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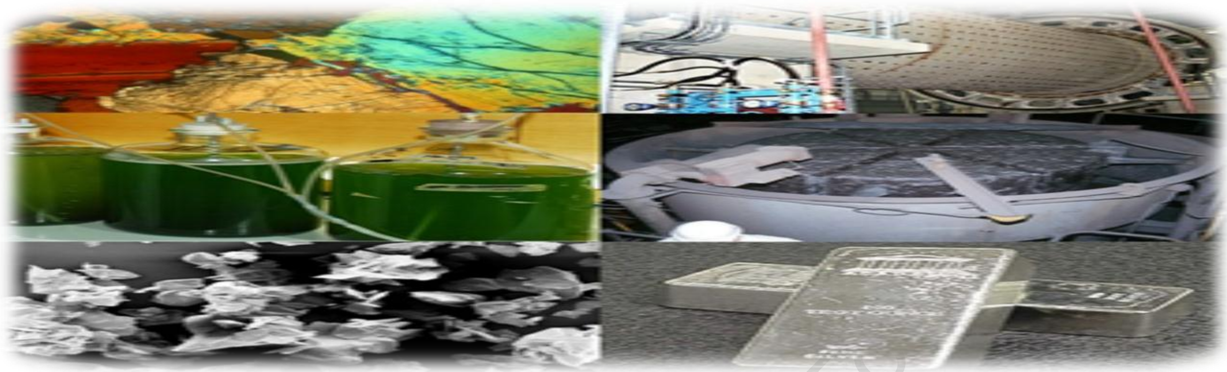

A SYTEMIC STUDY OF MINING ACCIDENT CAUSALITY: AN ANALYSIS OF 91 MINING ACCIDENTS FROM A PLATINUM MINE IN SOUTH AFRICA.

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A dissertation submitted in fulfilment of the requirement of a Master of Science in Engineering, MSc (Eng)

Minerals to metals Initiative

Department of Chemical Engineering

July 16, 2013

Declaration

I declare that this dissertation, submitted for the degree of Master of Science in Engineering 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.

Jude Bonsu

ABSTRACT

The mining industry is a very important sector of the South African national economy. A major factor threatening the sustainability of this industry is the worrying effect of mining accidents. These accidents usually lead to the destruction of property, injury/death of mine workers, and pollution of the environment. Although mining is generally seen as a hazardous operation worldwide, the accident rates in South African mines are still unacceptably high. Another worrying phenomenon is the fact that since 2003 reduction in fatalities and injuries has been 20–25% short of annual targets set by stake holders. These factors make the safety of the industry a very important subject.

The understanding of accident causality is a major step in the quest to reduce accidents. It is only with a good understanding of the accident process that effective remedies can be designed. Accident modelling techniques provide the necessary platform for the interpretation and understanding of accidents at workplaces.

The Swiss Cheese Model of accidents has proven to be a very efficient way of analysing industrial accidents. In this model, an accident is seen as a combination of unsafe acts by front line operators and latent conditions in the organization. The model helps to identify factors in an organizational structure that influence human behaviour/performance at workplaces.

This study is aimed at demonstrating how a systemic approach can be applied to the analysis of the causes of accidents in South African mines. In this study, an accident analysis framework has been developed from the Swiss Cheese Model, combining the Mark III version of the Swiss Cheese Model, the Nertney Wheel and safety management principles. The main section of the framework is made up of three layers of accident causality: proximal causes, workplace factors and systemic factors. The second section (metadata) of the framework incorporates contextual data pertaining to each accident such as age, experience, task being performed, and time of accident. These data enhance the understanding of accident causality. The third and final section of the framework incorporates information about accident causing agencies and the nature of barriers breached in the accident process.

In this study, ninety-one accident reports from a platinum mine in South Africa were used to populate the developed framework. The results show that while *routine violations* (45% of all incidents analysed) were the most common form of unsafe act, problems in the *physical environment* of workers were the most common workplace factor (39.6% of all accidents analysed) and inadequate *leadership* the most common systemic factor (51.6% of all accidents analysed) identified.

It was also realized that some workplace factors were more commonly associated with particular unsafe acts compared to others. For example, while problems in the *physical environment* were the most common workplace factor identified with *slips and lapses*, a poor *behavioural environment* was the common workplace factor identified with *routine violations*. The workplace factors identified with *mistakes* were fairly distributed amongst: *unsafe work practices*, problems with *competent people* and an un-supporting *physical environment*.

Other results from this study also reveal that some systemic factors were more associated with particular workplace factors than others. For example, while poor *behavioural environment* was usually due to *leadership* problems, problems in *housekeeping*, *risk management* and workplace *design* were the causes of poor *physical environment*. While problems with *hazard identification* was the common systemic factor identified with existence *unsafe work practices*, systemic factors identified with the absence of *fit-for-purpose equipment* were issues with *maintenance management*, *provision of resources* and *leadership*. The most common systemic factors identified with the absence of competent people were problems with *training and competence*, and *leadership*.

The results have been compared with other studies both locally and internationally and similarities and differences noted.

The outcome of this study is the demonstration that systemic factors rather than human errors and violations are the actual causes of accidents in the mining sector. Another benefit of the study is the availability of an accident analysis tool that can be further tested across other mining commodities in the South African mining industry.

Contents

DEDICATION

To the Bonsu family; my Father, Rev. Okontomene Bonsu, my mother Mrs. Katherine Bonsu and my four siblings: Rachel, Obed, Jerome and Gladys Bonsu. Your encouragement and prayers have brought me this far.

ACKNOWLEDGEMENTS

"Now praise we great and famous men, the fathers named in story"……………… (MHB 896)

This study was made possible by the contributions of some individuals and organizations.

This work is based on the research supported by the South African Research Chairs Initiative of the Department of Science and Technology and National Research Foundation of South Africa.

I also want to acknowledge the Minerals to Metals Initiative for sponsoring this research. Without such support, this study would have been impossible. A special acknowledgement goes to Professor J.P. Franzidis, the head of the Minerals to Metals research group for all the times he went out of his way to make this research possible. I am also grateful to my supervisor, Dr. A.J. Isafiade. His selfless attitude towards this study has been a major driving force.

I also want to acknowledge the contributions of Professor Francis Petersen, dean of the Faculty of Engineering and the Built Environment for the role he played in the acquisition of data for this study. Another acknowledgement goes to Dr. Wynand Van Dyk for his contributions to this study.

"Except the Lord build the house, they labour in vain that build it"..............................Psalm 127

Above all, I am grateful to the great I am for His providence, goodness and mercies. Had the Lord God not been my side, I would have been consumed by the tide. I say thank you Jesus.

Any opinion, finding and conclusion or recommendations expressed in this material is that of author and the NRF does not accept any liability in this regard.

CHAPTER ONE: INTRODUCTION

1.1 Background

The mining industry represents a very important sector of the economy of South Africa. The benefits of the mining industry in South Africa can be seen in terms of contribution to employment, export earnings, power generation and gross domestic product. Figure 1 below shows that over the past decade mining has contributed in 2010 real rand terms 2 477.9 billion ZAR as sales revenue, 1 847 billion ZAR as export earnings, 1 716.1 billion ZAR as gross domestic product, 553.8 billion ZAR as employee remuneration and 422.7 billion ZAR as fixed investment. These figures show how central mining is to the South African economy.

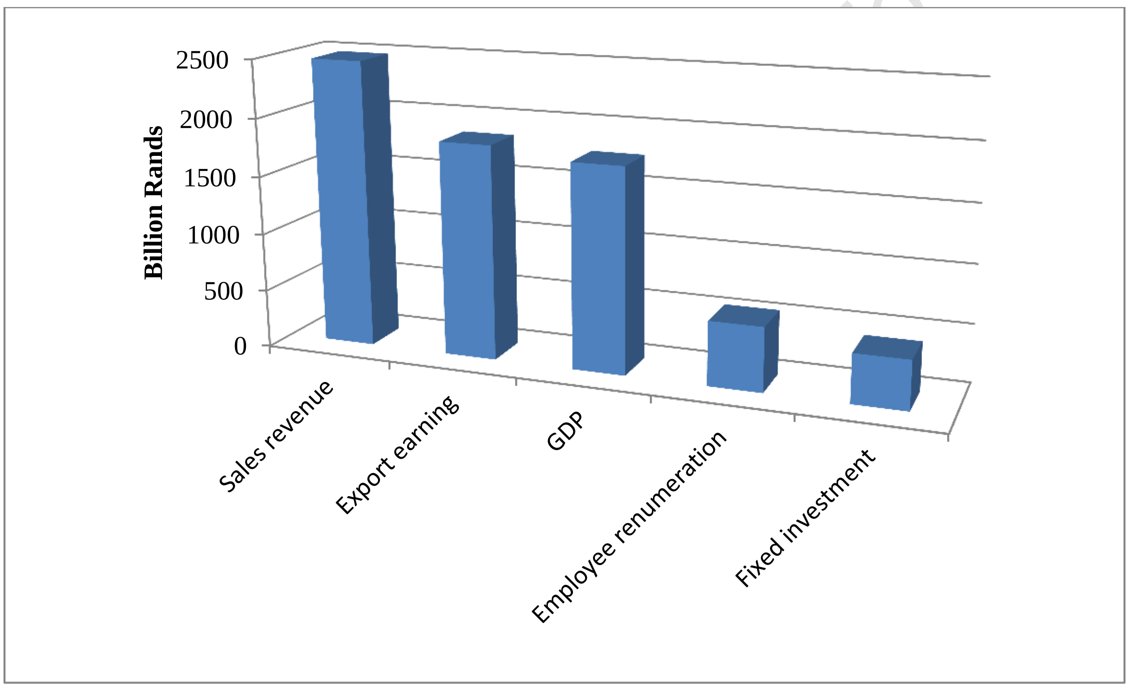

Figure 1: Contribution of mining to South Africa over the past decade expressed in 2010 real rand terms (Source: SA CHAMBER of mines, 2010)

A major problem facing the South African mining industry is mining related accidents. These accidents usually lead to loss of property, injury/death of personnel, and pollution to the environment. In the past, mining accidents have led to shut downs and threats of shut downs of mines (Ryan, 2008; Mail and Guardian, 2011).

As at 2007, the country stood the risk of directly losing a significant amount of money if the mining industry continued to experience shut downs. Such potential losses included: 120 billion ZAR per year amounting to 7% of gross domestic product, 215 billion ZAR per year in foreign revenues (equivalent to about 40% total foreign exchange earnings) and about one million direct and indirect jobs (Ryan, 2008). This makes mine safety an important subject in the sustainability of the sector.

Historically, South African mining has been seen as a high risk industry. From 1900 to 1993, over 69 000 mine workers died with more than a million seriously injured. In 1993 alone, 578 mine workers died in accidents, with 8 532 mine workers seriously injured (Stanton, 2003). Although there has been a reduction in the number of mining accident fatalities since 1993, the number of deaths per year across mines is still very high. In the years 2002 to 2007 a minimum of 200 mining related fatalities were recorded each year. As at 2011, one person dies every three days, on average, from mining related accidents (Figure 2). Figures from the South African Chamber of Mines show that the coal, platinum and gold mining sectors together contribute to over 80% of the fatalities recorded in the mining industry (SA Chamber of Mines, 2012). Since 2003, reduction in fatalities and injuries have been 20 – 25% short of annual targets set by stake holders at the mine health and safety summit of 2003 (Hermanus, 2007). These statistics show the enormity of the challenge surrounding mining safety in South Africa.

Although mining is generally seen as a hazardous occupation worldwide, the number of fatal and non-fatal mining related accidents in South Africa is significantly higher than in countries such as Australia, Germany, Great Britain, New Zealand and the United States of America (Ural and Demirkol, 2008). Human error has been blamed for most of these. Various mining companies allude to the fact that they run efficient systems, hence behavioural problems of workers are to blame for most accidents. However, evidence gathered in other countries has shown that human factors are usually is a result of deeper problems in organizations. Based on this, this research aims to elucidate the factors affecting accidents in South African mines through the analysis of accident causality at a typical South African mine.

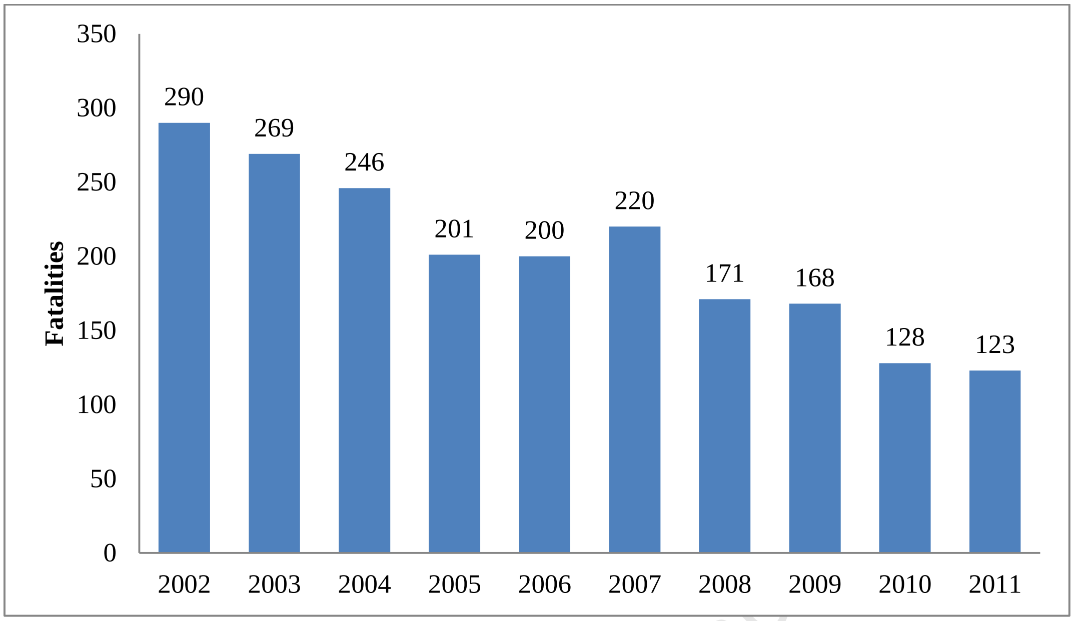

Figure 2: Mining fatalities in South African. (Data Source: SA Chamber of Mines, 2012)

1.2 Analysis of Mine Accident Causality

The understanding of accident causality is the first and major step in the quest to reduce accidents. It is only with a good understanding of the accident process that effective preventive measures can be designed. Accident modelling techniques provide the necessary platform for the interpretation and understanding of accidents at workplaces.

