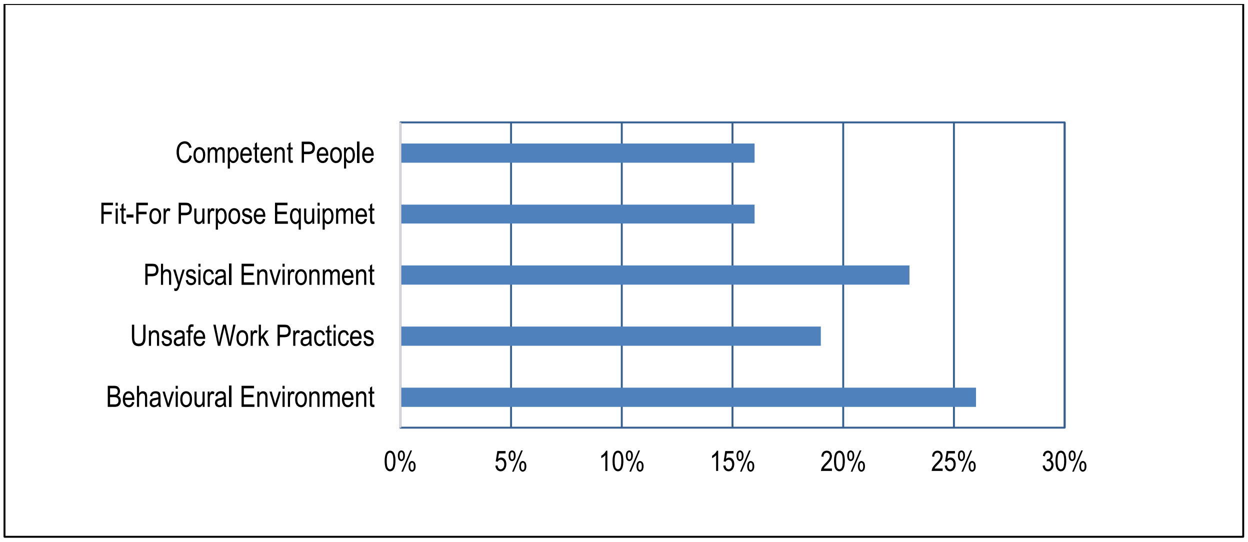

Figure 30: Overall distribution of workplace factors (year 2013 to 2014)

Considering the summarized results in Table 3 and Figure 31, the workplace factor identified in this study as a major contributor to accidents was *behavioural environment* at 26%, followed by *physical environment* at 23%, then unsafe work practices at 19% and the least were f*it-for purpose equipment* and *competent people* at 16% each. The situations identified in the study involving *behavioural environment* comprise, failure to coordinate activities of workers, non-existence of supervisors, inspiration to disobey rules or procedures and failure to rectify violations of rules. Typical examples of *physical enviroment* include working in a confined space, poor lighting, unstable geological environments and existence of tripping hazards (unlevelled grounds, wiring, obstacles, and slippery floors).

Cases of *unsafe work practices* recognized in this study include situations where a worker was pressurized to work, and lack of supervision among workforce. Conditions of *competent people* recognized comprised of circumstances where the training that was established did not satisfactorily prepare employees for the jobs they execute, workers yet to undertake on the job training, and non-appearance of training for a specific assignment. The study recognized occasions of *fit-for-purpse equipment* which include the non-existence of mandatory tools, tools having inadequate components and faulty machine.

The results for the overall distribution of workplace factors under this section were compared to the studies of Bonsu (2013) from the platinum mine in South Africa and Mwansa (2021) from the other mine site of the same company as this study.

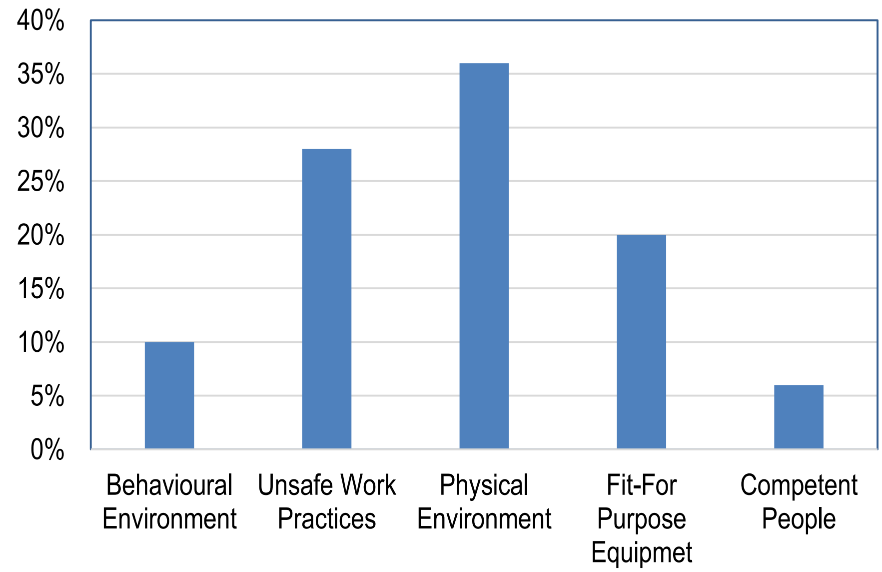

Figure 31: Distribution of workplace factors (Mwansa, 2021)

Different results were found by both studies of Bonsu (2013) and Mwansa (2021). The study of Bonsu (2013) identified *physical environment (31%)* and *behavioural environment (28%)* as the most common workplace factors while *competent people* (16%), *fit-for-purpose equipment (13%)* and *unsafe workplace practices (12%)* were in the minority. The overall distribution of workplace factors in the study of Mwansa (2021) is shown in Figure 32. The most common workplace factors identified were *physical environment* (36%), followed by *unsafe workplace practices* (28%) and finally *fit-for-purpose equipment* (20%). The less common workplace factors recognized in the study of Mwansa (2021) were *behavioral environment* (10%) and *competent people* (6%).

4.4.1 Unsafe acts due to workplace factors

The purpose of showing workplace factors according to unsafe acts was to link specific unsafe acts to workplace factors. This section was presented because of the motivation by Reason's (1990) elucidation of unsafe act as being a symptom rather than the actual problem to be dealt with. As stated by Bonsu (2013), investigating this will help managerial positions to understand specific workplace factors that can lead to unsafe acts.

4.4.2 Routine and exceptional violations as a result of workplace factors

Workplace factors identified with violations are much more diverse as shown in Figure 33. Whereas *physical environment* and *fit for purpose equipment* were the two leading workplace factors identified with violations, *competent people*, *behavioural environment* and *unsafe work practices were* also significant. Competence of an individual contributes to the violation of rules and standards during normal working hours. The performance of the equipment/machine exacerbates the operator to violate rules and standards.

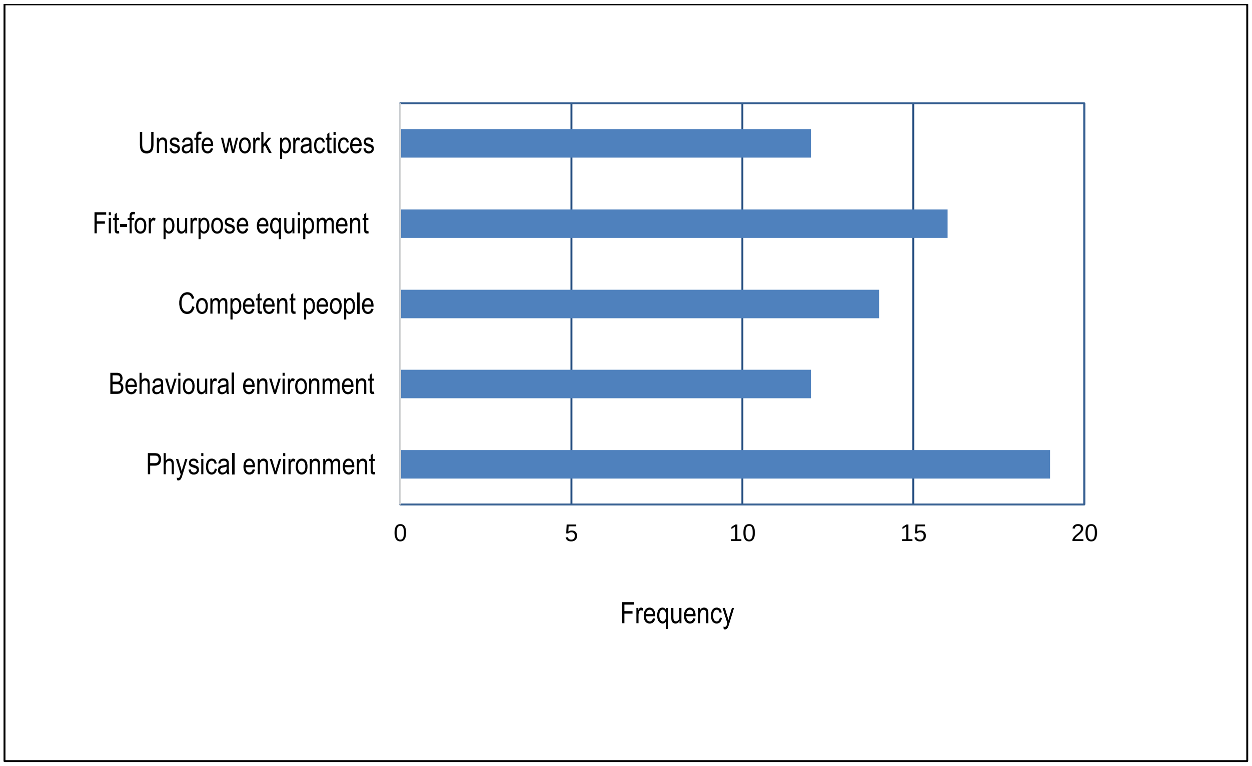

Figure 32: Distribution of Workplace factors leading to violations (year 2013 to 2014)

The result of this study under this section were compared to the studies of Kansumba (1995) from Zambia, Laurence (2004) from Australia, Paul and Maiti (2008) from Australia, Lenne et al (2011) from Australian mines, Bonsu (2013) from platinum mine in South Africa and the parallel study of Mwansa (2019) from the other mine site.

The results obtained in the study conducted by Kansumba (1995) shows that work stresses and some known factors were identified to influence the level of compliance to workers in the Zambian mining industry.

Nevertheless, the author could not authenticate such assertions because reports used for this study were not intended to accommodate those factors reported by Kansumba (1995).

Laurence (2004) conducted a study from the Australian mines and concluded that writing more regulations and procedures were not the medicine to solve problems of compliance at the workplace. Paul and Maiti (2008) conducted a study on work injuries from the mines in Australia for the role of socio technical and characteristics of the person and concluded that there is need for existence of social support (from co-workers and leadership) and endless possibility of workers to have an opposing attitude (this is behavioural environment). The study evidently demonstrated the need to build the workplace to be free from violations.

The study by Lenne et al (2011) also revealed that violations were reported to have been highly associated with team resource management (i.e., absence of collaboration, supervision failures as well as how the social environment behaviour affects the employee to accomplish the assigned task. This is analogous to this study in which *physical environment, fit-for-purpose equipment* and *competent people* were significant to workplace factors leading to violations. Similar results were obtained by Bonsu's (2013) study, in which the most common workplace factors linked to violation were *behavioral environment* and *fit-for-purpose equipment*, whereas *competent people, unsafe work practices* and *physical environment* had less frequency as contributing to violations.