Over the years, in accident modelling, there has been a shift from a sequential or event based approach to a systems approach. This is because sequential or event based methods cannot adequately illustrate the causes of accidents in complex socio-technical (a combination of social and technical components) systems. Event based models consider the cause of an accident as the result of a chain of discrete events that occur in a particular temporal order over time. Accident investigation procedures in event based models focus on the main events leading to the accident, and are usually truncated immediately after a proximal cause of the accident is identified. Human error, component failures and energy related events are usually identified as the initiating cause of most accidents (Qureshi, 2008; Leveson, 2004). Using this method, human error is seen as the cause of 50-90% of all industrial accidents (Kletz, 2001). Solutions following these methods of accident investigations usually entail penalizing those involved in the accidents, substituting human activities with automation and creating several layers of protection. According to Reason (1990, 1997), these kinds of remedies to causes of accidents are seen as treating the symptoms instead of the cause of a problem.

A new approach to accident investigation is to analyse the accident in the context of the system in which the accident occurred. In this approach, accident investigation does not end when a proximal cause is identified but there is a continued search for other upstream/hidden factors that could have prevented the unwanted event. This search leads to the revelation of factors in the systems which are responsible for the direct causes of accidents usually identified by sequential models.

The Swiss Cheese Model developed by Reason (1990, 1997) is a model used in accident analysis under the systemic method. The Swiss Cheese Model has proven to be a very efficient way of analysing industrial accidents. In this model, an accident is seen as a combination of unsafe acts by front line operators and latent conditions in the organization. The model helps to identify factors in an organizational structure that influence human behaviour at workplaces. Techniques based on this model have been applied to the petroleum (Reason, 1997), aviation (Li and Harris, 2006; Li et al, 2008) and railway industries (Baysari et al, 2008) and more recently to the mining industry (Patterson and Shappell, 2010; Lenné et al, 2011).

The number of mining fatalities in South African mines is still very high (see Figure 2 above) despite all efforts put in place by stakeholders in the industry to eliminate the occurrence or mitigate the effect of accidents (Hermanus, 2007). This makes it reasonable to hypothesize that investigation and mitigation methods are not being directed at the root causes of these accidents. It is believed that it is only when the root causes of these accidents are identified that appropriate mitigation methods can be developed to significantly reduce mining fatalities and injuries.

In this study, an accident analysis framework has been developed from the Swiss Cheese Model. The framework was developed by combining the Mark III version of the Swiss Cheese Model (Reason, 1997), the Nertney Wheel (Bullock, 1979) and safety management concepts in analysing accident causality. A set of ninety-one accident reports from a platinum mine in South

Africa have been used to populate the framework developed from James Reason's Swiss Cheese Model. The results have been compared to other studies both locally and internationally, and similarities and differences noted. The study provides an accident analysis tool that can be further developed and tested across other mining commodities in the South African mining industry.

1.3 Aims and Objectives

This study aims to demonstrate how systems modelling can be applied to the analysis of causes of accidents in South African mines. The approach used involves developing an appropriate framework for systematically analysing the causes of accidents. The developed framework is then applied to accident data obtained from a South African mine in order to establish its applicability.

The specific objectives of this study are as follows:

1. To develop a framework that can be used for the analysis of the causes of accidents in mines.
2. To determine the distribution of human error in mining accidents at the specific mine of study.
3. To determine the effect of personal and situational variables such as age, experience, time, status of employee, etc., on the propensity of mine workers to commit unsafe acts, in the accident reports analysed.
4. To establish the links between upstream factors (workplace and systemic) and unsafe acts committed by mine workers, in the accident reports analysed.

1.4 Scope

The scope of this research is limited to using a developed framework to analyse accident reports from a South African mine. This involves explaining the reasoning behind various sections of the framework, as well as presenting examples of how accident reports were coded into the framework. The results obtained from this study illustrate the distribution of the various factors contributing to the accidents analysed.

1.5 Structure of Dissertation

This section intends to give a brief overview of the entire dissertation.

Chapter Two presents a review of appropriate literature on the topic. The major themes covered in this chapter include the global nature of mining accidents, human error as major causal factor in mining accidents, the concept of human error, accident modelling techniques, the Swiss Cheese Model and other accident analysis frameworks, and safety research applying systems theory and safety research in South Africa. These topics are aimed at justifying the need for a systemic safety research into mining accident causality in South Africa.

Chapter Three explains the detailed methodology employed in this study. The topics covered include the description of the framework developed and used in this study, the source of accident reports used in the study, the tools used for data analysis and an example of how the framework was used.

In Chapter Four the results obtained are displayed. The first section characterizes or explains the nature of accidents occurring at the mine under study. The second section focuses on the distribution of causal factors identified in this study and the links between different levels of accident causality as presented by the framework.

In Chapter Five the results displayed in Chapter Four are discussed forming the basis of the conclusions summarized in Chapter Six. Recommendations are also made in Chapter Six.

CHAPTER TWO: LITERATURE REVIEW

In this chapter appropriate literature concerning the study is reviewed. The chapter begins with a discussion of the global mining safety problem. This is done by highlighting mining disasters across various countries in the past to put into perspective the need for an extensive/ across-countries literature review. This is followed by an initial review on the causes of mining accidents. This is done to help establish the importance of human error and violations in mining accident causality.

The next section is dedicated to explaining the basic concepts and terminologies in human error. Accident modelling and its importance in the understanding of accident causality are then explained. The main types of accident modelling are discussed to justify why a systems approach is better than an event based approach. The discussion of accident modelling techniques leads to the explanation of the choice of the Swiss Cheese Model of accident causality.

The focus of the literature review is then shifted to the description of the Swiss Cheese Model and other accident frameworks that have been developed based on this model. This is done to facilitate the comparison of results obtained from these other frameworks with the results obtained in this study.

The last but one section of this chapter discusses results from systemic studies of mining accident causality and conclusions that can be drawn from such studies. The chapter ends with a review of safety research focused on South African mining.

This is done to demonstrate the gap in knowledge which this study aims to fill.

2.1 The Global Picture

It is a well-known fact that safety is still a big challenge in mining operations. This assertion is supported by recent mining disasters such as the Crandall Canyon disaster in United Sates of America (August 6, 2007), the Harmony Gold mine deaths in South Africa (June, 2009), the Zonguldak mine disaster in Turkey (May, 2010), the Chile mining accident (August 5, 2010), and the Xiaojiawan coal mine disaster in China (August 29, 2012). These incidents and many more have caused mining to be seen as the most hazardous occupation in the world. Although mining employees represent only 1% of the global workforce, they account for about 8% of workplace fatalities. Workplace injuries in the mining industry worldwide have also been reported to be very high by the International Labour Organization (ILO, 2010).

These problems with mining safety are a global phenomenon which has attracted significant international attention. This has precipitated various studies into different aspects of mining safety. The next section is a review of literature addressing mining safety research.

2.2 Mining Safety Research

Blank et al (1996) studied the relationship between technological development and accident rate in the Swedish mining industry from 1911 to 1990. The technological stages considered were handicraft, mechanization and automation. The results show that while a change in the mode of operation in the Swedish industry from handicraft to mechanization resulted in an increase in the accident rate, advancement into the use of automation reduced the accident rate. In the era of mechanisation, poorly designed human-machine interfaces and inadequate adaptation to newly installed machines were identified as factors responsible for the increase in the accident rate. Another finding of the study of Blank et al (1996) is that the unemployment rate had an effect on how technological development affected the accident rate: An increase in the unemployment rate also increased the accident rate. This was adjudged to be due to increase in working time and working intensity which accompanies increase in unemployment. Their study shows that the implementation of safety in any organisation is a complicated issue, as solving one safety problem may create another if not done from a systemic point of view. For instance, since technological advancement cannot totally remove the need for humans on a plant, human factors should be factored into any decisions made with respect to safety in any organisation.

Mitchell et al (1998) studied the causes of mining accidents in Australia. They found that behavioural problems such as poor work practices are the most prevalent causes of accidents. They also identified other factors such as unstable workplace terrain, faulty equipment or machinery, and the absence/inadequacy of safe working procedures as significant causes of accidents. The study however did not determine how behavioural problems may have been affected by the workplace deficiencies.

Jacinto and Soares (2008) used the European Statistics on Accidents at Work (ESAW) variables to analyse causes and circumstances of occupational accidents in the Portuguese mining and quarrying industry. The study identified human error as the most likely cause of accidents because the study was aimed at determining the effectiveness of the tool, hence no information was presented concerning how and why human error is the most likely cause of accidents.

Cawley (2003) focused on electrical accidents in mines in the United States of America. The study revealed amongst other things the problem of high reaching cranes in electrical accidents. His study concluded that although human fallibilities may have been involved in a lot of accidents, an engineering solution is a much better option.

Kecojevic and Radomsky (2004) analysed the causes and control of loader and truck-related fatalities in surface mining operations in the United States. Mechanical failures, inadequate procedures, failure to recognize adverse conditions, failure to respect the loader's working area, failure to maintain adequate barriers, and failure to adjust to poor weather conditions were identified as the main causes of the incidents. Ruff et al (2011) identified operator visibility issues, failure to shut equipment down and loss of control as the main causes of equipment related issues in United States mines.

A theme running through most of these previous studies is the ever present human behavioural problem in mining accidents. This makes the examination of human behaviour at the workplace a very important subject in the quest to achieve a safer mining industry. The next section seeks to explain the basic concepts of human behaviour and how it affects safety in a workplace.

2.3 Human Error

Errors and violations are seen as the two ways in which human behaviour contributes to accidents at the workplace. While an error can be defined as the failure of a planned action to achieve its intended outcome without the intervention of unforeseeable events (Reason, 1990), a violation is a deliberate deviation from standards and procedures (Reason et al, 1998). The

Rasmussen (1983) human performance model provides a viable reference for the analysis of human behaviour in an organizational setting. In this model human behaviours are classified into three groups, namely skill based, rules based and knowledge based behaviours.

Skill based behaviours are seen as those acts which following a statement of intention take place without conscious control. These represent routine activities that are automated and highly integrated patterns of behaviour. Errors at this level are due to variability in force, space or time coordination.

Rule base behaviours are those acts associated with tackling a familiar problem which is controlled by stored rules or procedures. These rules may be as a result of previous experience, or the actor's knowledge base. Errors at this level may be due to a misidentification leading to a misapplication of a rule.

Knowledge based behaviours are acts occurring in an unfamiliar setting which demands the use of one's analytical skills (observation, identification, goal selection and procedure selection) and knowledge base. An error can occur at any stage (observation, identification, goal selection and procedure selection) of the decision process.

Human error can be further grouped into slips and lapses, and mistakes (Reason, 1997). Slips and lapses are errors that evolve in the execution of an adequate plan. This leads to a plan not achieving its intended outcome. Slips and lapses are related to skill based tasks or behaviours. While slips are due to attention failures, lapses are due to memory failures hence the name memory lapses (Reason, 1990, 1997; Kletz, 2001).

Mistakes are said to occur when there is an error in the plan chosen for a particular task. They can be seen as an error in judgement or choice. This error can occur at the choice of inference, selection of objective or choice of means to achieve it. Mistakes are related to either rule or knowledge based problems and hence can be classified as rule or knowledge based mistakes (Reason, 1990; Reason et al, 1998).

Violations or non-compliance are defined as a deliberate deviation from practices deemed necessary by a designer, procedures, managers etc. (Kletz, 2001). Reason et al (1998) further grouped violations as routine, optimising and exceptional. Routine violations involve cuttingcorners or taking the path of least effort every time the chance presents itself. Optimising violations may be unrelated to the task; they might just be a personal goal of the operator. Exceptional violations are situational specific, which happen on occasions where the operator sees the violation as the only option to get the job done.

Dekker (2001) stated that although investigations can easily point out where people went wrong, this does not explain much. He suggested that moving human actions back into the flow of events of which they were part will help to explain their action.

2.4 Accident Modelling

The act of describing accidents with respect to the flow of events leading to an incident is known as accident modelling. Accident models provide a conceptualisation of the characteristics of the accident process by showing the relationship between causes and effects. They explain why accidents occur, and are used as techniques for risk assessment during system development, and in post hoc accident analysis to study the causes of the occurrence of an accident (Qureshi, 2008). During accident investigations, accident models impose patterns on the accidents and influence both the data collected and the factors identified as causative. Since accident models influence the factors considered in any accident investigation, they may either act as a filter and bias toward considering only certain events and conditions or they may expand activities by forcing consideration of factors that are often omitted (Leveson, 2004). The importance of accident models in the quest to achieve safety makes the choice of the right model a crucial decision.

Traditionally two main accident modelling techniques have been applied in industry for the analysis of accidents. These two techniques are event based/sequential and systemic accident modelling.

Event based modelling conceptualizes accidents as resulting from a chain or sequence of events (Leveson, 2004). In this kind of modelling, an accident process is seen as starting from the occurrence of an undesirable event (known as the root cause) followed by a sequence of subsequent events leading to an accident. The implication is that the accident is the result of a single cause, and if that single cause can be identified and removed the accident will not be repeated. This theory is the underlying principle for accident models such as Failure Modes and Effects Analysis (FMEA), Fault Tree Analysis (FTA), Event Tree Analysis, and Cause-Consequence Analysis (Qureshi, 2008). The common root causes of accidents identified by such models include human error, component failures and energy build up. Solutions prescribed by some of the above mentioned sequence based methods of accident modelling include substitution of human activities with automation and creating several layers of protection. These models may work well for relatively simple systems; however, in more complex systems they have been proven to be limited in their ability to clearly illustrate the reasons for the occurrence of accidents (Levenson, 2004; Qureshi, 2008).