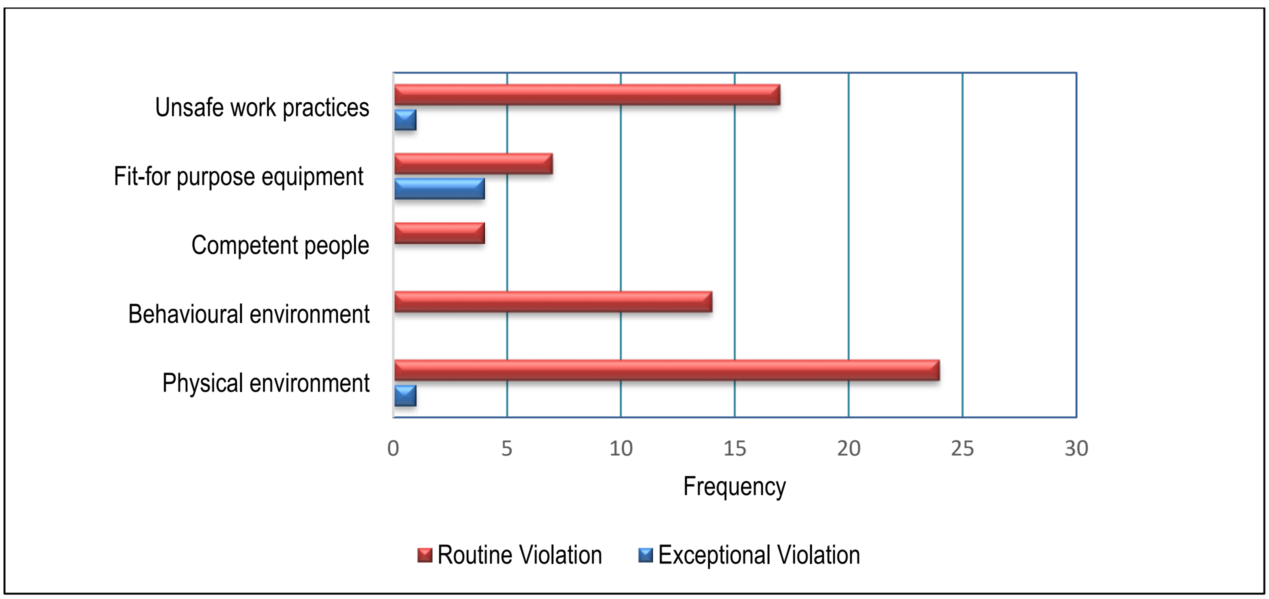

Figure 33: Distribution of workplace factors leading to violations (Mwansa, 2021)

The results obtained by Mwansa (2021) were presented in a different format compared to this study. The study of Mwansa (2021) analysed *exceptional* and *routine violations* separately (see Figure 34) whereas this study combined the two violations. Despite the difference in the analysis, the study of Mwansa (2021) identified *physical environment, unsafe work practices* and *behavioural environment* as the most common workplace factors leading to *routine violations* whereas the most common workplace factors leading to *exceptional violations* were *fit-for-purpose equipment*.

4.4.3 Mistakes as a result of workplace factors

The results of workplace factors leading to mistakes recognized in this study are shown in Figure 35. The more significant workplace factors leading to mistakes recognized are *behavioural environment* and *unsafe work practices*. Whereas the workplace factors of *competent people* and *physical environment* are also significant.

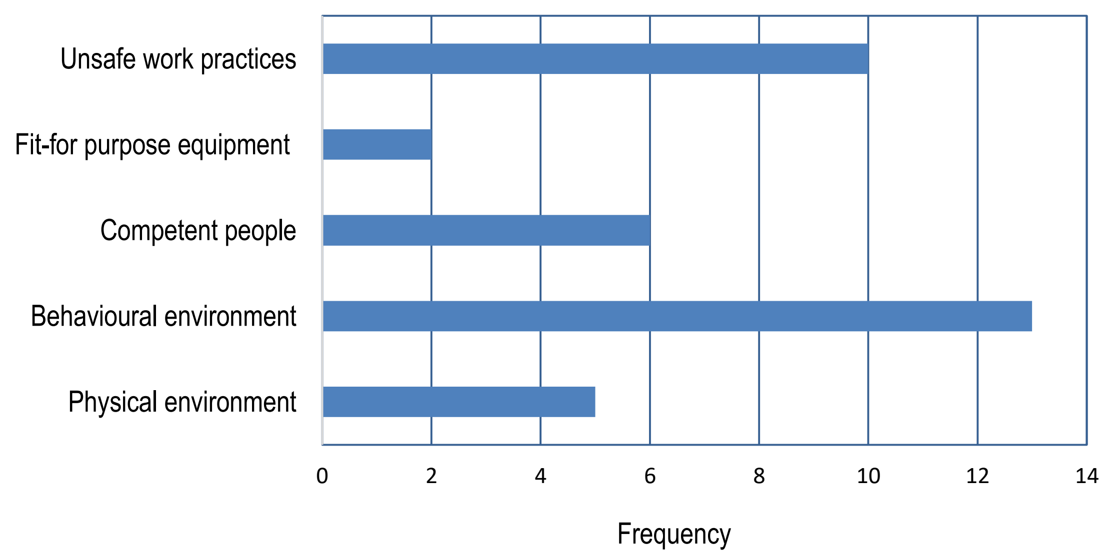

Figure 34: Distribution of workplace factors leading to mistakes (year 2013 to 2014).

Majority of the cases of *behavioural environment* recognized in this study which lead to mistakes include absence of risk assessments, poor communication and performing a task without a procedure. These situations clearly made employees more susceptible to commit *mistakes*. Majority of cases of *unsafe work practices* identified to be associated with mistakes included non-avaiability of procedures and standards for particular tasks, also instances of work standards where they were not completely covered during assigment execution. These instances made employees more susceptible to make mistakes. The absence of standards and procedures (*categorized as unsafe work practices)* were identified in cases were the training procedures provided to workers were insufficient to deliver the needed competency (*categorized as competent people*).

Most instances of *competent people* recognized with mistakes comprised of absence of necessary experience, insufficient skillfulness and not undertaking planned task observations when performing a task. These conditions clearly made mine workers more susceptible to commit mistakes.

The cases of *physical environment* recognized with mistakes comprised of confined spaces, poor illumination, poor housekeeping, working in unsupported area and poor ground conditions. The cases of *fit-for-purpose equipment* comprises situations involving availability of tools with capacity below that of task to be performed (e.g. pinch bar without rubber gauge, machine not functioning correctly, non availability of needed euiqment to perform a task and defective set of machines).

The results are compared to the earlier works of Lenne et al (2011), Bonsu (2013) and parallel study of Mwansa (2021). The study of Lenne et al (2011) recognized judgement errors (recognized as mistakes for this study) to have a link with technological environment (machinery and procedures) and adverse mental state (competence of operator).

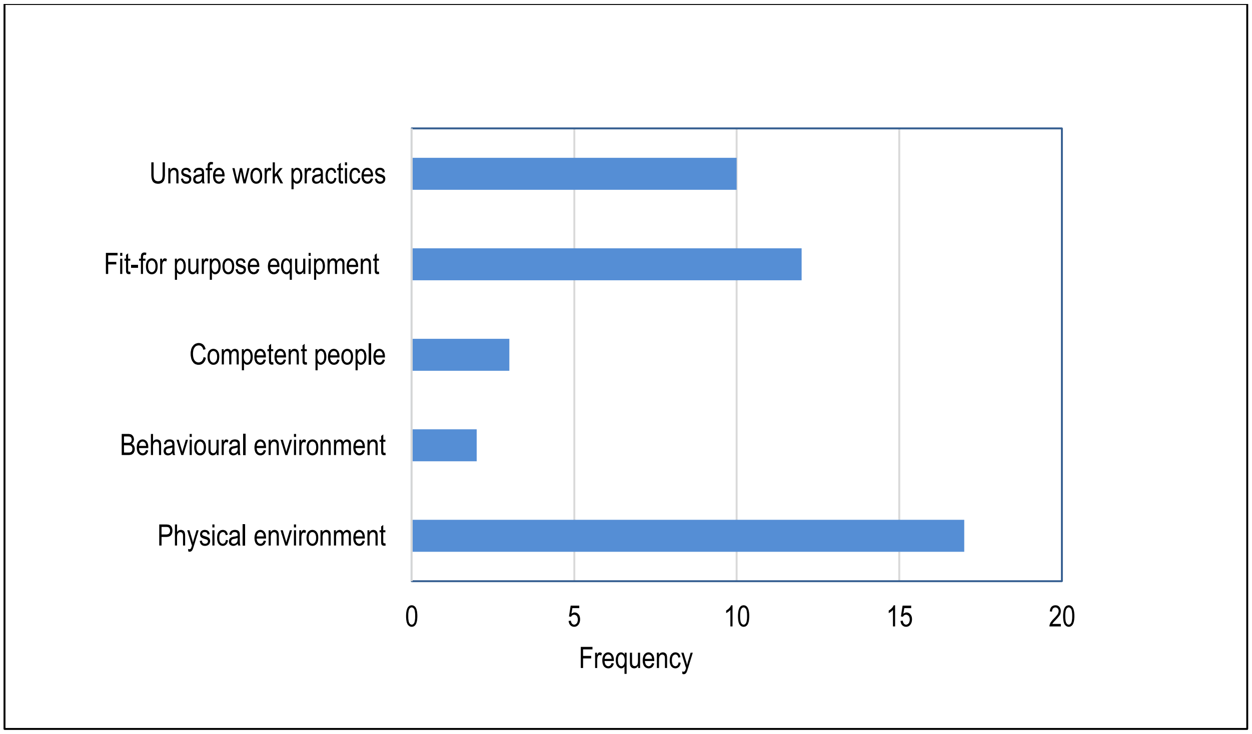

Figure 35: Distribution of workplace factors leading to mistakes (Mwansa, 2021)

Figure 36 shows the distribution of workplace factors leading to mistakes for the study of Mwansa (2021). The results presented showed that the most common workplace factors identified were *physical environment*, *fit-for-purpose equipment* and *unsafe work practices.* The workplace factors identified with lesser frequency of accidents were *behavioural environment* and *competent people*. The unsafe work practices was another common workplace factor identified in the study of Mwansa (2021).

4.4.4 Slips and Lapses as a result of workplace factors

From Figure 37, *behavioural* and *physical environments* were the greatest shared workplace factors recognized in this section when slips and lapses are linked to workplace factors. Certain workplace condition as described in the previous section can make the worker more susceptible to slips and lapses. Poor working environment (*physical environment*) can adversely affect the worker to change the work culture and this is regarded as *behavioural environment*. The least common workplace factors identified as leading to *slips and lapses* were *unsafe work practices*, *fit-for-purpose equipment* and *competent people* (see Figure 37).

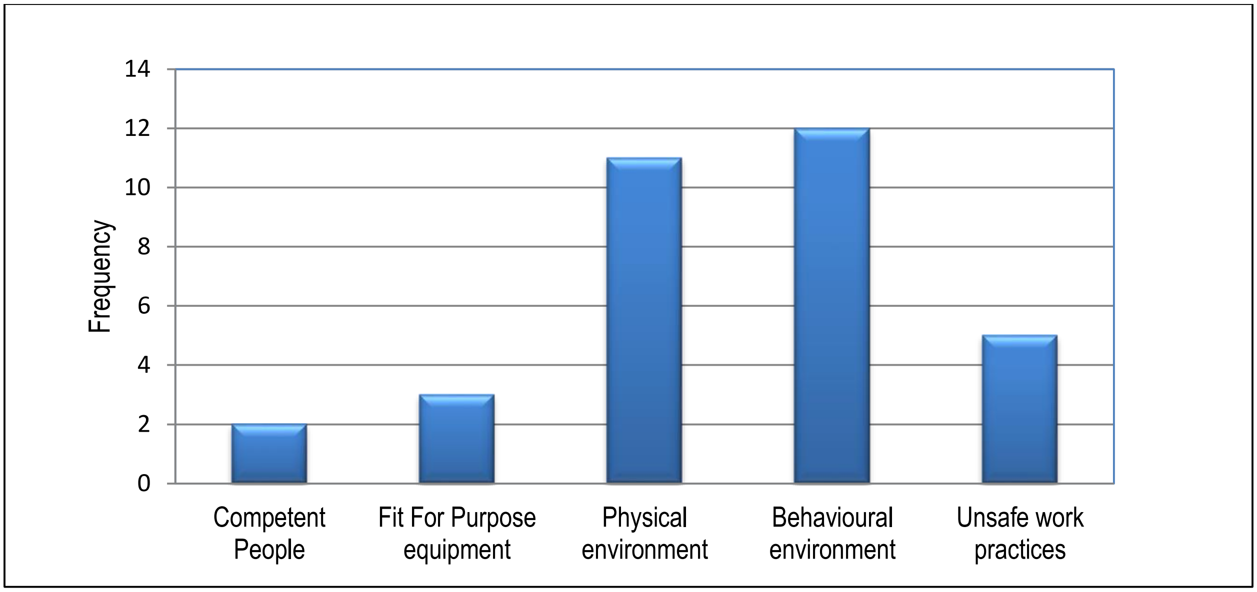

Figure 36: Distribution of workplace factors leading to slips and lapses (year 2013 to 2014)

The results of workplace factors leading to *slips and lapses* were compared to the earlier studies of Lenne et al (2011) from the Australian mines and the parallel study of Mwansa (2021) from the other site of the same company with this study.