Systemic accident models on the other hand consider accidents in the context of the system in which they occur. Accident models based on systems theory consider accidents as arising from the interactions between system components and usually do not specify single causal variables. Every production system is seen as the combination of human agents and technical artefacts embedded within complex social structures such as organisational goals, policies and culture, as well as economic, legal, political and environmental elements (Rasmussen, 1997; Levenson, 2004; Qureshi, 2008). Accident models developed from this theory do not stop when an immediate cause is found, but there is a continuous search for upstream factors that may have contributed to the accident. Models such as the Swiss Cheese Model (SCM) of James Reason (1990), the AcciMap of Jens Rasmussen (1997) and the Systems-Theoretic Accident Model and Processes (STAMP) of Nancy Leveson (2004) all have systems theory as their underlying principle.

A point of disagreement in systemic accident modelling is exactly what makes up a system of production, i.e. what comprises the system boundary? While organizational models (e.g. the Swiss Cheese Model) limit their definition of a system boundary to the managerial level of the organisation, other systemic based models (e.g. STAMP and AcciMap) expand the definition of system boundary to include regulatory authorities and government. While this approach by systemic models such as STAMP and AcciMap to broaden the scope of accident causality is commendable, Lees (1996) cautioned of the danger of making an accident process so incredibly complex that any attempt to understand it becomes very difficult. The Swiss Cheese Model developed by James Reason (1990) is a widely accepted tool for accident modelling due to its ability to combine real time unsafe acts by front line operators with latent conditions in an organizational structure.

2.5 The Swiss Cheese Model of Accident Investigation

The Swiss Cheese Model developed by Reason (1990) for accident investigation incorporates the basic components of all successful production systems such as decision makers, line management, pre-conditions for effective work, production activities and safe-guards against known hazards (see Figure 3). Effective production is only achieved when the right decisions are taken at each level of the production system.

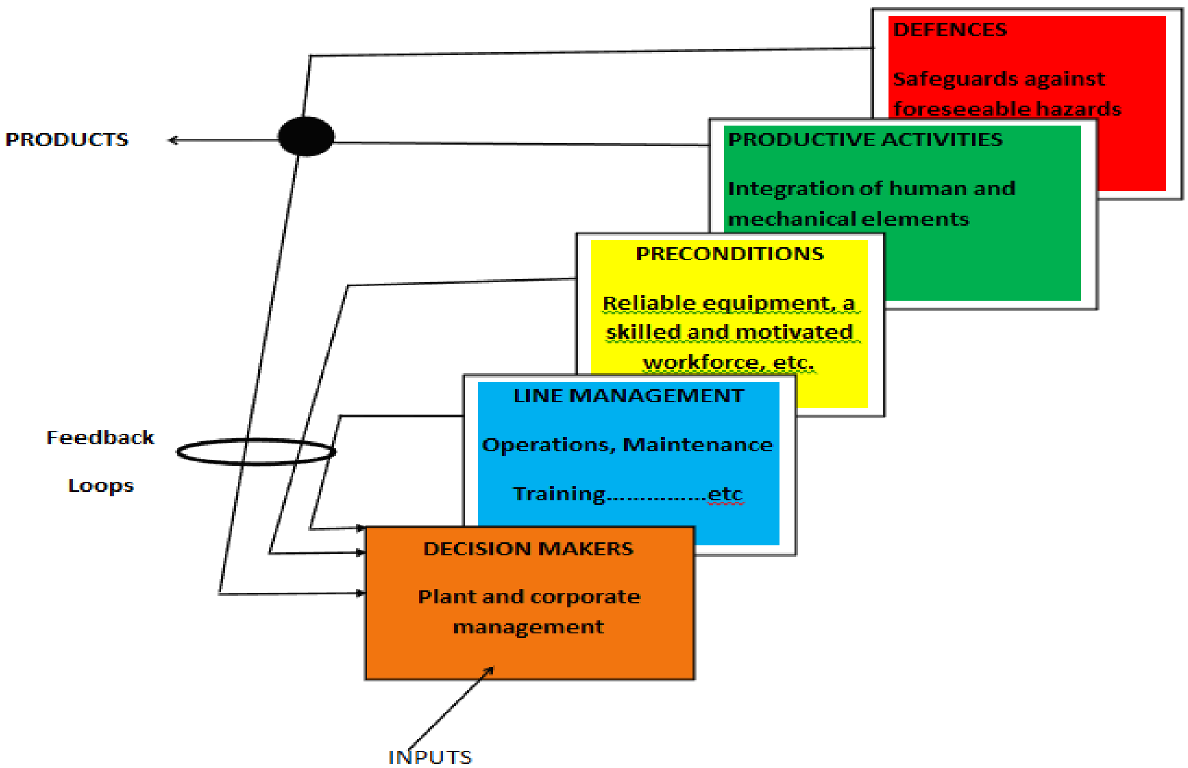

Figure 3: Components of a production system (after Reason, 1990).

The accident process starts when fallible decisions taken at the management level are propagated through the various components of the production system (see Figure 4). These decisions create holes in the barriers put in place to prevent accidents.

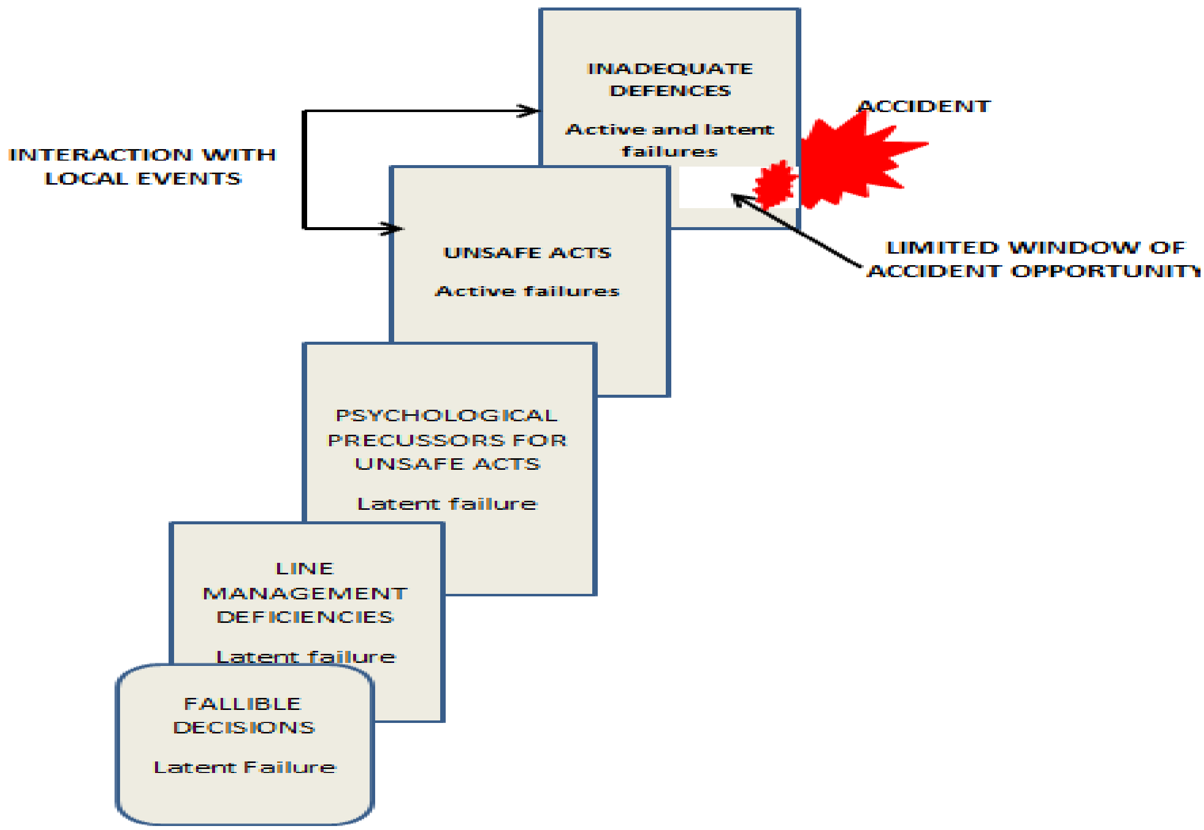

Figure 4: The Swiss Cheese Model, Mark I version (after Reason, 1990).

An accident is seen as the time when holes in the various safeguards line up for the accident trajectory to be complete (see Figure 5).

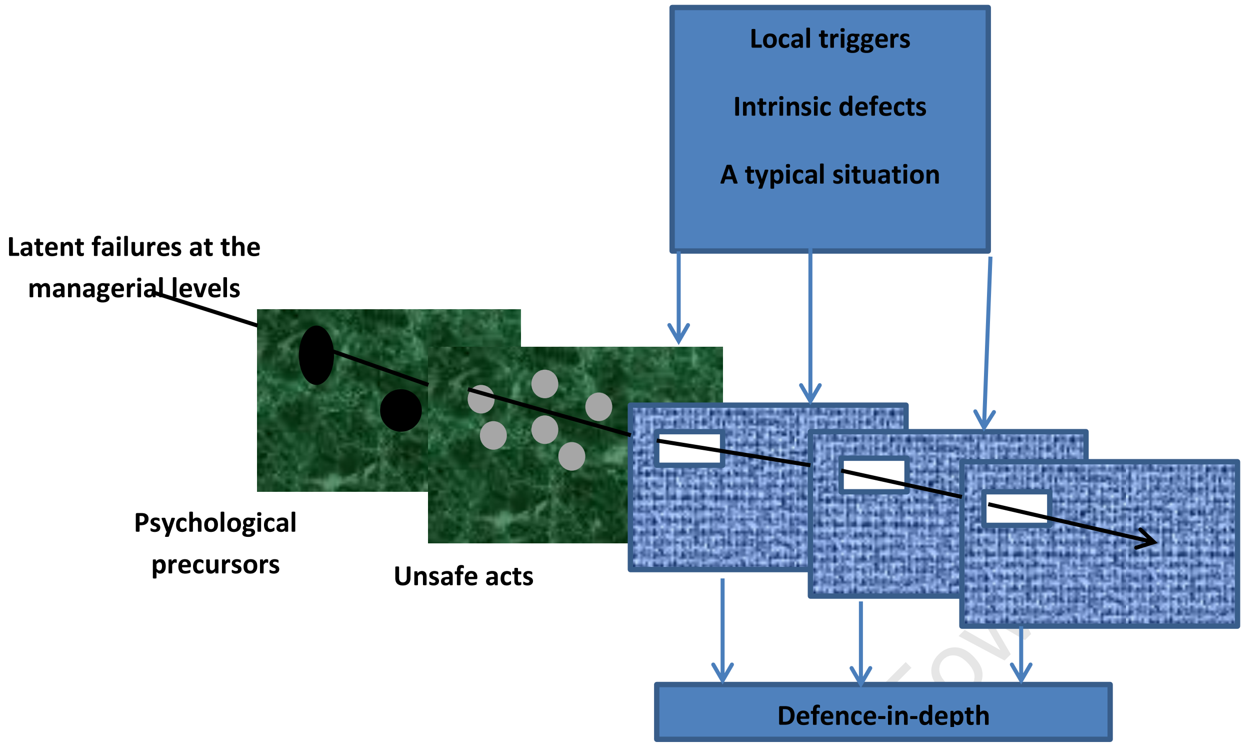

Figure 5: The accident trajectory (after Reason et al, 2006).

The significance of the Swiss Cheese Model is that the accident incubation period precedes the occurrence of the accident itself. It starts with the decisions taken by the top management of an organization. In the Swiss Cheese Model, human error is seen as a consequence rather than a cause. Reason (1990) believes that it is only when the systemic failures involved in an accident are tackled that accidents can be prevented. Reason (1997) likens sanctions and punitive actions which happen after accidents as treating the symptoms of a disease instead of the cause.

Since its inception, the Swiss Cheese Model has undergone some changes namely the Mark II and Mark III models. The main change has been the reduction of the layers of possible failure from 4 to 3 levels in order to pave the way for more specificity at each level (Reason et al, 2006). In the Mark III version of the model (see Figure 6), holes in organizational decisions are propagated into workplace deficiencies which in turn breed unsafe acts by frontline operators. These unsafe acts eventually lead to the creation of holes in existing defences leading to accidents (known as the active failure pathway). The model also caters for the possibility where organizational or workplace factors lead to accidents (known as latent conditions pathway).

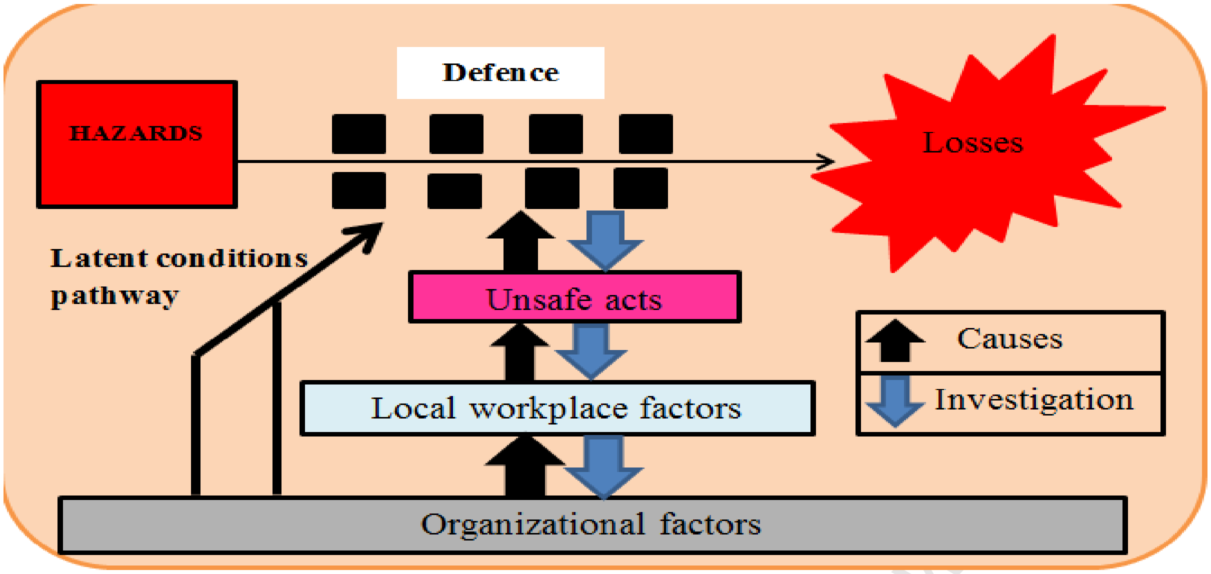

Figure 6: The Swiss Cheese Model, Mark III version (after Reason, 1997).