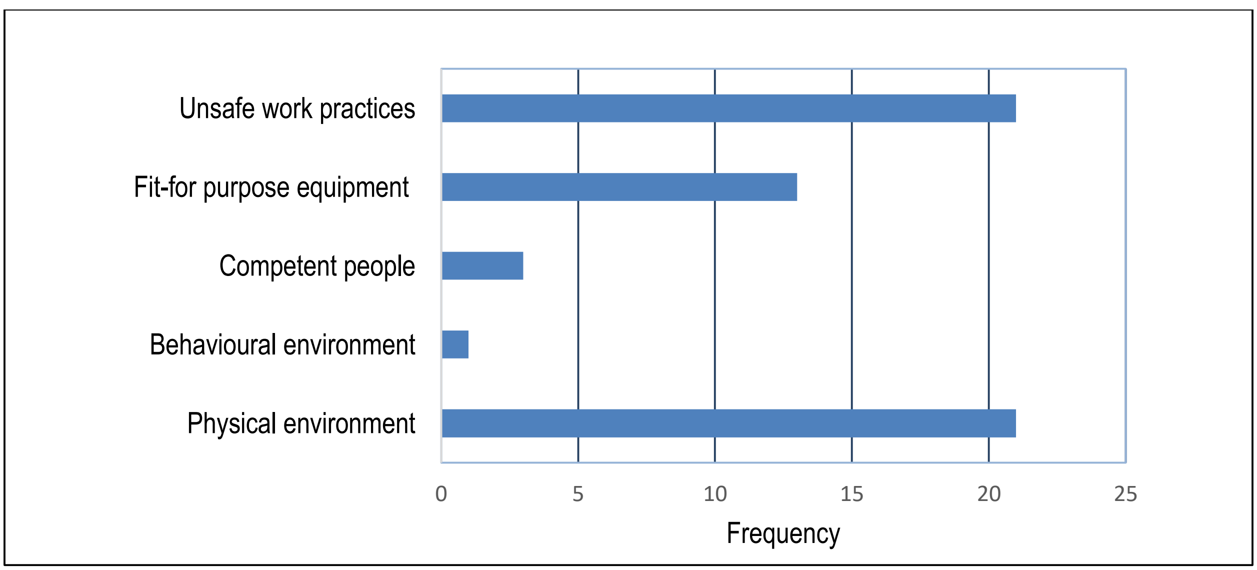

Figure 37: Distribution of workplace factors leading to slips and lapses (Mwansa, 2021).

Figure 38 reveals the results that were obtained by Mwansa's (2021) study under the section of workplace factors linked to slips and lapses. The most prominent workplace factors leading to unsafe acts were *physical environment* and *unsafe work practices*. Mwansa's (2021) study under this section on workplace factors linked to *slips and lapses* coincides with the results analysed in this study where *physical environment* had the most frequent causes of *slips and lapses*. However, Lenne et al (2011) from the Australian mine obtained different results, in which adverse mental state (synchronised to mental related problem) was identified to have been linked with skilled based errors (synchronized to slips and lapses). Therefore, lack of knowledge due to mental problem was considered to have an effect on the employee to cause slips and lapses. However, the accident reports used from the mine site of this study were not structured to capture such details. The accident reports had no such detailed information to show that the mental state of the employee led to a slip and lapse. Instances involving modification in equipment and equipment without handles are examples of occassions with fit-for-purpose equipment that contributed to slips and lapses. Therefore, with the results obtained in this section, to reduce cases involved with *slips and lapses* the company should put more effort to improve the physical environment of the working areas and behavior of workers.

4.5 General Distribution of Systemic Factors

This section proceeds to look at the general distribution of systemic factors (summarized in Table 3) recognized in this study. The general distribution of systemic factors presented in this section describes systemic factors to have been the root cause of the majority of accidents considered in this study. The results of overall distribution of systemic factors analysed are shown in Figure 39.

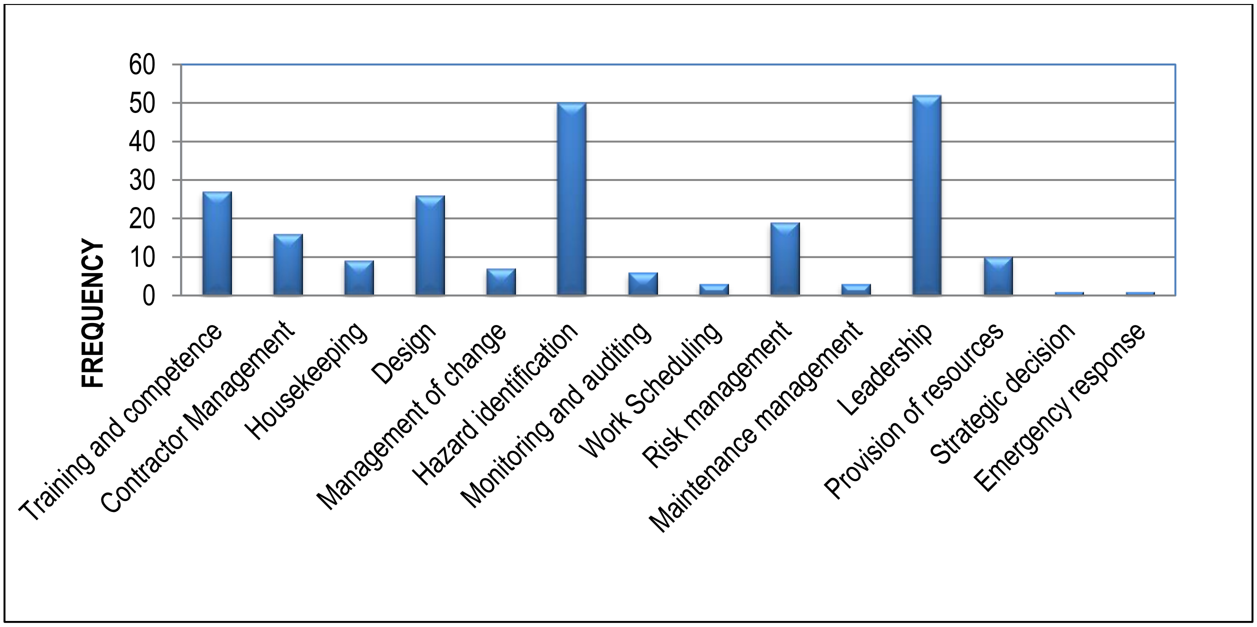

Figure 38: General distribution of systemic factors (year 2013 to 2014)

Fgure 39 shows that *leadership* and *hazard identification* were the most common dominant systemic factors recognized at this mining site under study as contributing to accidents. Failing to train employees, failing to rectify deviant behaviour, failing to conduct job safety analysis (JSA) and failing to solve well-known problems are examples of poor *leadership*.

The study recognizes *Leadership* as the most prominent systemic factor contributing to accidents. This is because most accidents analysed occur in the absence of leaders as explained in the previous sections. *Hazard identification* was also a significant contributor to accidents under systemic factors. This involves occurrence of an accident even though the worker followed the company laid down procedures and standards. This was due to insufficiency in identification processes of hazards during establishment of standards and procedures.

Design, training and competence, risk management, contractor management, and provision of resources were the additional systemic factors that were also recognized as contributors to most accidents. Precise illustrations of *design* comprised of occurrences where the underground excavation was poorly designed and inappropriate equipment design. Instances of *competence and training* were conditions involving the provided training could not cover particular jobs. Instance of *risk management* involved cases of not tackling the well-known risk such as recorded unsafe work practice, recorded faulty machinery, and machinery scarcity; failure to certify the safety of employees before initiation of any works. Typical examples of c*ontractor management* was recognized in situations where incompetent contractor workers were assigned do works without supervisors. *Resource provision* was quoted in situations in which the company fails to provide necessary resources to the workers in order to perform assigned tasks.

The author of this study is aware that effective supervision might have remained the explanation for systemic factors recognized in this study such *as hazard identification, risk management*, *contractor management*, *resource provision*, some traits of *training* and even *housekeeping.* The results under this section were compared to the study of Bonsu (2013) from the platinum mine in South Africa. Similar results were obtained in his study where the most prominent systemic factors identified were *leadership* and *hazard identification* whereas the other systemic factors that where recognized were in the minority.

4.5.1 Links between systemic and workplace factors

Typically, this was done to understand how systemic factors can be linked to workplace factors. This can strategically be used to assist in correcting workplace factors and this is in accordance with Reason's (1997) explanation of the Swiss Cheese Model which explains that to some extent the workplace conditions usually originated from organizational conditions.

4.5.2 Systemic factors linked to physical environment

Figure 40 shows the distribution of systemic factors linked to *physical environment* problems. The results were categorized into three groups, which are, the most common, second most common and least common identified systemic factors.

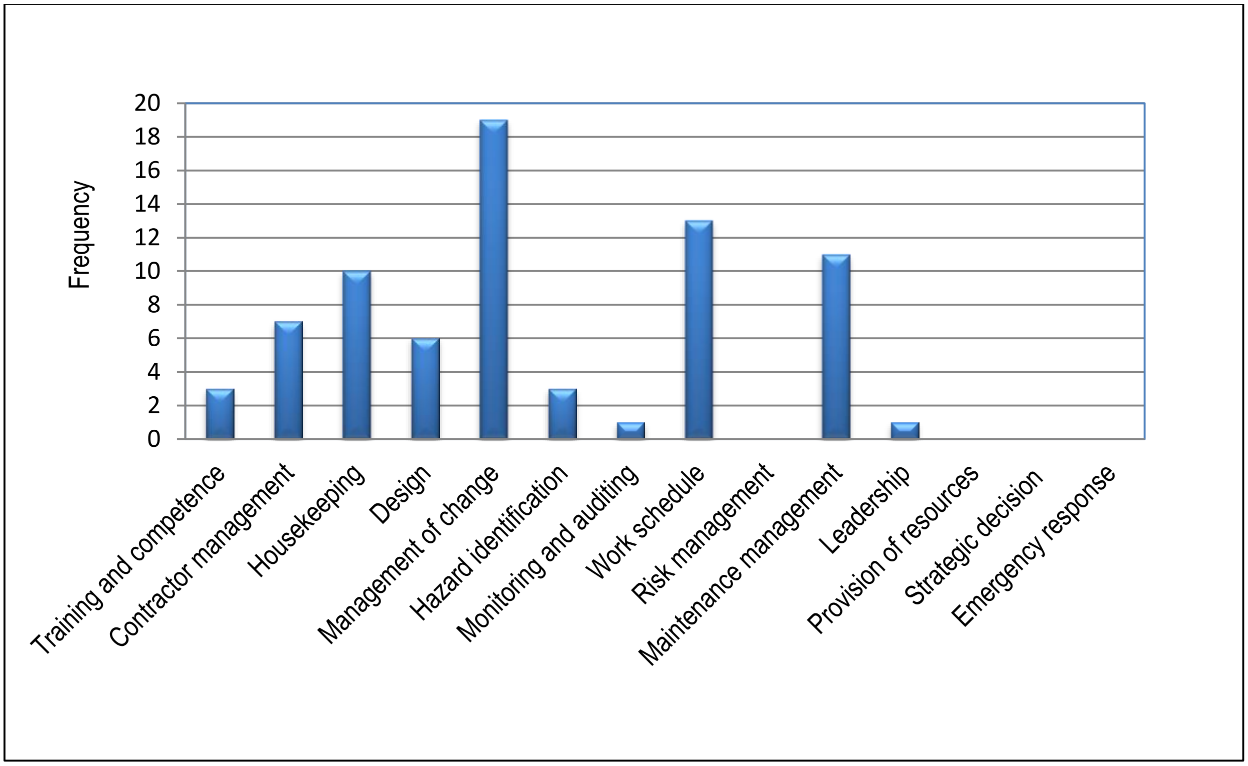

Figure 39: Systemic factors linked to physical environment (year 2013 to 2014)

The most common systemic factors leading to *physical environment* were *management of change, work schedule* and *maintenance management.* The second most common systemic factors leading to *physical environment* problems were *housekeeping, contractor management* and *design*, while the least common systemic factors leading to *physical environment* problems were *training and competence*, *hazard identification*, *monitoring and auditing*, and *leadership*.

Circumstances to do with *design* and *hazard identification* materialize during the process of building the workstation, while circumstances which have to do with *risk management*, *poor housekeeping*, *maintenance management, work schedule* and *management of change* happen in the normal mining operations. Some systemic factors linked to *physical environment* such as *hazard identification* and *design* are due to human error in nature. Failure to identify existing hazards at the workplace is due to poor leadership at the workplace. Poor designs of underground or working structure can also create hazards, which happen due to poor leadership. Systemic factors linked to *physical environment* such as *housekeeping*, *maintenance management* and *contractor management* can usually cause an adverse effect on the employee to perform assigned tasks. The *physical environment* when linked to systemic factors in this portion of the analysis shows that it has an impact on the ability of a worker to achieve desired results effectively and efficiently. This situation represents Reason's (1990) elucidation on the changing nature of holes in different structure of a system that can lead to accidents. The most prominent systemic factors linked to *physical environment* identified in this study such as *management of change*, *work schedule* and *maintenance management* are also considered as holes which lie latent in an organization while systemic factors linked to *physical environment* factors such as *housekeeping*, *contractor management, design, hazard identification* and *monitoring and auditing* are typically considered to be production-oriented activities. This explanation is like Reason's (1997) study in which safety of an organization is dependent on what it does and not what it has. *Supervision* problems were indirectly recognized in the *physical environment*. This was recognized in situations such as failing to rectify problems which are known and failing to impose inspections at workplace.

4.5.3 Systemic factors linked to behavioural environment

This section explains the systemic factors that are prominent when linked to *behavioural environment.* Figure 41 shows the analysed results under this section in which the most prominent systemic factors recognized when linked to behavioural environment were *leadership* and *hazard identification.* Poor *leadership* was identified at various ranks, starting from mine manager, underground manager, mine captain, technical heads, and shift boss to personal in charge (PIC). Hence, the analysis seems to suggest a problem of safety culture within the organization. The author acknowledges the fact that supervisor's failure to rectify violations at the workplace was the main reason for most cases involving *behavioural environment* at the organization.

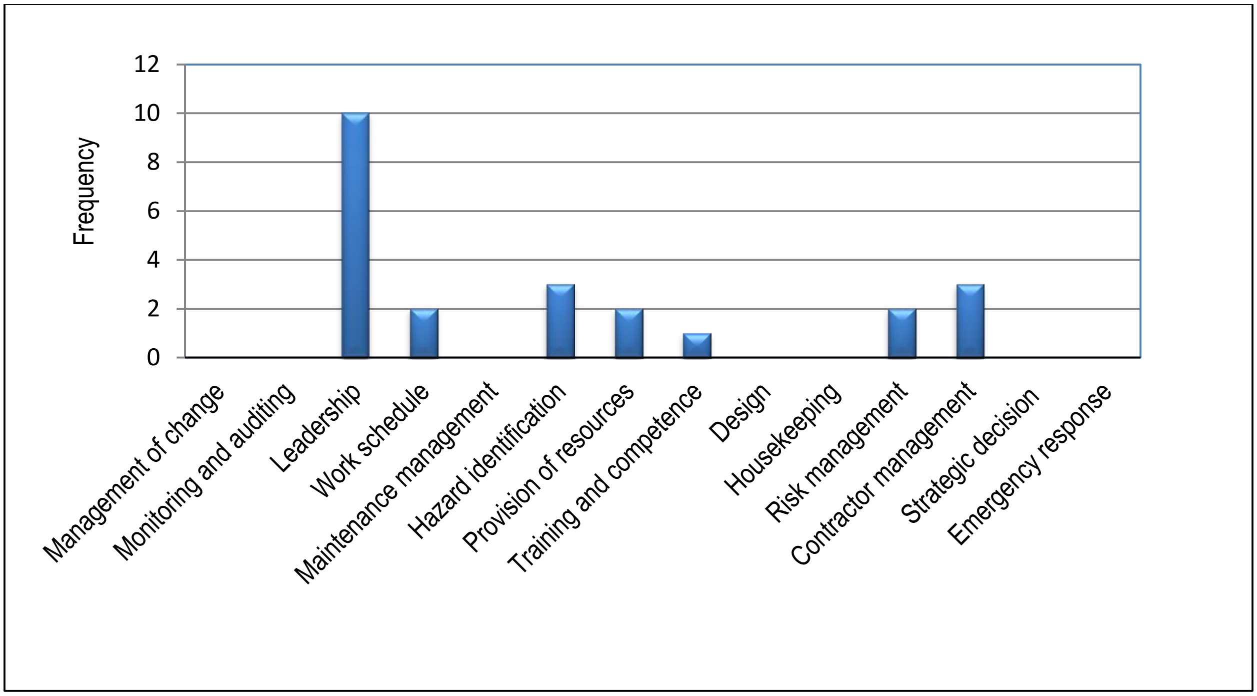

Figure 40: Systemic factors linked to behavioural environment problems (year 2013 to 2014)

The other systemic factors responsible for instances of behavioural environment were *risk management, contractor management, provision of resources, training and competence, risk management and work schedule.* These systemic factors were happening due to poor leadership at the workplace. Example for this study is a situation where a worker is allowed to perform a task using a wrong tool by the team leader. Performing a task using a wrong tool can cause a worker to make mistakes which can lead to an accident. Another example cited in this study is when incompetent workers were assigned to perform tasks by the team leader because the qualified workers resigned from the system. This *poor leadership* situation manifested from poor management of change which was happening within the organization. Specific instance of *contractor management* leading to *poor leadership* was cited in situations where contractor employees were working without supervisors. *Maintenance management, monitoring and auditing, management of change, design, housekeeping, strategic decision, and emergency response* were not identified as factors leading to instances of *behavioural environment*.

Similar results were obtained in the study of Bonsu (2013) and Mwansa (2021). The study of Bonsu (2013) identified *leadership* as the most common systemic factor responsible for the instances of *behavioural environment*. The other systemic factors identified in the minority were *contractor management*, *work* *scheduling*, *monitoring, and auditing* and *management of change* as being responsible for instances of behavioural environment.

The results of systemic factors responsible for instances of behavioural environment in Mwansa's (2021) study is shown in Figure 42.

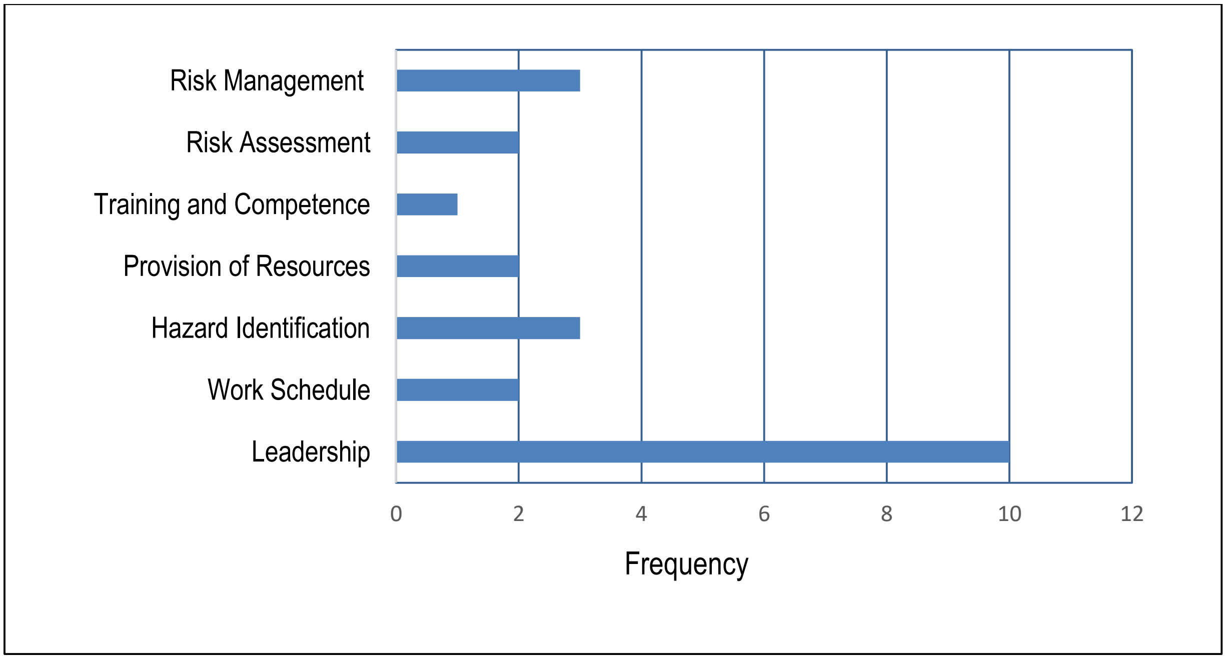

Figure 41: Systemic factors linked to behavioural environment problems (Mwansa, 2019)

Similar results were also obtained in this study in which *leadership* was recognized as the most common systemic factor responsible for instances of behavioural environment. However, other systemic factors in the minority identified in Mwansa's (2021) study were *contractor management*, *hazard identification, risk management, work scheduling*, and *training and competence*. This seems to suggest that there are some common safety issues at the two sites of the copper mining company used as case study in this work and that of Mwansa (2021).

4.5.4 Systemic factors linked to competent people

This section explains systemic factors recognized as being linked to *competent people* problems. The results (see Figure 43) show that *leadership, hazard identification, design* and *training and competence* were the most common systemic factors identified with incidents of *competent people.* A typical example of systemic factor such as *leadership* leading to *competent people* problems included situations where the team leader uses incompetent people to perform tasks without suitable training. These situations, in the view of the author of this study, made workers incompetent to perform the assigned task.

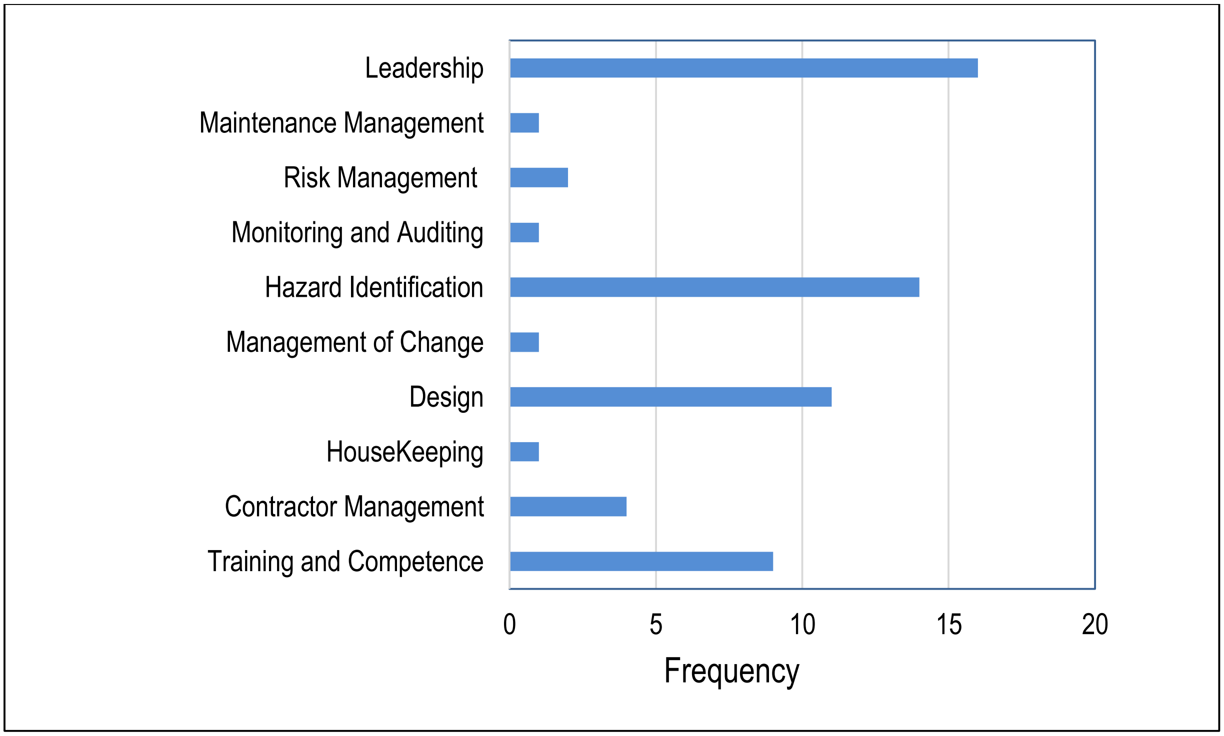

Figure 42: Systemic factors linked to competent people (year 2013 to 2014).