2.6 Human Error Frameworks

Although the Swiss Cheese Model is generally accepted as being able to depict situations leading to accidents in production systems, it has also been seen as lacking the sufficient details for practical applications (Shappell and Wiegmann, 2000). Professor James Reason himself, in a publication revisiting the Swiss Cheese Model (Reason et al, 2006) admitted that the model was not intended for such details, but a simplification intended to make it easier to understand the essential features of an accident in an organization. In an attempt to deal with this deficiency, various analysis techniques based on the Swiss Cheese Model have been developed to meet specific needs of various industries. Examples of such methods are the Human Factor Analysis and Classification System, the Incident Cause and Analysis Model, the Wheel of Misfortune, and the Behaviour Safety method, all of which are discussed in the sections which follows.

2.6.1 Human Factor Analysis and Classification System (HFACS)

The Human Factor Analysis and Classification System was developed by Wiegman and Shappell (1997, 2001) for the United States military. The analysis framework is based on the Swiss Cheese Model of Reason (1990) and the Software Hardware Environment Lifeware (SHEL) model developed by Edwards (as cited by Weigman and Shapell, 2001). The HFACS framework is made up of four levels of analysis (Figure 7). The first level represents the unsafe acts of operators. This level shows errors and violations of frontline workers that immediately lead to an accident. Within this level, four types of unsafe acts are identified, namely skilled based errors, decision errors, perceptual errors, and routine and exceptional violations.

The second level of the HFACS framework is the precondition for unsafe acts. This level shows underlying conditions that lead to the occurrence of unsafe acts in level one. This level comprises the following three categories: condition of operators, environmental factors, and personnel factors.

The third level of HFACS framework is unsafe supervision. This level shows places where a lapse in supervision or leadership contributes to the occurrence of unsafe acts. Unsafe supervision comprises categories such as supervisory violations, failure to correct problems, planned inappropriate operations and inadequate supervision.

The fourth and final level of the HFACS framework is organizational influences. This level seeks to identify the role of higher managerial levels in the causes of accidents. Categories in this level are resource management, organizational climate and organizational processes. The HFACS method works on the assumption that higher level factors are the causes of lower level factors. The method has been credited with its ability to operationalize the Swiss Cheese Model in order for it to be used by investigators in a wide range of industries (Reason et al, 2006).

The HFACS method was originally used in the analysis of military aviation accidents (Shappell and Wiegman, 2001) but has now been used in other industries such as railway (Baysari et al, 2008), civil aviation (Li and Harris 2006; Li et al 2008), mining (Lenné et al, 2011; Patterson and Shappell, 2010) and shipping (Celik and Cebi, 2009). The original HFACS method underwent various modifications before being applied in the aforementioned studies. Patterson and Shappell (2010) developed a version of the HFACS method known as HFACS-MI for the mining industry. The major change in HFACS-MI from the original framework is the inclusion of an additional level of accident causality known as outside factors. This is intended to cater for the contribution of factors such as regulatory and other external factors to an accident in an organization. Minor changes include the change of the layer "unsafe supervision" to "unsafe leadership" for it to reflect the effect of all forms of mine leadership on the accident process. A major criticism of the HFACS method is that there is an absence of clear boundaries for higher level causal factors (O'Hare, 2000). For instance a personal readiness problem can also be seen as a physical or mental limitation problem.

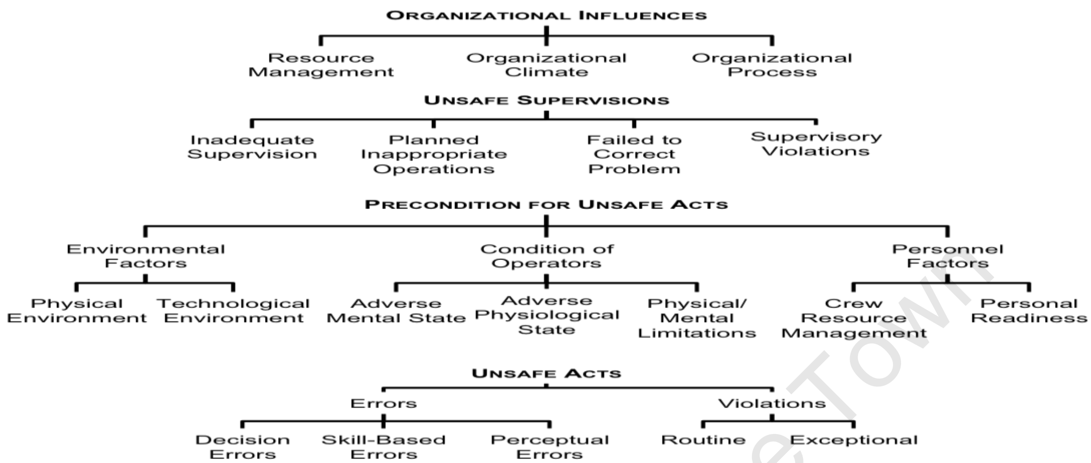

Figure 7: The HFACS framework (after Weigmann et al, 2005)

2.6.2. Incident Cause Analysis Method (ICAM)

The Incident Cause Analysis Method (ICAM) is an organizational approach to accident analysis based on the Reason (1990, 1997) model of latent and active failure. The ICAM model is based on the principle of the acceptance of the inevitability of human error. The ICAM model identifies and analyses accidents at four different levels (Figure 8).

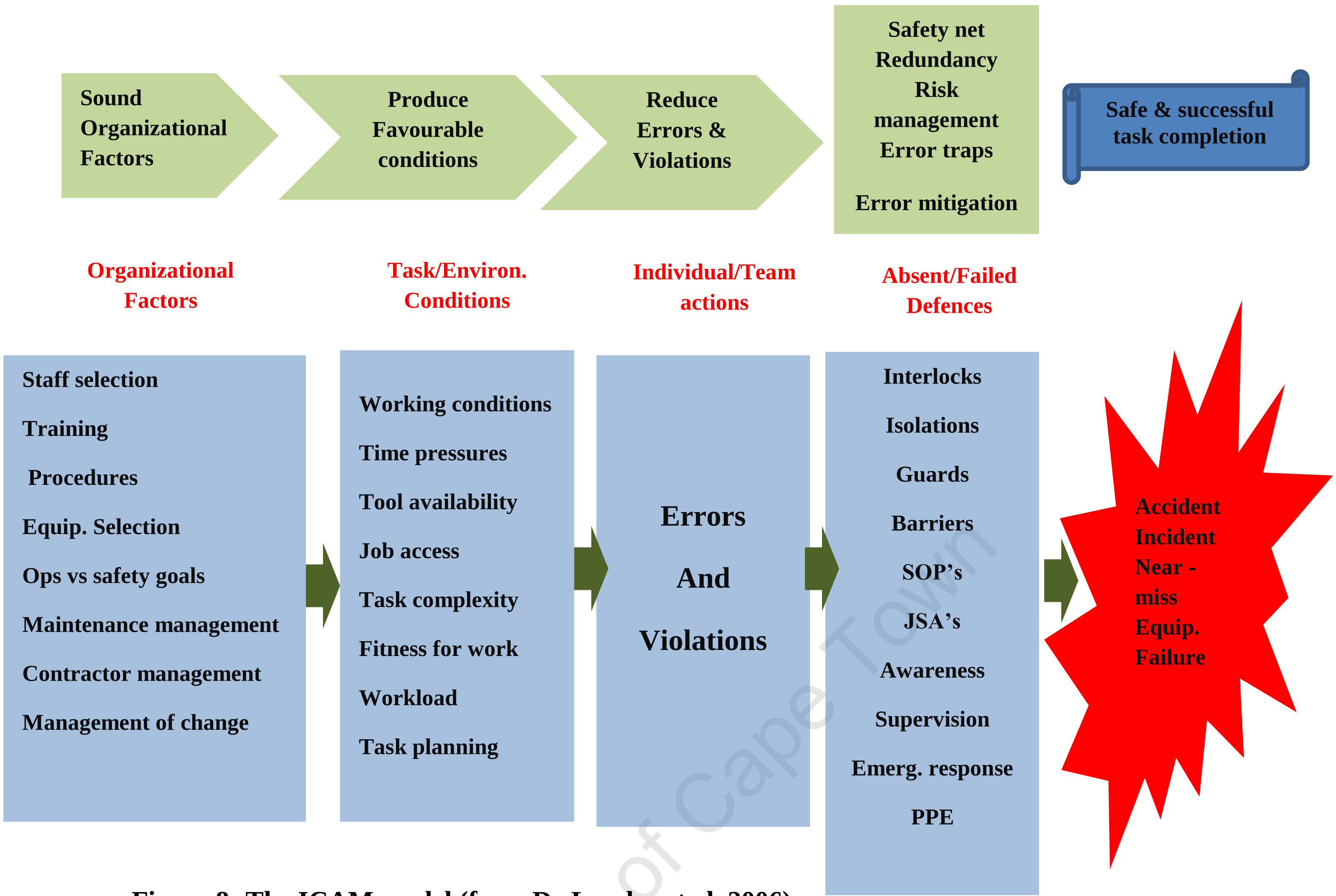

Figure 8: The ICAM model (from De Landre et al, 2006).

The first level is absence of defences or failed defences. This seeks to identify inadequate or absent defences that failed to detect and protect the system against technical and human failures. Under the ICAM model the roles of barriers include awareness, detection/warning, control and recovery, protection, escape/rescue and hazard identification.

The second level in the ICAM model is individual/team actions. This level seeks to identify the errors or violations of frontline operators that led directly to the incident under investigation. Examples of such conditions include working conditions, time pressures, tools availability etc.

The third level of ICAM is task and environmental conditions. This seeks to identify conditions that pre-existed before the incident that may have determined the actions of frontline operators or exacerbated the effects of their actions.

The fourth and final level of the ICAM is organizational factors. This level seeks to identify underlying organisational factors that produce the conditions that affect performance in the workplace. Examples of factors considered under this level are hardware, training, organisation, communication, incompatible goals, procedures, maintenance management, design, risk management, management of change, contractor management, organisational culture, regulatory influence and organisational learning (De Landre et al, 2006). The ICAM model is used by BHP Billiton in the analysis of its mining accidents.

A major problem the author of this current study identified with the ICAM method is the absence of categorization under the layer "individual and team actions". A major theme running through Reason's (1990, 1997) conceptualization of the accident process is that, although accident causal factors seem numerous, these causal factors can be categorized since they share striking similarities. For example, all forms of actions of frontline operators can be grouped into slips, lapses, mistakes and violations. The author of this current study believes that this categorization makes it easier for the design of remedies.

2.6.3. Wheel of Misfortune

The Wheel of Misfortune method was developed by O'Hare (2000) for the analysis of aviation accidents. This method is based on the fact that the performance of members at the lower structure of an organization is constrained by that of those at the top echelon of the organization. The Wheel of Misfortune model is based on Helmreich's concentric spheres and Reason's (1990) Swiss Cheese Model (cited in O'Hare, 2000). The framework of this model comprises three concentric spheres (Figure 9).

The innermost sphere represents the action of the individual that directly led to the event. Categories under this sphere include information error, deduction error, goal error, strategy error, procedure error and action error.

The second sphere of the Wheel of Misfortune model represents any condition that might have affected the performance of the operator. These conditions as represented in the wheel of misfortune framework are task demands, interface and resources.

The outermost sphere represents how management policies, philosophy and procedures create conditions that may lead to the conditions discussed in the second sphere. These categories are also interpreted with respect to recognised and unrecognised hazards (O’Hare, 2000). The author of this current study believes the categories under local actions as too ramified to be of use in any practical study.

Figure 9: The Wheel of Misfortune (from O’Hare, 2000).

2.6.4. BeSafe Method

The BeSafe (Behavioural Safety) method was developed by ergonomists at the British Coal industry as a tool for risk analysis and accident prevention. Originally known as the Potential Human Error Audit, the BeSafe method uses Reason’s (1990) idea of active and latent failure as a tool to develop accident prevention initiatives. This is achieved by identifying human error potential from task analyses and acting upon the identified errors.

The identification process (see Figure 10) involves the use of tools such as checklists, task analyses and questionnaires. Each analysis starts with assessing the environment or location where the task is likely to be carried out (environmental audit) and the effect it is likely to have on the performance of the task. This is followed by an assessment of the task requirement (job assessment) to know the kinds of abilities needed for the job. Finally, information about the person assigned to carry out the task is also analysed (person audit) to identify potential strengths and weaknesses. The knowledge from these three analyses is used to identify organizational factors that are likely to influence the occurrence of possible human errors. Other analyses carried out are a procedures and instructions audit (to identify violation inducing potential of rules), an ergonomic audit (to identify error inducing potential of work systems) and the performance factors checklist (to identify the causes of such error). The BeSafe method is not a post-hoc analysis like the earlier methods described. Accident statistics from the organization under study are only used as a check in this system as the approach is based on finding errors before they occur (Benedyk and Minister, 1998).