Leadership failure to supervise the non-experienced workers was identified as problem with *competent people* and this was generally recognized as responsible for accidents involved with non-experienced workers.

Another common systemic factor identified when linked to competent people was *contractor management.* The instances of unskilled and inexperienced contractor employees being used to perform tasks were the most typical examples of *contractor management* leading to *competent people*.

Risk management, monitoring and auditing, maintenance management, management of change and *housekeeping* were the least common systemic factors identified as leading to *competent people issues*. Instances of *risk management* leading to *competent people* found in this study was the situation where shift leaders fail to correct risks in the working environment. *Monitoring and auditing* was found in a situation where team leaders were not monitoring the workers during task execution and failure to monitor and audit the working environment. This signifies a poor monitoring system in place at the organization.

Specific example of *maintenance management* was poor maintenance of equipment which was affecting worker's ability to perform assigned tasks. Instances of *management of change* was found in situations such as the team leader failing to manage the shift change over to check and rectify on the hazards. Specific example of *housekeeping* was cited in a situation where the working environment was poor and, in the process, affecting workers' ability to perform assigned tasks effectively.

The results in this section were compared to the earlier study of Bonsu (2013) from the platinum mine in South Africa and the study of Mwansa (2021) from the other mine site of the same company with this study. Similar results were obtained in the study of Bonsu (2013), in which the most prominent systemic factors recognized for instance of competent people were *leadership*, *training and competence* and *contractor management* while *management of change*, *monitoring and auditing* and *hazard identification* were the minority. However, the study of Bonsu (2013) identified *work schedule* as a systemic factor responsible for instance of competent people whereas this study did not recognize this factor as contributing to instance of competent people.

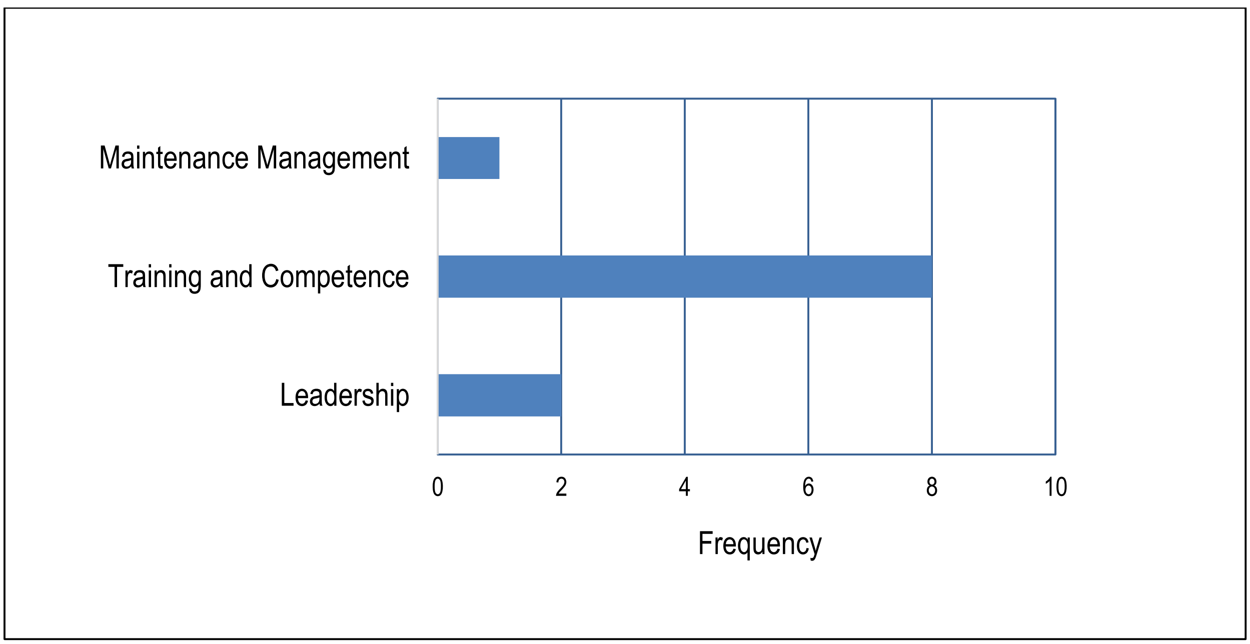

Figure 43: Systemic factors linked to competent people (Mwansa, 2021).

The results of systemic factors linked to competent people for Mwansa's (2021) study are shown in Figure 44. Similar results obtained in the study of Mwansa (2021), which revealed that *training and competence* was the most prominent form of systemic factor responsible for instance of competent people. The other common systemic factors recognized in the study of Mwansa (2021) as leading to instance of competent people were *leadership* and *maintenance management*. However, it was noted that other systemic factors (*Design, contractor management, housekeeping, management of change, hazard identification, monitoring and auditing* and *risk management*) that were recognized in this study were not recognized in the study of Mwansa (2021) as being responsible for instances of competent people.

Similar results in the study of Mwansa (2021) revealed that systemic factors such as *work schedule, provision of resources, strategic decision* and *emergency response* were not identified as response to instance of competent people. As earlier elucidated in the previous section, this seem to suggest that there is a common problem in terms of safety culture in the two sites of the mining company studied.

4.5.5 Systemic factors linked to fit-for-purpose equipment

This part offers explanation of systemic factors which were responsible for instances to do with fit-for-purpose equipment problems identified in this study as shown in Figure 46.

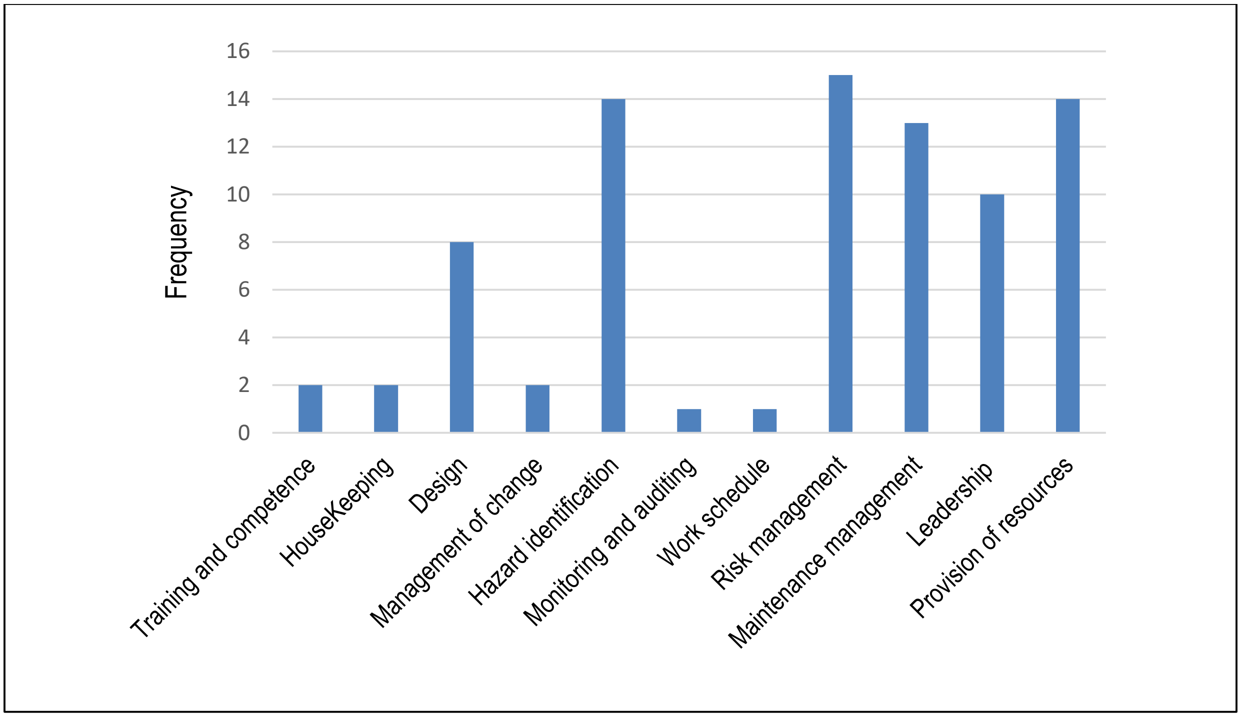

Figure 44: Systemic factors linked to fit-for-purpose equipment (year 2013 to 2014).

The results in Figure 45 show that the most dominant systemic factors when linked to fit-for-purpose equipment were *risk management, provision of resources, hazard identification, maintenance management, leadership, and design.* Poor *risk management* was cited in circumstances involving the alteration of existing machinery, yielding new risks, and thus leading to accidents. This condition of the failure to rectify the reported equipment problem was recognized as a link to hazard identification. Failure by the company to provide necessary tools or equipment for tasks to be performed adequately was the reason for *provision of resources* when linked to fit-for-purpose equipment.

Hazard identification, maintenance management, leadership and *design* were also significant systemic factors leading to problems of *fit-for-purpose equipment.* The most dominant situations cited in this study are where team leaders fail to report shortage of equipment, or supervisors provided employees with incorrect equipment which were below capacity to accomplish specified tasks.

Poor *design* the equipment was also cited in this study to influence the performance of the worker leading to accidents.

The systemic factors involving *training and competence, housekeeping, change management, monitoring and auditing, and work schedule* were insignificant contributors to fit-for purpose equipment. *Training and competence* were cited in this study in situations where incompetent worker uses an equipment to perform a task without appropriate training. Examples of poor housekeeping leading to *fit-for-purpose equipment* accidents were cited in instances where workers were using machinery to perform tasks in an environment with poor arrangement of appliance and other apparatus. An example of *housekeeping* leading to fit-for-purpose equipment were discovered in situations where supervisors failed to clean the work environment and allow workers to perform tasks.

This section of systemic factors linked to *fit-for-purpose* equipment were compared to the earlier study of Bonsu (2013) from the platinum mine in South Africa and the parallel study of Mwansa (2021) from the other mine site of the same company used as case study. The most prominent systemic factors that were identified in Bonsu's (2013) study as responsible for instances of *fit-for-purpose equipment* were *leadership*, *provision of resources* and *maintenance management*. Although this study identified *risk management* and *design* among the most common systemic factors when linked to *fit-for-purpose equipment*. However, the study of Bonsu (2013) recognized these systemic factors to have low frequency of accidents when linked to *fit-for-purpose equipment*. The study of Bonsu (2013) recognized *provision of resources* and *maintenance management* as the most common systemic factors when linked to *fit-for-purpose equipment*. The other systemic factors that were identified in the study of Bonsu (2013) as contributors to *fit-for-purpose equipment* were *risk management*, *design*, *management of change* and *contractor management*. *Contractor management* was not recognized in this study as contributing to *fit-for-purpose equipment* whereas Bonsu's (2013) study recognized it as a contributor to *fit-for-purpose equipment*. This study also recognized the systemic factors involving *training and competence, housekeeping*, *hazard identification*, *monitoring and auditing* and *work schedule* as contributing to *fit-for-purpose equipment*, whereas Bonsu's (2013) study did not recognize these systemic factors as contributing to accidents with instances of *fit-for-purpose equipment*. However, the study of Bonsu (2013) did not recognize the systemic factors involving *strategic decision* and *emergency response* as contributing to accidents when linked to *fit-for-purpose equipment*.