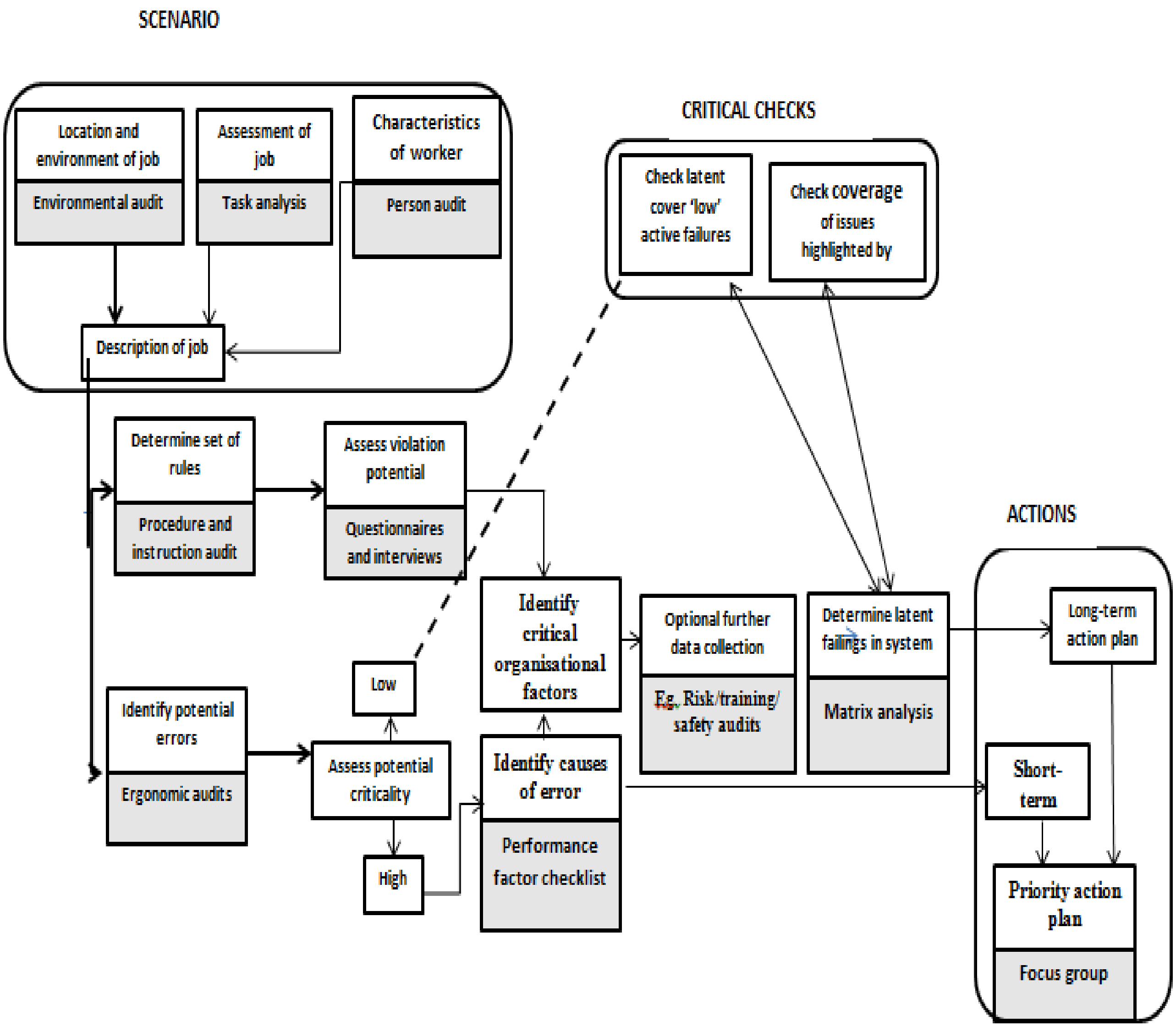

Figure 10: Besafe Method (after Bendedyk and Minister, 1998).

2.7 Systemic Safety Research

The methods described in the last section show different ways in which the Reason (1990) model can be further developed and applied to various industries. This section reviews previous studies that found a link between operator error and systemic factors in mining accidents.

Laurence (2004) conducted an attitudinal survey across the Australian mining industry. The conclusions drawn from the study suggest that management should not continue to produce more rules and regulations to cover every aspect of mining. This is because detailed safe work procedures will not connect with miners and having more effective rules and regulations is not the only answer to a safer workplace. This study seems to imply that miners want a more systemic approach to safety problems.

Paul and Maiti (2008) analysed the sequential interactions between sociotechnical and personal factors leading to accidents in mines. They found that a safe work environment was encouraged by the presence of social support and negatively impacted by job dissatisfaction and job stress, and that negative personality is encouraged by job stress but is discouraged by the presence of social support.

Kecojevic et al (2007) analysed equipment-related fatal accidents in United States mining operations. They found out that workers with less than 5 years of appropriate experience were involved in 44% of all incidents that occurred.

Sanmiquel et al (2010) analysed the causes of accidents in the Spanish mining sector. The analysis was such that causes were divided into precursors and contributing factors. The study also sought to establish how close (with regard to sequence) a causal factor was to the incident. The study reported that while environmental problems are the most dominant initiating cause of accidents, behavioural problems are usually the final cause of accidents. Environmental events were seen to be due to deficiencies in the preventive system of organisations. Skill based errors were reported as the most dominant behavioural problem. The study also identified unsafe work practice, lack of training and equipment as the main contributory factors to accidents. This study revealed why human behaviour is blamed for most accidents in the mines: *it is usually the last precursor to most incidents*. It also confirms Reason's (1990) concept of accident pathogen, which has to do with the fact that some factors are much more of the contributory nature than causal. This study however did not construct links between these accident pathogens and the behavioural factors.

Patterson and Shappell (2010) studied human factor trends and system deficiencies within mining by analysing Australian mining accidents using the HFACS-MI method. The results showed that unsafe acts were involved in almost all incidents. Skill based errors were the most pre-dominant unsafe act and did not vary across mine types. Pre-conditions for unsafe acts were present in 81.9% of the cases analysed. The environment of mine workers was the most common pre-condition for unsafe acts. Unsafe leadership was identified in 36.6% of the cases while organizational influences were identified in only 9.6% of the cases. This study represents a much more structured organizational analysis of incidents where causal factors at each level of the organizational hierarchy were identified. The results seem to show that higher level factors are involved in fewer accidents. This may be due to one of two reasons. The first is that it may be that a single deficiency in an upper organizational factor has the potential to affect more factors beneath it. The second reason is that it may be due to the focus of the accident investigation. Most accident investigations are conducted by people occupying high positions in the organizational hierarchy, which makes it less apparent for them to focus on their own misdeeds. A third reason may be found in the studies of Sanmiquel et al (2010) which found out that behavioural problems are usually the final cause of accidents. This means that, during the time of the investigation, earlier causes may have been less apparent.

The study of Lenné et al (2011) examined the extent of association between high level organisational factors and operator performance by analysing mining incidents in Australia using the HFACS method. The results showed that skill based errors are the most common causes of unsafe acts. The results further showed that while adverse physiological state was the most common cause for skill based error, adverse mental state and technological environment (level 2 factor) were the most common causes of decision error (level 1 factor), and team resource management (level 2 factor) was the most common cause of violations (level 1 factor). The study also showed that while inadequate supervision and planned inappropriate actions (level 3 factors) were the causes of most cases of crew resource management (level 2 factors), supervisory violations and inadequate supervision were the causes of adverse physiological state and adverse mental state respectively. The study identified resources management and organizational climate (level 4 factors) as the most common causes of inadequate supervision (level 3 factors). The essence of this study is the ability to construct linkages between different levels of accident causes. This study demonstrates Reason's (1990) theory of accident trajectory in mining accidents

2.8 Safety Research in South Africa

The results obtained from different studies using different methods supports the view that a systemic approach to accident causality is the right approach to tackle mining related safety issues. Although the results from the previous studies conducted in other countries are very insightful (discussed in Section 2.7), the context in which these studies were conducted is very different from that of South Africa and hence may be of limited applicability. Many of the profound differences between mining in South Africa and the rest of the world may be viewed from the human factors perspective.

One major difference between mining in South Africa as compared to other mining countries like Australia, Canada and the United States of America is that mining in South Africa is less mechanized compared to its counterparts in the aforementioned countries and much more labour intensive. While the operation of the coal industry in South Africa is similar to what obtains elsewhere, the gold and platinum mines in South Africa employ a lot of personnel due to the narrow stopes being operated (Willis et al, 2004; CSIR, 2007; Cohen, 2012). Williams (2012) reported that, in South African mines, 20 to 30 people work on a 3m by 3m development tunnel where only two people would work on the same area in Canada.

Furthermore, the Council for Scientific and Industrial Research (CSIR) of South Africa has predicted that South African mines will be labour intensive for many years to come (CSIR, 2007). The Leon Commission (Stanton, 2003) report also highlighted the relative unimportance of surface mining in South Africa as compared to underground mines. Surface mining operations are usually more mechanized than underground ones. The fact that more people are involved in activities in South African mines implies that human factor problems should be more central in the quest to achieve safety in the industry. It also speaks of the fact that the people are very close to hazards and that the current safety approach might be more administrative.

Another major difference between the South African mining industry and others around the world is the literacy level of its workforce. The Leon Commission of Enquiry (Stanton, 2003) reported that the general level of education of mine workers is dismayingly low compared to other advanced mining countries and that the absence of a common language makes communication in the industry difficult.

Consequently, one of the major focuses of mining research in South Africa has been on investigating the use of various technologies and innovations to solve specific safety challenges in the industry. For example, Squelch (2001) and Etienne (2008) explored the possibility of using a virtual reality program to enhance training for hazard identification by mine workers in underground mining conditions. This may have been prompted by earlier studies of Ashworth and Peake (1994) citing poor risk assessment and the absence of effective training methods as the main causes of fall of ground accidents. The independent studies proved that virtual reality technology has the potential to provide effective training systems that are relevant to the South African mining industry.

Teleka et al (2012) studied the potential of an automated making safe process in underground mines in South Africa. This study was in response to the long standing problem of roof falls in South African gold, coal and platinum mines. Most of these roof falls have been attributed to systemic deficiencies such as the absence of adequate make safe procedures. The study reported that the automated process had the potential to reduce roof fall related accidents.

These researches address specific problems in the mining industry. The knowledge of the fact that the mining industry is yet to fully embrace these innovations and human factors issues (due to the labour intensive nature of the South African mining industry) makes research focusing on human factors very important. The next set of paragraphs present other studies that focused on various forms of accident causality.

Ashworth and Peake (1994) studied the dominant factors affecting safety in the gold and platinum mining industries. They reported an even distribution of unsafe acts amongst slips, lapses and violations for most accidents, with the exception of rock related accidents. For rock related events the most dominant cause was inadequate entry examination. The study also reported that the lack of fit-for-purpose equipment was generally not an issue with the exception of a few mono rail and mono rope accidents. Poor communication and lack of adequate and suitable training were identified as playing significant roles in various accidents.

Moseme et al (2003) studied the causes of accidents on scraper systems in the gold and platinum mining industries. Poor adherence to standards and procedures, lack of/deficient training systems, poor hazard identification, poor risk perception and management, and poor supervision of safe working practices and procedures were identified as the principal causes of the accidents investigated.

Maisa and Pienaar (2011) investigated the relationship between work stress, job insecurity, job satisfaction and commitment, and safety compliance in a mine. The results showed that work stress and job insecurity have an inverse relationship with safety compliance. Job satisfaction was a significant predictor of safety compliance.

These studies show the wide range of factors that influence accident causality in South African mines. Some of the direct causes identified include procedural violations and poor risk and situational assessment (all forms of human error). Some systemic factors identified include poor training and supervision. Although the findings from the above studies are insightful, in that they give an idea of the causality of accidents in South African mining, no attempts were made to find the relationships between the causal factors identified in the studies.

To the best knowledge of the author, there has not been any structured study linking human error to upstream causal factors of accidents in the South African mining industry. A systemic study of mining accident causality in South Africa would be useful for a full appreciation of the dynamics of safety issues in the industry. The author of this study believes that it is only with the availability of such knowledge that stakeholders would be able to appreciate the effect of decisions made on the propensity of mine workers to commit unsafe acts leading to accidents. This study involves developing a new systemic accident framework for the analysis of accident reports from South African mines. The decision to develop a new framework in spite of existing ones and the choice of application on accident data is justified in the next chapter. The next chapter explains the framework and the reasons behind its development.

CHAPTER 3: METHODOLOGY

This chapter describes the methodology employed in achieving the set objectives. The chapter begins with the description the accident framework developed for this study. The framework is explained and compared to other previously existing frameworks. This is done to partly justify the need to develop a new framework and also to help compare results from this study to results from other studies using previously existing frameworks. This is followed by an explanation of how the accident reports used in this study were gathered. Background information about the mine from which accident reports were obtained and the format of the accident reports are provided to give the reader a contextual view. The merits and demerits of the data used are also discussed. Section 3.3 explains how the data was captured into the framework. In the last but one section, a detailed explanation of the analysis of two accident reports is provided to enhance the reader's understanding of how to use the framework. Finally Section 3.5 explains the various data analysis method used.

3.1 The Development of an Accident Analysis Framework

An analysis framework was developed to analyse accident data from a South African mine. The aim was to develop a systemic framework which is simple but applicable to accident causality in the mining context. The framework, which was developed on a Microsoft 2010 Excel spreadsheet, has three major sections, namely: causal analysis, agency and barrier analysis, and metadata. The three sections of the framework are described next.

3.1.1. Causal Analysis

This section of the framework is responsible for the analysis of accident causality (see Appendix C1 to C3). Accident causality is described in a similar manner to the Mark III version of the Swiss Cheese Model (see Figure 6). The causal section of this framework is further divided into three levels of accident causality, namely proximal causes, workplace factors and systemic factors, which are discussed in the following sections.

3.1.1.1. Proximal causes

The first level of the causal section of the framework seeks to find the activities that lead directly to an accident (see Appendix C1). These are subdivided into unsafe human acts and non-human causes. The use of the word ‘unsafe’ in this context implies any action or activity of an operator that directly leads to an accident. It may also be due to the operator’s actions failing to achieve their intended objectives. Unsafe acts are further classified into slip and lapses, mistakes, routine violations and exceptional or deviant violations. The choice to stay with this categorization is due to the fact that these are terminologies (slips, lapses, mistakes and violations) that are already being used in the safety parlance. During the development of the framework, it was deemed not necessary to use a less common classification for unsafe acts since, one of the aims of developing a new framework was ease of usage. These subdivisions (slips, lapses, mistakes and violations) cover all possible ways human behaviour can lead to accidents.