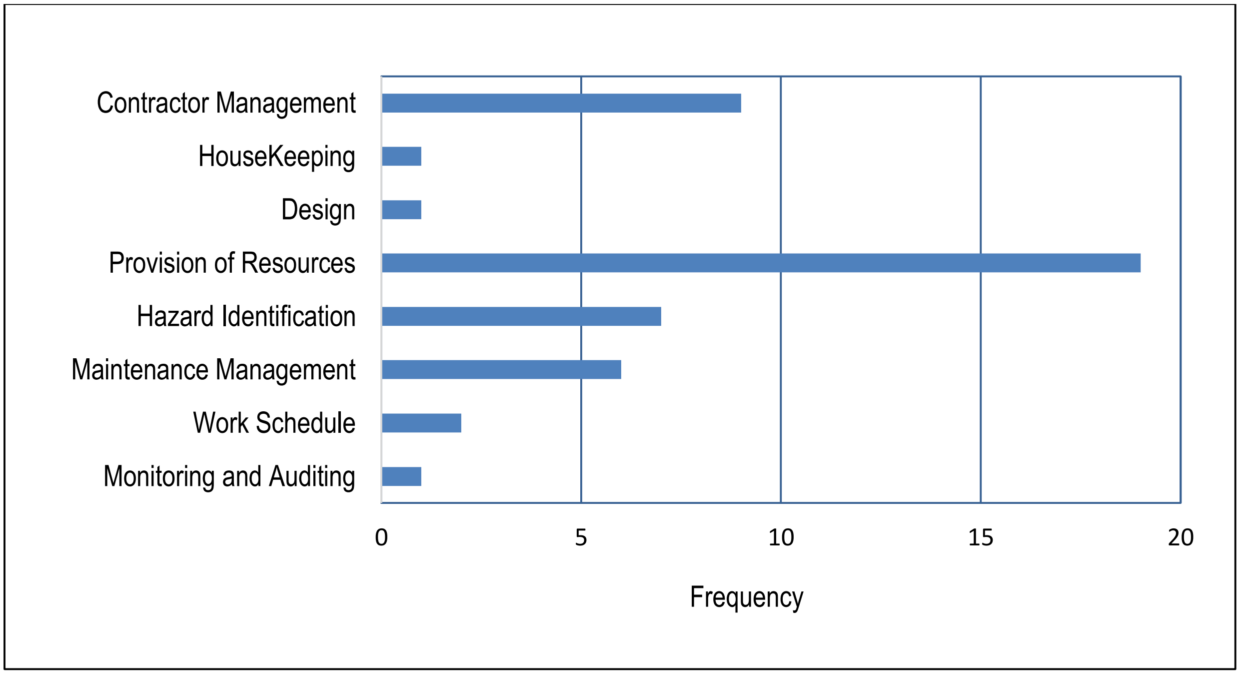

Figure 45: Systemic factors linked to fit-for-purpose equipment (Mwansa, 2021).

Figure 46 shows the results that were obtained by Mwansa (2021) from the other mine site when systemic factors were linked to *fit-for-purpose equipment*. The results obtained by Mwansa's (2021) study showed that the most common systemic factors recognized when linked to *fit-for-purpose equipment* were *provision of resources, contractor management, hazard identification and maintenance management* as contributing to accidents (see Figure 46). Systemic factors involving *work schedule, housekeeping*, *design*, and *monitoring and auditing* were the least contributing to *fit-for-purpose equipment*. Although this study identified *risk management* as the most common systemic factor contributing to *fit-for-purpose equipment*, the systemic factor involving *risk management* was not recognized in Mwansa's (2021) study as leading to instances of *fit-for-purpose equipment*. In both studies, *provision of resources*, *hazard identification* and *maintenance management* were identified as the most systemic factors leading to fit-for-purposes equipment.

The systemic factors such as *management of change*, *leadership*, *training and competence* and *risk management* identified in this study were not recognized in Mwansa's (2021) study as contributing to *fit-for-purpose equipment* problems. Contractor management was identified in Mwansa's (2021) study as systemic factor leading to fit-for-purpose equipment whereas in this study it was not identified as contributing to *fit-for-*

purpose equipment. Similar results revealed that systemic factors involving *strategic decision* and *emergency response* were not identified in both studies as contributing to *fit-for-purpose equipment* problems.

4.5.6 Systemic factors linked to unsafe work practices

This section offers elucidation on systemic factors when linked to unsafe work practices for this study. When systemic factors are linked to unsafe work practices in this study, the prominent factors identified were *leadership*, *training and competence* and *hazard identification* (see Figure 47).

The most common example of *poor leadership* identified in this study as being a contributor to unsafe work practices was a scenario where the team leader gave inexperienced workers a task to perform without supervision. *Training and competence* was identified in situations where untrained and incompetent workers were assigned to perform tasks without even a risk assessment prior to start of the work. Examples of *hazard identification* responsible for unsafe work practices, was in situations where hazards were not considered in the procedures, thereafter, putting employees at risk when accomplishing the assigned tasks. In this situation, the existing standard operating procedure did not protect employees from hazards.

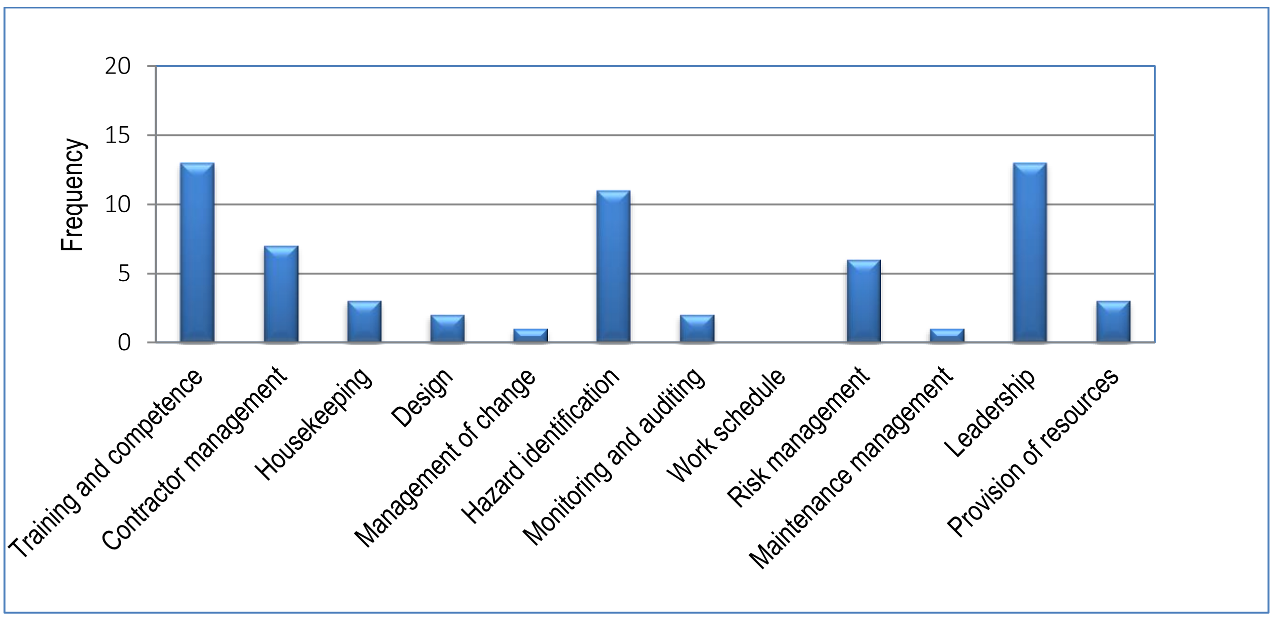

Figure 46: Systemic factors linked to unsafe work practices (year 2013 to 2014)

Contracor management and *risk management* were also identified as significant in terms of contributing to unsafe work practices. The least common systemic factors contributing to unsafe work practices identified in this study were *housekeeping*, *design*, *provision of resources*, *management of change, monitoring and auditing* and *maintenance management*.

The results in this section were compared to the studies of Bonsu (2013) and Mwansa (2021). The results obtained in Bonsu's (2013) study showed that the most common systemic factors identified as leading to unsafe work practices were *hazard identification, monitoring and auditing* and *management of change*. The systemic factors identified as contributing to unsafe work practices such as *leadership*, *training and competence*, *contractor management*, *risk management*, *provision of resources*, *housekeeping*, *design* and *maintenance management* were not recognized in Bonsu's (2013) study.

The result of systemic factors linked to unsafe work practices in Mwansa's (2021) study is shown in Figure 48.

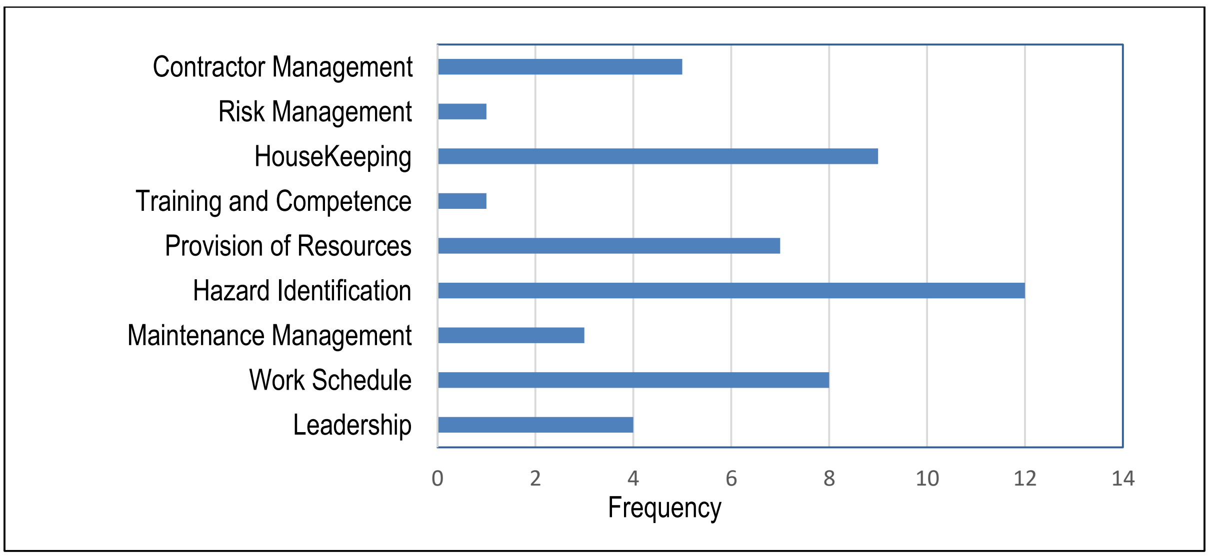

Figure 47: Systemic factors linked to unsafe work practices (Mwansa, 2021).

Mwansa's (2021) study revealed that the most common systemic factors linked to unsafe work practices were *hazard identification, housekeeping, work scheduling, provision of resources, leadership and maintenance management*. Whereas the least common systemic factors identified as contributing to unsafe work practices were *training and competence* and *risk management* (see Figure 48). *Design*, *management of change*, *monitoring and auditing* were identified in this study as contributing to unsafe work practices whereas the study of Mwansa's (2019) did not identify these factors as contributing to unsafe work practices as shown in Figure 48.

The next Chapter discusses the interpretation, clarification and meaning of the results of analysis obtained in this current chapter.

CHAPTER FIVE: GENERAL DISCUSSION

The first section of this chapter is a summary on the findings of the results on *accident characterization*. The second section of this chapter is a summarized result of the accident causation at various level of causality, with consideration of practical implications of the findings of the organizational culture at the copper mine. The chapter concludes with some key argument that were identified from this study and more broadly, as well as highlighting future safety actions that can be accomplished to get a safe working environment.

5.1 Accident Characterization

Accident characterization has laid a foundation to understand the results obtained in this study and possible causes of the accidents. The results presented revealed that the method of operations at the mine studied exposes employees to hazards. Another argument presented is that as the mine goes deeper, workers are more likely to be exposed to hazards (see Figure 16). The driving factor to this is that it becomes difficult to provide critical services such as ventilation to the working environment as the mine gets deeper (as demonstrated in Figure 16, where UG 1 and UG 2 were deep mines). Shaft sinking was another operation where workers were highly exposed to hazards as was observed with significant number of accidents involved. This suggests that shaft sinking operations at this mine were not mechanized. With exception of the concentrator (*surface 1*), most of the surface operations recorded low frequency of accidents. This shows that most jobs are performed using *manual handling* tools (manual in nature). The results in Figure 18 showed that *material handling* as well as drilling works were the most common accident-prone tasks. Hand-held tools such as drill rigs, jackhammers and spanners are common tools that are used to perform such tasks. These tools place workers very close to existing hazards. The results of *accident characterization* according to place of incident were compared to Mwansa's (2021) study from the mine site of the same company with this study. In the study of Mwansa (2021), underground accidents were less than those of surface operations (as demonstrated in Figure 17). This is because there are more surface operations in Mwansa's (2021) study site compared to the site of this study. Also, considering underground operation, this study site has more underground operations compared to Mwansa's (2021) study site. The *accident characterization* according to tasks performed in the study of Mwansa (2021) revealed similar results, in which the most common tasks prone to accidents were *engineering task*, *transportation of material* or *equipment* and *material handling*. However, *drilling task* were identified with few frequencies of accident in Mwansa's (2021) study. This is because the underground operations were few compared to the surface operations in the site of Mwansa's (2021) study. Similar results were obtained by Mwansa (2021) on *accident characterization* according to job title, in which the most common job titles that were involved in accidents were workmen and operators.

In the area of employee type, different results were obtained in Mwansa's (2021) study, in which company employees (52%) were involved in most accidents compared to contractor employee (48%). Whereas this study revealed that contractor employees (69%) were involved in most accidents compared to company employees (31%). This also coincides with the earlier explanation that there are more surface operations compared to underground operations in the site of Mwansa's (2021) study. Most surface operations are executed by company employees whereas most underground operations are executed by contractor employees at the company used as a case study in this work. Similar results are also revealed for this study, in which most accidents were recorded by contractor employees compared to company employees.

The *accident characterization* according to agency were also compared to the study of Mwansa (2021) from the other mine site of the same company. The results obtained in this study revealed that the most common frequent agency were *fall of ground, fall of material*, *handling material, moving machinery* and *slip and falling* and *handling tools* (see Figure 23). Similar results obtained in Mwansa's (2021) study revealed that the most common frequency agencies were *slip and falling*, *material handling* (referred to handling material in this study), *tool/equipment handling* (referred to handling tools in this study) and *ground strata failure* (referred to *fall of ground* in this study).

This study recognized the assessment of exposure to hazards to be echoed by the types of *slip and fall* accidents recorded. Most *slip and fall* accidents analyzed happened when the victim was running from another hazard. This is suggesting that there is inadequate protection from physical hazards. This assertion supports the author's understanding that substantial increase in accidents was because of the closeness between employees and hazards.

The level of human exposure to hazards in *drilling* and *material handling* (e.g. maintenance) tasks are slightly the same throughout most of the industries. Although most of the manufacturing sectors mechanize the operations, by moving employees away from hazards, *material handling* associated problems remains the challenge (Reason, 1997).

The explanation drawn from Reason's (1997) argument is that operations at this copper mine incorporates closeness between tools or equipment, human and hazards which are somehow responsible for human error.

This argument is also supported by the results obtained in the barrier analysis section of this study. The study revealed that *standard and procedure*, *supervision*, *risk assessment, training and induction* and *job safety analysis* were the most frequent barriers that were breached (see Figure 23). Similar results were obtained in Mwansa's (2021) study, in which the most frequent barriers breached were *standard and procedure*, *job safety analysis* and *supervision*. This concludes the fact that safety at the copper mine used as a case study is deeply dependent on either the worker's willingness to obey the rules and regulation, supervisor's ability to enforce rules and regulation, or the worker's ability to identify hazards and dodge.

The results were also compared to the earlier study of Ashworth et al (1994) from the South African mining industry. The results obtained by Ashworth and Peake (1994) suggests that the approach and techniques employed to address falls of ground accidents in developing countries were not adequate or sufficient, and that technological solution can be put in place to help mine workers to determine whether a workplace is safe or not. However, automation or mechanization of the mines cannot be the remedy to solve all the safety problems facing the mining industry in Zambia. The study of Reason (2000) revealed that defense-in-depth (which is a by-product of mechanization) is a mixed blessing and it confirms the fact that a single failure on the part of the worker cannot lead to accidents but offers a means for the building up of individual failures up to the point where the situation gets out of hand. The best approach to manage safety at any organization is to apply the suitable safety management principles and techniques. The report by the ICMM (2013) recommends that in order to prevent accidents from happening at the work-place, the critical management controls must be clearly defined and understood for implementation. Critical control management approach is an effective way of achieving this by focusing on risk-management (ICMM, 2013). The critical control management process must include planning, implementation, performance, evaluation, and remedy.

The summarized results of accident characterization of this section have evidently revealed that the prospective existence of the working system at the mine site used as a case study serves as precursors from induced various human accidents. The appropriate human factors identified in this study are discussed in the next section.

5.2 Accident Causation

The accident causation analysed in this study revealed that *routine violation* (38%) were the most common unsafe acts identified. The second most common unsafe acts identified in this study were *slips and lapses*

(30%), the third were *mistakes* (20%) and the least unsafe acts identified were *exceptional violations* (10%). These results were compared to the earlier study by Bonsu (2013) from the South African platinum mine and the study of Mwansa (2021) from the other mine site of the same company used as case study in this work. Similar results, to those of this work, were obtained in the study of Bonsu (2013), in which the most common unsafe acts identified were *routine violation* (37%), closely followed by *mistakes* (35%), then *slips and lapses* (26%) and finally *exceptional violation* (2%). The results of Mwansa (2021) revealed that the most common unsafe acts identified were *routine violation* (36%), closely followed by *slips and lapses* (34%), then followed by *mistakes* (27%) and finally *exceptional violation* (4%). These results of accident causation according to unsafe acts were also compared to the earlier study of Patterson and Shappell (2010) from the Australian mines and the most common identified unsafe acts were skilled based errors (synchronized to slips and lapses in this study). The accident reports used in this study were from both surface and underground operations whereas the accident reports from Bonsu (2013) were only from the underground operations. Mwansa's (2021) study from the other mine site used the same method with this study of collecting data from accident reports that were recorded from surface and underground operations. A key point to note is that the study of Patterson and Shappell (2010) had a balance of reports from underground, open pits, quarries, and metallurgical operations. This assertion can be supported by the fact that mining operations in developed countries are automated and mechanized compared to those of developing countries. This is not a surprise that majority of human errors encountered in conventional mines were unintentional in nature (slips and lapses). In both operations (surface and underground), the worker tends to develop similar work culture which can lead to violation of standards and procedures.

Most of the cases involved with slips and lapses were because of poor physical environment. This is due to the harsh environmental working condition to which workers are exposed to. The influence of the environmental working condition on the performance of a worker substantiates the studies conducted by Patterson and Shappell (2010) and Sanmiquel et al (2010) in the Australian and Spanish mining industries respectively where the working environment was identified as the major factor affecting the performance of workers. However, in some incidents, proper designs of working places improve the working environment whereas in some other cases physical environment were temporary situations produced as operations are being carried out. Therefore, if the working environment were to be safe, major consideration must be given to *hazard identification*, *risk management*, *change management* and *housekeeping.*

Accident causation in this study also endorses the fact that *poor leadership* was the root cause of most of the violations acknowledged. This was acknowledged because the most common workplace factors identified in this study were *behavioural environment* (26%), followed by *physical environment* (23%), and then followed by *unsafe work practices* (19%), then *competent people* (16%) and *fit-for-purpose equipment* (16%). The significant cause of violation recognized in this study was *behavioural environment*. Examples of such instances were cases in which people broke *standards and procedures* and were not rectified by the supervisors. For example, a conflict may arise between a company goal and/or objective in terms of following standard operating procedures (e.g., conducting mid-shift barring down) and committed to individual objective of achieving a production bonus. Based on the results of analysis in this study, it can be taken that gaps in leadership and supervision are the root causes of most violations.

Production pressures may have contributed to the high rate of violations on workers. However, production pressure was not mentioned in any of the accident reports collected from the mine site. For instance, one of the most common violations identified was failure to do mid-shift barring down. This means that at the middle of a working shift, workers must first stop working and then attend to barring down. This situation was very common because workers were behind schedules to complete assigned tasks. In some of the accident reports analyzed, there was an instance where an accident happened in the presence of supervisors. The most important point to take note is that most of the violations identified were repetitive or routine, this hints of the possibility of conflict goals (as shown in Figure 25). This fact is shared by previous studies of Bonsu (2013) from the platinum mine in South Africa, Ashworth and Peake (1994) from the gold and platinum mines in South Africa and Lenné et al (2011) from the Australian mines, reporting significant causal connection between violations and adverse mental state. The study of Lenné et al (2011) defined adverse mental state as conditions of mental fatigue that occurs due to long working hours.

The instances of mistakes when linked to work-place factors revealed that most of the incidents were complex and diverse in nature. This was supported by the results obtained in Figure 36 where all the work-place factors identified were significant as contributing to mistakes except *fit-for-purpose equipment*. The condition may be happening because of the complex nature of the underground mining environment, in which the existing hazards make it more dangerous to work in. Instances involving the lack of *communication* and *adequate risk assessment* in this study were identified among the workers as the most prominent mistakes.

The earlier study of Patterson and Shappell (2010) from the Australian mining industry using the HFACS-MI method revealed procedural error, faulty risk, and situational assessments, as being the most prominent decision errors (like mistake in this study). The earlier study of Ashworth and Peake (1994) from the gold and platinum mines in South Africa revealed that of all accidents analysed, 21.4% were because of poor examination and inspection of the working environment. The finding by Ashworth and Peake (1994) agrees with this study in which lack of risk assessments by workers was linked to inadequate inspection of the working environments by the supervisors and the use of tools with low capacity. For example, the supervisor may not have inspected the working environment to check for loose rock, so they can be barred down or the worker may be using a wrong tool to bar down the loose rocks. These actions cited in this study can led to fall of ground accidents. Therefore, it can be concluded that *hazard identification*, *risk management, training and competence, housekeeping* and *provision of resources* are the systemic factors that need to be dealt with if mistakes leading to ground strata failure (falls of ground accidents) were to be reduced.

Some existing company procedures were ambiguous on how far to stand when *barring down* the loose rocks or what type of tool was supposed to be used for *barring down* (Brady and Brown, 1985). Certain tools that were used for barring down such as the pinch bars where inappropriate and cannot be used everywhere due to height of the excavations. However, the underground excavations with height of more than 5.0 m cannot be barred down with the pinch bar (Brady and Brown, 1985). These excavations will be required to be barred down by mechanical means using drilling rig. Allowing workers to bar down such excavations with pinch bars, usually exposes them to more hazards.

The results were compared to the earlier study of Lenné et al (2011) from the Australian mining industry and technological component (synchronized to fit-for-purpose) was recognized to have been the major cause to decision errors (synchronized to mistakes). The finding is similar with this study in that the nature of the tools used in performing a task by a worker can affect the quality of the worker's decision. The proposed concept of defense-in-depth by Saleh and Cumming (2011) is the best method to deal with hazards which are found in mines. There are advantages and disadvantages of defense-in-depth as discussed in the previous Section 5.1.

The leadership level considered in this study includes mine captains, shift bosses, section bosses, engineers, foremen and team leaders. The responsibility of the leader in ensuring that operations are safe at this mine site cannot be over exaggerated, this is due to the organizational nature of barriers in place. Different levels of leaders are responsible for operations of various components of safety managements such as conducting risk assessments on new tasks, enforcement of rules and regulations, provision of resources and ensuring safe housekeeping. This is the reason as to why *leadership* was identified as a root cause of most workplace factors. The author of this work is of the view that further investigation of factors affecting performance of *leadership* should be carried out at the mine site.

To conclude this chapter, the study has evidently recognized involvedness and complexity of accident causation. Nevertheless, the results presented in this study propose that with the right attitude regarding improvement in safety plans, actions and commitments, a free accident environment at the workplace can be accomplished. The next chapter closes the study with factual research findings, summarized comparisons with Mwansa's (2021) study from the other mine site of the same company with this study, significance, limitations and the recommendations of this study.

CHAPTER SIX: CONCLUSIONS AND RECOMMENDATIONS

This section is aimed at presenting the conclusion of the whole study. The section is divided into Key findings, comparison with Mwansa's (2021) study from the other mine site of the same company with this study, significance, limitations, and recommendations of this study.