Slips and lapses as used in this framework represent all situations in which an adequate plan fails to achieve its intended purpose due to a distraction in the original plan. They can also be seen as the errors associated with highly routine activities which are carried out in an autopilot mode. While slips are due to loss of concentration, lapses are due to loss of memory. Slips and lapses although classified separately by Reason (1990), are combined in the framework developed in this study because they both entail the same psychological process which is skilled based activities. This is synonymous with skilled based errors in the HFACS and HFACS-MI frameworks or action errors in the Wheel of Misfortune framework.

Mistake: The term mistake is used in the newly developed framework to describe all situations in which a plan carried out proves to be inadequate. Mistakes are due to wrong judgement which may further be due to inadequate knowledge or wrong interpretation of a situation. Further ramifications such as diagnosis error or procedure error are also used; however, diagnosis error as presented in the Wheel of Misfortune taxonomy (O’Hare, 2000) was deemed not necessary in this framework. Such details were only seen to be necessary if further research was being conducted on the various forms of mistake. The author also believes that the nature of most accident reports do not make it possible for such details to be extracted from the reports.

Violation or non-compliance are used in this framework to describe situations where there is a deliberate attempt not to follow laid down procedure or rules. They are grouped into routine violations and exceptional/deviant violations. What distinguishes a violation from a mistake is whether or not there was an organizational rule concerning the particular act.

Routine violations involve all the times when rules are breached to save time, reduce effort or any other reasons. These violations may have been noticed by management which has not taken any step to curb them as long as they did not result in an accident. In the mining context, an example of a routine violation may be a failure to use the protective equipment specified for a particular task or starting a task without a permit to work.

Deviant violations are out of the blue violations. These are difficult to predict and control. They may occur when workers see an act as the only way to get a job done. They may also be due to a personal goal of the operator or personnel involved.

A clear distinction between routine and deviant violations can be judged from the number of times they occur.

Non-human causes: This category was created to accommodate situations in which no human error is directly involved in the cause of an accident. Events such as sudden failure of equipment, structures, natural disasters etc., are classified under this category.

3.1.1.2 Workplace factors

This level of the framework addresses conditions at the workplace/work-environment that contribute/lead to accidents (see Appendix C2). They may also be described as latent conditions that generate what been termed the proximal causes of accidents (section 3.1.1.1 above). The factors considered were adopted from the Nertney wheel or the work process model (Bullock, 1979), which identifies four components necessary for every safe and productive system.

The identified components are: competent people, safe work practices, fit-for-purpose equipment and a controlled work environment. The framework identifies lapses and deficiencies in the above four components as ways in which workplace factors can lead to accidents or affect performance.

Figure 11: The Nertney Wheel (Source: New South Wales Government, 2011)

Competent people: The quality of the human resources being used for a particular task is essential for its success or otherwise. Operations in hazardous processes such as mining require the use of *competent people*. Competence is defined in relation to the task in question. The technical know-how is judged based on whether the personnel were trained for the particular task, the training process was adequate for the task in question, and the operator was permitted to perform the task in question. This category describes all situations in which an operator did not have the ability to achieve the assigned task. People who have the requisite knowledge but did not have the physical or medical fitness to achieve the requisite task are also classified under this category. Situations in which there was a lack of numerical strength are also classified under this category. The category *competent people* may be compared to substandard conditions of operator in the HFACS. Categories such as personal readiness in HFACS and fitness for duty in HFACS-MI (by Patterson and Shappell, 2010) are placed under the category *competent people* in this framework. This view is influenced by the notion that readiness and fitness affect the competence of an operator for a particular task.

Fit-for-purpose equipment is a necessity for effective production. This category is included in the framework to cater for situations in which the quality of equipment being used influenced the output of the task or the behaviour of the operators. This includes amongst others: faulty equipment, less than adequate equipment, poor designs as well as equipment capacity below the task it is being used to perform, and the absence of any other job aid needed. Typical examples of the absence of *fit-for-purpose equipment* include malfunctioning alarms, unavailability of PPE, faulty vehicular breaking systems etc. This is analogous to technical environment in the HFACS and HFACS-MI frameworks and resources and interface in the Wheel of Misfortune framework.

Unsafe work practices: A safe working system is needed for safe production in any organization. This category is included in the framework to cater for all situations where the manner in which work is carried out at the workplace exposes workers to hazardous situations. This includes situations in which there is a lack of standards on how a particular task is to be carried out or the method described in procedures proves inadequate for safe completion of the task.

Controlled work environment: This category of the framework describes situations where the quality of the working environment affects the performance of mine workers. This category is further divided into two, namely: physical and behavioural environments.

Physical environment includes but is not limited to situations such as noisy environment, inadequate lighting, poor ventilation, slippery floors, unstable roofs, absence of safety symbols and poorly demarcated workplace. These situations are known to influence the performance of mine workers. This category is similar to *physical environment* in the HFACS and HFACS-MI frameworks and task demands (which the author of the framework explained to be affected by the task environment) in the Wheel of Misfortune framework.

Behavioural environment describes situations in which unsafe behaviours are either condoned or not frowned upon. Example of poor *behavioural environment* is when a worker finds him/herself working in a team that does not frown upon flouting of working procedures. *Behavioural environment* as used in this study is analogous to crew resource management in the HFACS framework or communication and coordination in the HFACS-MI framework (both embody poor leadership and poor coordination). Paul and Maiti (2008) also found that safety behaviour is improved by the presence of a social support group.

3.1.1.3 Systemic factors

An underlying theme in the Reason (1990, 1997) model of accident causality is that accidents occur because components of the system stopped acting in a safe manner. This layer of the framework looks at ways in which the top hierarchy of organizations acts in an unsafe manner (Appendix C3). Most of the components under this section are elements of safety management systems. Most factors considered here are similar to those discussed by De Landre et al (2006) in the ICAM model.

Training and competence: This category of the framework addresses situations where training being offered to a worker does not help him to perform the required task in a safe way. It also includes situations when a worker has not been made to undergo all the training necessary before being assigned tasks. This is not only limited to task training but also job safety/hazard training. The selection of people totally unqualified for tasks assigned to them is also included under this category.

Contractor management*:* This involves situations where lack of company standards on work performed by employees of contractor companies results in unwanted events. This includes making sure that employees of contracting companies have received the necessary training on tasks they perform and that they adhere to the safety standards of the company. This also includes briefing contractors on dangers specific to the site of the company. This category of the framework is included to cater for situations in which poor contractor management serves as the root cause of an accident.

Design*:* This category of the framework represents situations when poor design of either equipment or workplace leads either directly to accidents or the existence of *physical environmental* problems. Poor design of workplace can lead to situations such as narrow roads, easily flooded workplaces, absence of warning signals etc. This is seen as one of the main causes of the workplace factor *physical environment*. Poor design of equipment includes designs that do not take into consideration the natural abilities and limitations of the end user such as confusing interfaces, weak signals and injury prone equipment.

Management of change*:* Changes that occur in organizations introduce new risks into the system. This category covers situations where management's inability to appreciate the full risk that comes with a new project, equipment, and task, leads to an accident. This category is included in the framework to cater for situations in which failure to fully appreciate the risk accompanying changes in an organization serves as a root cause for accidents.

Hazard identification*:* Controls put in place can only protect workers against hazards for which they were designed. This makes the identification of major hazards associated with each task important. This category of the framework represents situations in which there were no organizational controls for a hazard due to lack of identification.

Monitoring and auditing*:* For safe production there must be a system of control in place. These control systems must be constantly audited and monitored to ensure that they are being adhered to and also sufficient to deal with the ever changing working environment. This category is included in the framework to identify situations in which lack of monitoring and auditing of existing controls leads to accidents

Maintenance management*:* This category of the framework covers all situations when poor maintenance of equipment and structures leads to accidents. A culture of poor equipment maintenance can lead to equipment not being fit for purpose which will also lead to operators making mistakes and committing a whole lot of unsafe acts. This is also a major root cause of the existence of equipment which is not fit for purpose. Poor workplace maintenance usually leads to situations of unstable roofs, poor sanitation, unmaintained ventilation and illumination systems, unmaintained structures etc. This is also seen as a major root cause (aside from poor design of the workplace and poor housekeeping) of *physical environment* problems. These conditions affect the performance of mine workers.

Resource provision*:* This category covers situations in which failure of management to provide the needed resources for the accomplishment of tasks leads to accidents. Unsafe acts such as failure to wear personal protective equipment have been traced in some accident investigations to the management's failure to provide the required personal protective equipment at workplaces.

Strategic planning*:* Investigations into past accidents have revealed that management is frequently confronted with decisions involving conflicting goals (Reason, 1997). Decisions such as reduction in the number of workforce, how long a shift should take and all other decisions that border on the balance between safety and production, can sometimes lead to conditions that create accident liability. This category is not easily identified in accident reports.

Risk management*:* This category of the framework represents situations in which the refusal to deal properly with an identified risk or to manage a known problem in the organization serve as a root cause of an accident. It also includes situations in which the risk management approach was deficient in dealing with identified risk.

Leadership*:* The effect of leadership in the behavioural patterns in a work place cannot be overestimated. Safety climate has been described as the employee's perception of how concerned leadership is about safety. In an industry like mining where most defences are hinged on the willingness of employees to obey the company's standards and procedures, the presence of visible leadership to serve as an example and to enforce rules is very important. This category is included in the framework to cater for situations such as ineffective supervision, failure to correct deviant behaviours and any other situation in which actions or inactions of leaders could have prevented an incident.

Housekeeping: The nature of tasks in high risk occupations such as mining is accompanied with hazards of varying nature. Some of these hazards such as spills, trip hazards (e.g. ropes and other object lying in walkways) and fallen rocks evolve with the task hence proper housekeeping procedures are needed to keep the workplace safe. The category is included in the framework to cater for situations in which failure by management to enforce good housekeeping policies lead either directly lead to an accident or serves as a precursor for an unsafe act.

Work scheduling*:* The manner in which an organization schedules its work affects the safety compliance of the employees and risks associated with tasks. Situations such as working long hours without breaks, continuous night shifts, long shifts (> 8 hours) and overtime increase the risks faced by employees. Work schedules which collide with bad weather and other nonconducive environmental situations increase the risks faced by workers. This category is included in the framework as a systemic factor to cater for situations in which work schedule serves as a root cause of an accident.

***Emergency response**:* An emergency can be defined as a sudden unforeseen crisis which usually involves danger. These situations require immediate action to protect people, property and the environment. It is the duty of mine management to train workers with regards to what to do in an emergency and also provide the right tools to use in such situations. This category is included in the framework to cater for situations in which the lack of proper emergency procedures exacerbates the effect of an accident.

3.1.1.4 Comparison with other frameworks

The section discusses how the causal analysis section of the new framework compares to other frameworks. The comparisons are made between the newly developed framework and other models such as the Human Factors Analysis and Classification Method (HFACS) and the Human Factors Analysis and Classification Method for Mining Industry (HFACS-MI), the Wheel of Misfortune and the Incident Cause and Analysis Model (ICAM). These frameworks were chosen because of their relative popularity.

The first difference between the new framework and the HFACS method of analysis is the number and kind of levels used to identify accident causality. While the new framework identifies three levels of accident causality (consistent with the Mark III version of the Swiss Cheese Model), the HFACS identifies four (consistent with the Mark I version of the SCM). The difference arises from the inclusion of a separate level for the effect of leadership/supervision on accidents that is created in the HFACS method (also existent in the Mark I version of the SCM). This additional level was however not seen to be necessary in the new framework since in most systems the role of leadership is to make sure that systemic structures work, hence it cannot always be argued that organizational factors place a constraint on the performance of leadership. The new framework is developed based on the view that effective leadership is part of systemic/organizational factors which constrains lower level factors such as the workplace and proximal causes. The three layers of accident causality used in the new framework are shared with both the ICAM and the Wheel of Misfortune frameworks.

A significant difference between the new framework and the ICAM model is the absence of categories under the layer of human error (in the ICAM model). This has already been discussed in Section 2.6.2. This also may have been noticed during the discussion of the proximal and workplace factors of the new framework: no comparisons were made with the ICAM model due to the absence of such categories. The new framework shares categorization of proximal and workplace factors with the HFACS and Wheel of Misfortune models.

3.1.2 Agency and Barrier Analysis

The agency and barrier analysis section of the framework was designed to capture information of the accident causing agents and the safety barriers broken in each accident (see Appendix B). This was done with the belief that information from this section gives more meaning to the results obtained from the causal section.

Safety barriers

This section of the framework records the safety barriers that failed during the accident process. Safety barriers can be defined as any means (physical or non-physical) instituted to prevent, control, or mitigate accidents (Hollnagel, 2008). The need for safety barriers in industry arises from the fact that the nature of some industrial activities is such that it is not always possible to remove all hazards by design. In such situations the safety of employees is ensured by placing a barrier between them and the hazard. This implies that the harm from a hazard only reaches a target when there is no safety barrier to prevent it or the barriers put in place were not effective. This section of the framework is responsible for analysis of the safety barriers that were breached in order for a hazard to reach a target. Knowledge of the nature of barriers broken, and how and why they were breached, provides a lot of insight into the causes of accidents. The nature of the safe barriers in place also tells a lot about the nature of the industry and the kinds of unsafe acts which will dominate in such industry. The ICAM framework also has a barrier analysis section (see Figure 8).

Accident causing agencies

This section of the framework records information on the agencies involved in each of the accidents analysed. While recording the hazards provides information on the energy causing the harm, recording the agencies provides information on the material carrying the energy. The latter classification was chosen for the new framework developed in this study to ensure that the output of the work was comparable to earlier and future work. The accident classification codes employed in Item 12 of the South African Mines Reportable Accidents Statistics System (SAMRASS) were used in the categorization of the accidents analysed (Department of Mineral Resources, 2007). Under Item 12 of the SAMRASS code book, agencies identified include *fall of ground*, *machinery tool and equipment*, *transport and mining*, *conveyance accidents*, *electricity*, *fire*, *explosives* and *caving*. The nature of the mine being studied and the types of accidents prevalent in the mine necessitated slight modifications in the use of agencies which will be discussed with the results. "Agencies" as used in this work is synonymous with the term "material agent of contact" used in the European Statistics on Accidents at Work (ESAW) variables. This classification was employed in the work of Jacinto and Soares (2008).