6.1 Key findings

The key findings are as follows: -

1) The operations at the copper mine investigated in this study are labour intensive, indicating that humans were highly involved in executing most of the operations, hence causing accidents due to human errors.
2) The results presented in this study show that unsafe acts were involved as causes in many the accidents occurrence at the copper mine of this study. Despite the existence of standard operating procedures for most tasks, in most cases were not followed during task execution (*routine violations*). This made workers more vulnerable to cause accidents.
    a) 89% of all accidents analysed were due to unsafe acts.
    b) 38% of all accidents analysed were due to *routine violations.*
3) Unsafe acts due to slips and lapses, and mistakes were also found to have been causing accidents at the copper mine site studied.
    a) 30% of all accidents analysed were due to slips and lapses.
    b) 21% of all accidents analysed were due to mistakes.
4) The effect of workplace and systemic factors were also identified to have been contributing to accident occurrence at the copper mining site. Under the workplace factors, the study identified *behavioral* and *physical environments* (controlled work environment) as the main causes of accidents at this copper mining company. *Leadership* and *hazard identification* were the most common systemic factors identified in this study as contributing to accidents;
    a) 78.2% of all accidents were due to *workplace* and *systemic factors.*
    b) 49.2% of all accidents analysed were due to *behaviora*l and *physical environments* (controlled work environment)

   c) 22.6% and 21.7% of all systemic were *leadership and hazard identification* respectively.

5) The types of conditions in which human error was involved in this study is unique in that most of the operations were labour intensive compared to other operations which are mechanized. Mechanization will increase productivity, improve safety, and reduce the incidents of low-skilled work. The introduction of machines and remote-control systems have the potential to remove people from often very dangerous areas of the mine.

6.2 Comparison with Mwansa's (2021) study

Similarities and differences were observed in both studies, suggesting some common safety and organizational cultures.

1) Similar results were obtained in both studies under accident characterization according to job title, in which the most involved title were *workmen*, *operators* (*machinery operator* and *rock drillers*) and *artisans.*
2) The results under accident characterization according to place of incident were similar in the two mine sites. Although this study had more underground operations (5 underground mines) and less surface operations (4 surface operations) while that of Mwansa's (2021) had fewer underground operations (1 underground mine) and more surface operations (5 surface operation), the frequency rate of accidents in both mines were relatively high.
3) *Material handling*, *engineering task* and *drilling* tasks were identified in both studies as the most common tasks prone to accidents.
4) The accident characterization according to employee type was different between this study and that of Mwansa (2021). Mwansa's (2021) study revealed that company employees (52%) involved in accidents were higher than contractor employees (48%). However, this study revealed that company employees (23.7%) involved in accidents were lower than contractor employees (76.3%). This was attributed to the fact that most of the underground operations such as mine development were executed by *contractor employees* whereas most metallurgical surface operations are executed by the *company employees.*
5) The most common agencies identified in this study and that of Mwansa (2021) were *fall of ground*, *mobile equipment* (in this study stated as *moving machinery*), and *handling equipment* or *tools* (in

this study stated as *material handling*). In this study, *slipping and failing* was identified as lower, whereas in Mwansa's (2021) study it was identified as among the most common agency.

6) *Standard and procedure, supervision* and *job safety* analysis, were identified in both studies as the most common broken barriers. The broken barriers involving *safety equipment*, warning systems and communication were not identified in any case in the study of Mwansa (2021).
7) This study identified all the general systemic factors as contributing to accidents whereas the study of Mwansa's (2021) did not identify *management of change* as contributing to accidents. Instances of problem of poor leadership and hazard identification were identified in both studies, suggesting similar challenge to improve safety of workers.

6.3 Significance

1) Based on the data analyzed, and comparison done with the study of Mwansa (2021), this study has contributed to the understanding of the influence of safety culture in the two mines sites of the copper mining company studied. The findings are significant to changing employee attitudes and behaviours in relation to workplace safety. To have a safe workplace, the company must demonstrate commitment to workplace safety by reflecting on the values and actions. This must be conducted through a thorough investigation of every workplace accident.
2) The framework developed by Bonsu (2013) using the technique from Swiss Cheese Model can be used to analyse accident data. The importance of this framework is that systemic and workplace factors, and direct causes of accidents can be identified which are of great significance to understanding safety culture in an organization.
3) The operations at the copper mine site studied involves underground mining, surface mining, shaft sinking and metallurgical operations. The analysis presented is very important to understanding the effect of human error in task executions in both conventional mining operations.
4) The mine site studied uses the incident cause analysis method (ICAM) which does not consider the underlying factors that contributed to the actions, or the context in which accidents occurred. Considering only the transparent 'active' failures and unsafe acts, rather than potential causes or 'latent conditions' lying dormant within the system, limits the potential of investigation to prevent the same event from recurring. The Swiss Cheese Model owes its success to systemic foundation that broadens the scope of analysis to an organization's complexity, environment, management and defenses.

6.4 Limitations

1) The major challenge was with the information that was provided in the accident reports. Certain information in the reports were not entered according to cause of an incident due to confidentiality reasons, and verifying such information during coding was a challenge and cannot be avoided.
2) The results presented were only for one mining site of a copper mining company in Zambia. The results obtained would be more reflective of safety culture if other mining companies in Zambia can be investigated using the same framework as used in this study. However, the main aim of this study was to investigate the systemic causes of accidents in the mine site studied. Another aim was to compare the results of this study with those obtained, using the same framework, from the other mining site owned by the same company, so to understand the similarities and differences in safety of the operations.
3) This research work involving systemic analysis of the causes of accidents in the Zambian mining industry, using the Swiss Cheese Model, has never been conducted before. Comparing results to other studies in the Zambia's safety research was a challenge due to the fact that information was limited.

6.5 Recommendations

1) The author believes that some leaders had poor supervisory skills inorder to ensure that safety policies are enforced at the workplace. Supervisory courses are required to some leaders in order to guide and identify hazards so that remedial actions can actions can be implemented immediately.
2) The systemic causes of accidents at the copper mine has never been investigated due to lack of systemic framework tool for analysing accidents as used in this study. Therefore, it is difficult to develop specific strategy to prevent accidents. The author recommends that the company adopt the systemic approach methodology of this study to analyse the causes of accidents.
3) The difference in remuneration amongst contractor and company employee must be audited and normalized. Although not stated in the accident reports, the monthly income amongst employees probably might have affected the worker to perform unsafe acts.
4) Regular visits, inspections and audits by leaders to contractor's working site are recommended. The unsafe acts were common amongst contractor employees and this may be due to irregular statutory inspections.

APPENDIX

Table A 1: Questionnaire for a sample of employees (Both contractor and company employee

Job Title	No. of Samples	Employee Type	Experience	Monthly Income (Net Pay) $100 - $250	Monthly Income (Net Pay) $261 - $300	Monthly Income (Net Pay) Above $300	Comment
Workman	1).	Contractor	3 year	✓			Most Workman Contractor employees get a net pay of less than $300 per month
	2).	Company	4 year			✓	
	3).	Contractor	5 year	✓			
	4).	Contractor	7 year		✓		
	5).	Company	10 year			✓	
	6).	Company	10 year			✓	
Artisan	1).	Company	2 years			✓	Most Artisans Contractor employees get a net pay of less than $300 per month as well
	2).	Company	2 years			✓	
	3).	Company	3 years			✓	
	4).	Contractor	1.5 years	✓			
	5).	Contractor	4 years		✓		
	6).	Contractor	7 years		✓		
Operators	1).	Contractor	5 years		✓		Similar data of contractor employee getting less than company
	2).	Contractor	4 years	✓			
	3).	Contractor	6 years		✓		
	4).	Company	2 years			✓	
	5).	Company	4 years			✓	
	6).	Company	5 years			✓	

Table A 2: Meta data section

Incident	Time	Task	Place	Employee Type	Task Schedule	Age	Experience	Job Title
1).	16:45		UG1 #	CNTRCT	D/S	33	4	WORKMAN
2).	13:00		UG2 #	COMPY	N/S	48	18	ARTISAN
3).	15:00		UG3 #	CNTRCT	A/S	53	28	ROCK DRILLER
4).	14:00		UG4 #	CNTRCT	D/S	34	10	OPERATOR

a 1

KEY

- **#,** SHAFT
- **UG 1 #**, Underground mine number 1
- **UG 2 #**, Underground mine number 2
- **UG 3 #**, Underground mine number 3
- **UG 4 #**, Underground mine number 4
- **CNTRCT**, Contractor Employee
- **COMPY**, Company Employee
- **D/S,** Day Shift
- **N/S,** Night Shift
- **A/S,** Afternoon Shift

Table A 3: Agency and barrier analysis section

Incident	Description	Agency	Consequence	Broken/absent Barriers	Comment on Barriers
1).	He was dislodging ground build ups from a moving hopper fleet using a pinch bar when his finger was caught in between the side door chain of the hopper and pinch bar. In the process he sustained a deep laceration on the right finger and the incident was recorded as a lost time injury (LTI).	Material Handling	lost time injury (LTI)	Supervision, Job Safety Analysis, Training and Competence	Lack of supervision to monitor the workman performing the task, lack of training and competence of the worker performing the task
2).	Four workers were installing wire mesh support when a piece of rock dislodged and struck one of the workers on his right hand.	Fall of Ground	lost time injury (LTI)	Standard and Procedure, Supervision and Risk Assessment	Risk Assessment was not conducted prior to start of the task, there was no adequate supervision and the standard and procedure was not followed
3).	He was disembarking from the front-end loader when his cap lamp got entangled into a joy stick lever and the loader articulated, in the process trapped him and causing dislocation of the pubis.	Moving Machinery	lost time injury (LTI)	Standard and Procedure	Failure to follow the laid down standards and laid down procedures when disembarking from the front-end loaders.

Table B 1: The Causal Section (Proximal causes)

Incident Number	Slips and Lapses	Mistakes	Routine Violation	Exceptional Violation	Non-human cause	Comment on choice
1).	0	0	1	0	0	He was cutting a 25mm hand rail pipe to free a jammed steel finger when the steel finger which was secured to the winch dislodged and trapped his finger
2).	0	0	0	0	0	He was standing on an improvised platform to cut a loose hanging thread of a running conveyor belt
3).	1	0	0	0	0	After finishing showering, decided to leave the shower room and then slipped and fell
4).	0	1	1	0	0	Standing on top of the stock piled ground to bar down loose rocks using a wrong pinch bar and then the same loose rock dislodge

Table B 2: The casual section (Workplace factors)

Incident	Proximal Cause	Competent People	Fit for Purpose Equipment	Physical Environment	Behavioural Environment	Unsafe Work Practices	Comment
1).	RV	0	1	0	0	0	Using a wrong tool
2).	M	0	0	0	0	1	Unsafe Practices of improvising the platform
3).	SL	0	0	0	0	0	Slipped on the slippery floor tiles
4).	M & RV	1	1	0	0	0	Using a wrong tool for barring down

KEY

- **RV –** Routine Violations
- **M –** Mistakes
- **SL –** Slips and Lapses

Table B 3: The causal section (Systemic factors)

Incident	**Workplace Factors**	**TC**	**CM**	**HK**	**D**	**MC**	**HI**	**MA**	**WS**	**RM**	**MM**	**L**	**PR**	**SD**	**ER**	**Comment**
1).	FFPE	0	0	0	0	1	1	0	1	1	0	1	0	0	0	More than 2 systemic factors were identified
2).	UWP	1	0	0	0	0	0	0	0	1	0	1	1	0	0	Lack of TC, failure to conduct RM, poor L, failure to provide Resources
3).	PE	0	0	0	1	0	1	0	0	0	0	0	0	0	0	Poor Design
4).	FFPE	1	0	0	0	0	1	1	0	1	0	1	0	0	0	Lack of TC, failure to identify hazards, lack of MA and poor L

KEY

Workplace Factors

FFPE – Fit- For- Purpose Equipment, UWP – Unsafe Work Practice, PE – Physical Environment,

Systemic Factors

TC – Training and Competence, CM – Contractor Management, HK – housekeeping, D – Design, MC – Management of Change, HI – Hazard Identification, MA – Monitoring and Auditing, WS – work Scheduling, RM – Risk Management, MM – Maintenance Management, L – Leadership, PR – Provision of Resources, SD – Strategic Decision and ER – Emergency Response

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