3.1.3 Metadata

In addition to data on barriers and accident causing agencies, the new framework was designed to capture specific metadata about the accidents analysed (see Appendix A). Although the studies of Patterson and Shappell (2010) incorporated some situational data, metadata has never been formally integrated into any of the frameworks based on the Reason (1990, 1997) model. Metadata can simply be described as data about data or data describing data. These data were chosen to elucidate other factors that may have influenced these accidents. For example, knowledge of a particular time in which most specific unsafe acts occur could help in understanding why those unsafe acts are occurring. The variables chosen were time of accident, day of accident, activity the victim was involved in which resulted in the accident, place of the accident (underground, surface etc.), status of the victim (contractor employee or company employee), age of victim, relevant work experience of personnel and the last vacation period of victim. This information on an individual basis may not be very significant but when used together proved very useful. These variables were chosen to synchronize with variables specified in the December 2007 code book of South Africa Mines Reportable Accident Statistics System (SAMRASS). This is because the accident reports being used for the study were written as prescribed by the SAMRASS system.

3.2 Data Gathering

Data used for this work involved accidents that occurred in a platinum mine in South Africa. Data could only be obtained from a single mine due to confidentiality issues surrounding mine safety in South Africa. The author is aware that using data from just one mine has the disadvantage of limiting the applicability of the results obtained in this study. However, the use of data from just one mine is advantageous based on the fact that great deal of contextual information accompanying the data was obtained thereby making the analysis relevant. This is unlike the use of summarised accident reports from the SAMRASS system where such details may be not obtained. The reason for choosing a platinum mine is because of its relative importance in terms of safety in the South African mining industry. It is known that the platinum mining sector has the second highest annual fatalities and Jansen and Brent (2005) reported that the safety situation in the platinum industry is getting worse.

3.2.1 Background of mine used as case study

The mine has two production shafts and a process plant and it has since 2011 developed its own accident framework by adapting the Swiss Cheese metaphor of Reason (1990) to reflect its safety dynamics. Each accident report obtained from the mine has sections containing information about the victim such as date of birth, job title and experience, and situational data like time, agency and date of incident. In addition, every report has a description of the event, a sketch or a photograph of the incident, an immediate and basic cause sections, an analysis section and a remedial action section. The reports used were from accidents that occurred from 2010 to 2012.

Two forms of accident reports were used in this study. While the 2011 and 2012 reports each contained a barrier analysis section developed from Reason’s (1990) Swiss Cheese Model, the

2010 reports did not. A total of 91 accident reports were used in the study. The reports used included 1 fatality, 27 serious injuries, 31 Lost Time Injuries and 32 minor injuries. In the organization's context, a fatality is defined as any incident that results in the death of one or more people. A serious incident is defined as any incident that leads to a permanent deformity of the victim or renders its victims unable to work for 14 days or more. A Lost Time Injury is defined as any incident that renders its victim unable to work for 1 to 13 days. A minor injury is any injury that is able to render the victim unable to work for up to one day. These definitions are in harmony with the standards prescribed by SAMRASS (Department of Mineral Resources, 2007).

3.3 Coding

The author spent two weeks on the premises of the mining firm. During the two weeks, the author was exposed to the firm's operations and safety philosophy. The author had access to the firm's standards and procedure books to help clarify the causes of the accident analysed. Throughout the period of coding, the author was in constant contact with the safety manager of the firm to explain the terminology used in the reports.

Accident data from the reports were coded into the new framework using the form as presented in appendices A,B and C. Framework categories (such as mistakes, slips and lapses) were identified using the description of events, sketch or photographs, immediate and basic causes, analysis and recommendations from the accident reports. Each category in the framework (such as mistakes, physical environment etc.) was counted a maximum of one time as a cause of accident. This count acted as an indication of the presence or absence of a given category for each incident. This was also done to prevent over representation of a single incident. Other relevant data about each accident were recorded.

3.3.1. Coding of direct causes of accidents.

The classification of the direct causes of accidents was based on information captured under the immediate causes section of the accident report. Though the report never categorized accidents as mistakes, slips and lapses and violations, the exact unsafe act committed by workers was usually written in the report (e.g. failure to conduct risk assessment). The author had to use knowledge obtained from organization's standards and procedure to determine what kind of unsafe act had been committed. The differentiating factor between *violations* and other unsafe acts (*mistakes*, *slips and lapses*) was whether or not a rule broken by the victim. The distinguishing factor between routine and deviant violations was the frequency of that particular kind of violations. The distinguishing factor between *slips and lapses* and *mistake*s was intentionality (whether the action proceeded as planned).

3.3.2. Coding of workplace and systemic factors

The classification of workplace and systemic factors leading to accidents were obtained from the basic causes and the recommendation section of the accident reports analysed. Although the sub-categories used in the framework were not directly present in the accident report, decisions of workplace and systemic factors responsible for the accidents were deduced from information such as "failure by supervisor to conduct planned task observation", "poor housekeeping", "unlevelled ground" etc. available in the reports analysed.

To illustrate the process, two case studies are presented in section 3.4 below.

3.4 Case Studies

To clarify the coding process that took place, two accidents that occurred at the mine will be used for illustration.

3.4.1 Example 1: A Fall of ground leading to the death of an employee

The following paragraph gives an account of the event that occurred:

The accident occurred on the 6^{th} *of February 2012 at around 1:20 pm. A worker was walking underground in the north shaft when a fall of ground occurred during the installation of hydrabolts. The victim died as a result of being struck by the falling rock on his skull and neck. The investigation by the Department of Mineral Resources revealed that the fall was due to a* ***geological defect*** *that was not noticed during the pre-shift inspection. The inspection was done by an employee of the rock engineering department who* ***was not qualified per company standards to do that inspection****. The employee did it because he* ***was instructed by the chief rock***

engineer to do the inspection. *The chief rock engineer ordered an unqualified worker to do the inspection because his department* ***was understaffed*** *as a result of the* ***resignation of three qualified rock engineers.***

During the coding, the unsafe act identified in the above report was the employee who carried out a task he was not qualified to do. This act is indicated in the framework (Table C.1) as *routine violation* because the author believes it was not the first time it was happening (this is motivated by the knowledge that the rock engineer position has been vacant for a while). The workplace factor responsible for such behaviour was the encouragement from his supervisor to disobey the standards; this is indicated in the framework as *behavioural environment* (Table C.2). The systemic factors identified included poor leadership commitment to safety (indicated in framework as *leadership*) and inadequate management of the effect of the resignation of three qualified rock engineer (indicated on framework as *management of change*).

3.4.2. Example 2: A Lost Time Injury resulting from a machinery accident

The following paragraph gives an account of the event that occurred:

The accident occurred on the 8th of December 2011 at around 10:30 am. A belt attendant was struck by a load-haul-dump (LHD) while sitting against the sidewall in roadway. The accident led to the injury of the victim. A belt attendant was attending to an electrical water pump in the material decline when he sat down to rest against the side wall. The victim might have fallen asleep as he did not see or hear the LHD coming. The internal investigation of the mine management revealed that the victim was ***sitting at a place not approved by the rules****. Investigations also revealed that* ***the place (cubby) was not properly cleaned*** *and might have contributed to the victim sitting there. The investigations also revealed that* ***the victim was suffering from a chronic illness*** *which might have led to him falling asleep.*

During the coding of the accident, two unsafe acts categories were identified, namely *routine violation* and *slips and lapses* (Table C.1). In the framework, the 'victim sitting at an unsanctioned place' was classified as *routine violation* (with the belief that it was not the first time it was occurring) while ‘not hearing the sound of an oncoming LHD was classified as a *slip*. The workplace factors identified to have contributed to the unsafe acts were *physical environment* and *competent people*. The dirty cubby (*physical environment*) might have been the reason why he chose to sit by the road side while his chronic illness (affecting his competence) might have impaired his ability to hear the oncoming LHD. The systemic factors identified to have contributed to the accident were *housekeeping* and *contractor management*. Poor *housekeeping* was identified as the reason why the cubby was dirty while poor *contractor management* was identified as the reason why an unfit contractor was being made to work.

3.5 Data Analysis

This section explains the tools that were used for data analysis and representation in this study. The pivot table and chart tools in Microsoft Excel 2010 were used to categorize and summarize the data. The filter tool was used to single out sections of the needed information needed. The first group of charts generated from the framework (Figures 12 to 16 in Chapter Four) are accident characterization diagrams. These charts represent the different ways in which the nature of the accidents analysed can be viewed. Accidents were classified according to the task that the victims were performing, the type of employee, the nature of agencies, the job title of victims and the nature of barriers broken. Such charts can be used to determine whether specific categories of people are more vulnerable to accidents than others. For example, the chart on the task being performed during the accident (Figure 12) can give a rough idea of the most accident prone tasks.

The second group of charts generated using the pivot chart tools (Figures 17, 23 and 27 in Chapter Four) relate to accident causality. Specific charts generated include the distribution of human error, the distribution of workplace factors and the systemic factors identified in the accidents analysed. The last group of charts generated (Figures 18 to 22, 24 to 26 and 28 to 32) establish links between different kinds of variables. These charts were generated to determine the effect the variables have on one another. For example, charts were generated to determine the effects of variables such as time on the unsafe acts committed. Charts were also produced to portray the link between downstream causal factors and upstream ones, e.g. charts showing the kind of workplace factors that usually cause violations (Figure 24).

To conclude, the various sections of this chapter have demonstrated that verifiable methods have been employed in this research. The developed framework has been explained in detail and compared to previously existing frameworks such as the HFACS and HFACS-MI, the ICAM model and the Wheel of Misfortune. The source of data and how the framework was applied to them has also been clearly demonstrated with two examples. The next chapter presents the results obtained from the processes explained.

CHAPTER 4 RESULTS

This chapter presents the results of the analysis of the 91 accident reports described in section 3.2 above. The first sets of results (Section 4.1) are from the accident characterization process. As already explained in Chapter Three, such results are aimed at portraying the nature of the activities at the mine under study. This was done because of the belief that the nature of the operations on a particular site is closely linked with the causes of accidents on that site. It is also believed that this serves as the foundation for the causal analysis results.

The second sets of results (Section 4.2) are from the causal analysis of each incident. A summary table is first presented alongside highlights of the preliminary findings. This is followed by detailed presentation of results on each level of accident causality identified, i.e. unsafe acts, workplace factors and systemic factors (Section 4.3 to 4.5). The predominant causal factors identified at each level are presented alongside with background information which is not apparent from the results.

Other results presented in this section include the analysis of the metadata data pertaining to each incident, looking for the possible effects of variables such as time, age, experience etc. on unsafe acts, and identified links between higher and lower level causal factors.

4.1 Accident Characterization

This section presents results of characterizing the accidents according to factors such as type of task being performed, type of employee involved, nature of agency, job title of victims and type of barrier broken.

4.1.1. Task

The characterization of accidents according to task (see Figure 12) was done to give an indication of the level of sophistication of technology used in the industry (e.g. manual or mechanized). This was done in synchrony with codes prescribed by Item 1, Section F of the SAMRASS code book. Figure 12 shows that *drilling, engineering task, handling of material,* and *transportation of people* were the most accident prone tasks.

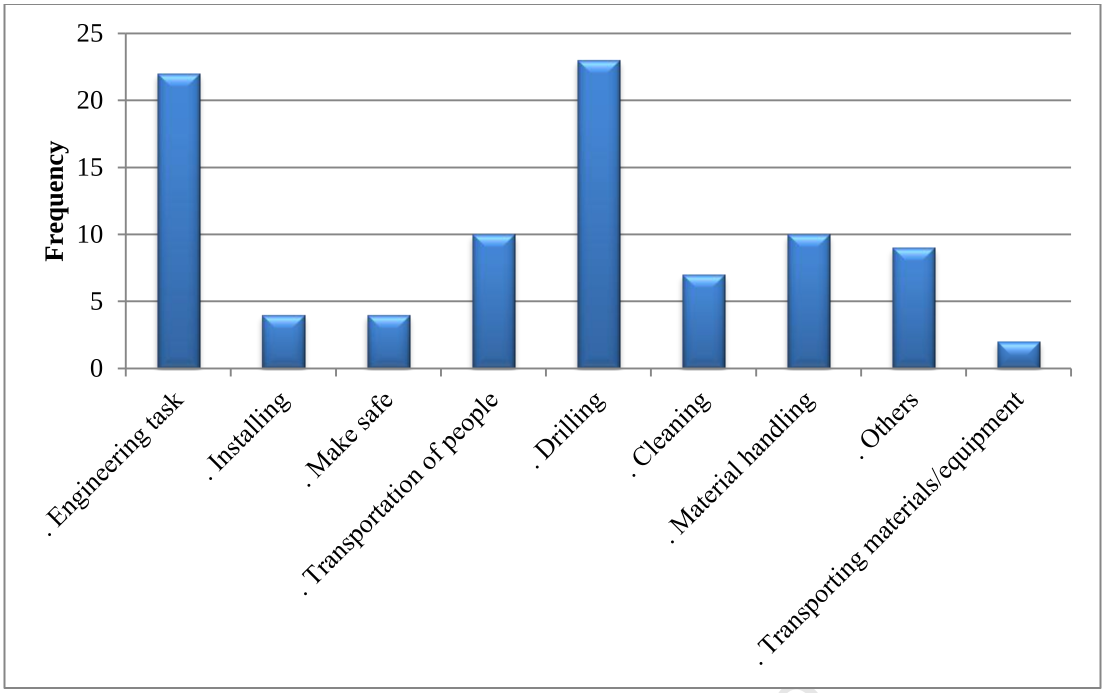

Figure 12: Distribution of accidents according to task being performed.

The term *drilling* as used in this study represents tasks involving the use of hand held drilling machines on the job being performed. *Drilling* tasks were involved in lots of accidents due to the numerous hazards associated with drilling such as the possibility of *fall of ground* and the threat of being hurt by equipment. The fact that *drilling* is usually done on unlevelled ground and in confined spacing also makes it an accident prone task.

The accidents classified under the term *engineering task* occurred during periods of maintenance, assembling, installation and erection of equipment. *Engineering task* represents a category of tasks where workers are very exposed to hazards.

Accidents that occurred under the category *transportation of people* usually involved self-transport situations (e.g. walking, ascending and descending). The main reason for such accidents was the poor environmental conditions existing at the time of the incident. Accidents involving *material handling* tasks occurred in situations such as manual loading/unloading, stacking and lifting of items. *Cleaning* related accidents involved housekeeping task such as removing fallen rocks. Accidents under the task *make safe* category mostly occurred during *barring*. The term *barring* is used to describe the act of bringing down hanging and loose rocks in an unsupported area (places without safety net installation) before a shift starts. It usually involved using a long spanner to hit these rocks. This was done to prevent *fall of ground*. The category *others* was used not necessarily for tasks that did not fit any classification but for those that had very low frequencies on an individual basis.

Even a preliminary analysis of the tasks which take place at the mine under study show that a lot of human labour is being used; hence the accidents recorded involve a lot of human inputs. This is unlike chemical plants and the mining industry in developed countries of the world where most activities are either mechanized or automated.

In their study of the South Africa gold and platinum industries, Ashworth and Peake (1994) also identified drilling and engineering works (installation and maintenance) as activities frequently leading to accidents. However, while their study identified cleaning, transportation of ore, supervisory activities as being involved in a significant number of accidents, the results of the present study did not corroborate those findings. This may be due to the fact that their work included the gold industry or some changes in the industry that may have happened since that time.

4.1.2. Characterization by employee type

The result of the characterization of accidents according to employee type (Figure 13) shows that the percentage of accidents involving contractor employees is very significant. The tasks assigned to contractor employees were very similar to those of the company's employees. This seems to suggest that every safety strategy that is implemented should have factored into it the hazard being introduced by workers from outside the firm. This work however could not categorize company employees into casual and permanent workers, as prescribed by the SAMRASS accident sheet. This was due to the lack of distinction in reports used for this work.

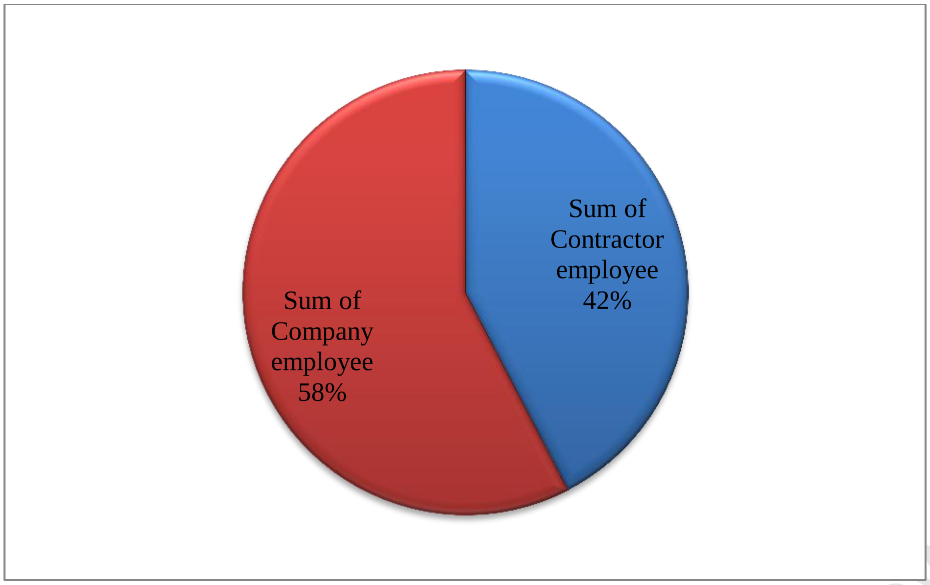

Figure 13: Distribution of accidents according to employee type

4.1.3. Job title

The characterization of accidents according to job title (see Figure 14) was done to determine the groups of workers usually prone to accidents. The comparison of such results with the characterization according to task also helps to ascertain whether workers were doing jobs for which they were trained. The characterisation according to job title (Figure 14) shows that rock drill operators, machinery operators and artisans were most involved in accidents. This is consistent with the earlier characterization of accidents according to task (Figure 12), where drilling and engineering tasks were the most accident prone tasks. This shows that most tasks which were involved in accidents were being done by people trained to do them.

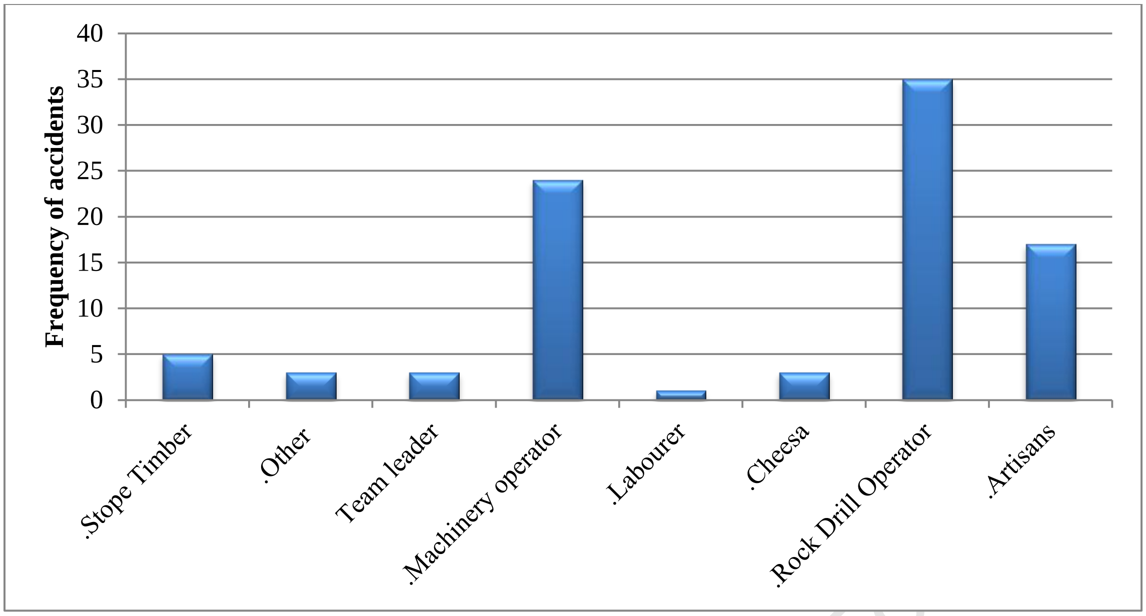

Figure 14: Distribution of accidents according to job title of victims. (Note: A cheesa is a person in charge of charging up mining panels with explosive for daily blasting activities).

4.1.4. Agencies

To give an indication of the common modes of injury, accidents were characterized according to the agencies involved. Figure 15 shows that while *hand tools/equipment* and *fall of ground* were the most common accident causing agencies, *falling material/rolling rock*, *slipping and falling*, *manual handling of material*, *track bound equipmen*t and *scraper and winches* were also involved in a significant number of accidents. The next few paragraphs are intended to elucidate how these agencies were used.

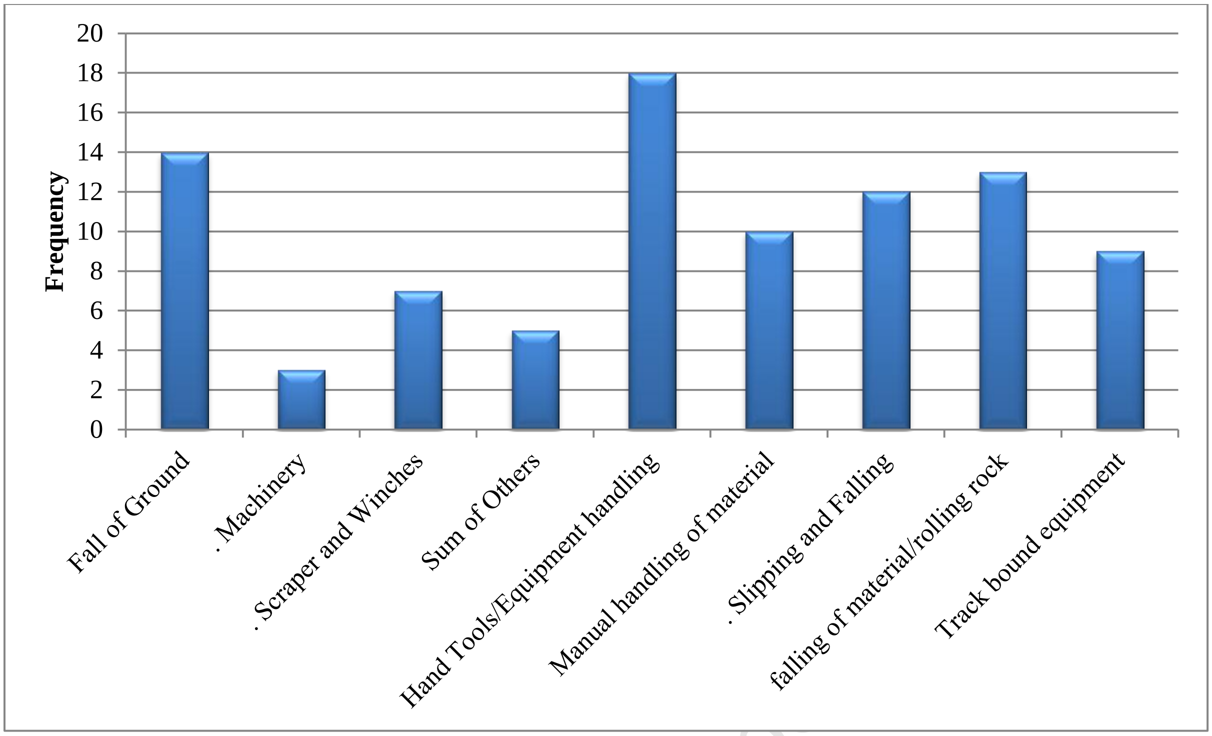

Figure 15: Distribution of accidents according to the agency involved

In this study, the category *hand tools/equipment* represents a slight modification of the classification used in the SAMRASS code book which is *portable power tools* (hand held drilling machines). The modification entails the inclusion of other hand held tools such as pinch bars and camlock jacks used by employees in most engineering tasks and activities such as *barring* (bringing down) of loose rocks.

The category of *hand tools/equipment* being the most dominant accident causing agency is consistent with the fact that drilling and engineering tasks were the most accident prone tasks identified when accidents were characterized according to tasks (Figure 12). Most injuries involving the use of drilling machines were related to the detachment of the drilling leg, while most of the injuries involving pinch bars and camlock jacks involved either pinching or being struck by the tool.

While most *fall of ground* occurred during drilling and *barring* down of rock (make safe activities), injuries resulting from contact with *track bound equipment* (mainly locomotives and hoppers) occurred during coupling/uncoupling and re-railing of the equipment. There were no instances of accidents occurring as a result of the operation of the track bound equipment. Situations in which falling rock strike a victim after coming into contact with the footwall are classified as *rolling rock*.

Most examples of *slipping and falling* occurred during *self-transport activities* such as walking and running. There were no situations such as falling from heights. While injuries resulting from *manual handling of material* (metal screens, vent pipes, chain blocks) also coincided with *material handling* task in Figure 12, injuries resulting from *scraper and winches* were frequently installation related incidents. *Machinery* was used to classify any other machinery which did not fall in the previously specified machines (*track bound equipment*, *scraper and winches*). The conclusion that can be drawn from these results is that, in most of these accidents, workers were much too close to the injury causing hazards.

The results shown in Figure 15 were compared with those of Ashworth and Peake (1994), Sanmiquel et al (2010), Kecojevic et al (2007), Cawley (2003) and Lenné et al (2011). Ashworth and Peake (1994), who studied causes of accidents in the South African platinum and gold industries, also identified *fall of ground*, *track bound equipment*, *slipping and falling*, and *scraper and winches* as frequent causes of accidents. This implies that the profile of accidents in the mine used as a case study in this research can be said to be a reasonably good representation of the accident profile of the South African platinum industry.

Sanmiquel et al (2010), whose study was based on Spanish mines, reported that most of the underground accidents reported were caused by falling and collapsing objects followed by victims being trapped between objects. These incidents are very similar to *fall of ground*, *falling material or rolling rock* identified in this study as some of the most common agencies. Kecojevic et al (2007) reported that annual mine fatalities attributable to mine equipment (e.g. haul trucks, belt conveyors, front-end loaders, and miscellaneous equipment) in the United States ranged from 37% to 88%. This may be due to the fact that mining in the United States is more mechanized. Cawley (2003) reported that electrical related accidents represent the fourth highest cause of mining accidents in the United States. Lenné et al (2011) reported that operations involving surface mobile equipment, working at heights and electrical operations were the highest causes of mining accidents in Australia. However, it is worth stating that neither the study nor that of Ashworth and Peake (1994) (which are both based in South Africa) identified electrical accidents as a significant cause of accidents in South African mines. These differences in the types of agencies dominating accidents highlights fundamental differences in safety concerns between the mining industry in South Africa and in more developed countries. While key safety concerns in the aforementioned countries may be how to deal with residual hazards associated with a high level of mechanization of mining activities, the South African mining industry is still faced with the challenge of removing well known hazards (e.g. fall of ground) which have existed in its operations for a long period.

4.1.5. Broken Barriers

This section analyses the results obtained from the characterization of accidents according to the barriers broken; this gives an indication of the nature and efficacy of safeguards designed by the mine to mitigate the effect of hazards. From Figure 16, the most breached safety barriers are *supervision*, *standards and procedures* and *risk assessments*. This illustrates the fact that existing controls (like supervision) which are put in place so as to ensure that workers obey standards and procedures are not very effective. It further shows that most barriers used for the prevention of accidents are administrative in nature (e.g. rules, supervision, job safety analysis) rather than mechanised (alarms, barricades, interlocks, etc). Most incidents analysed involve the breaching of two or more barriers.

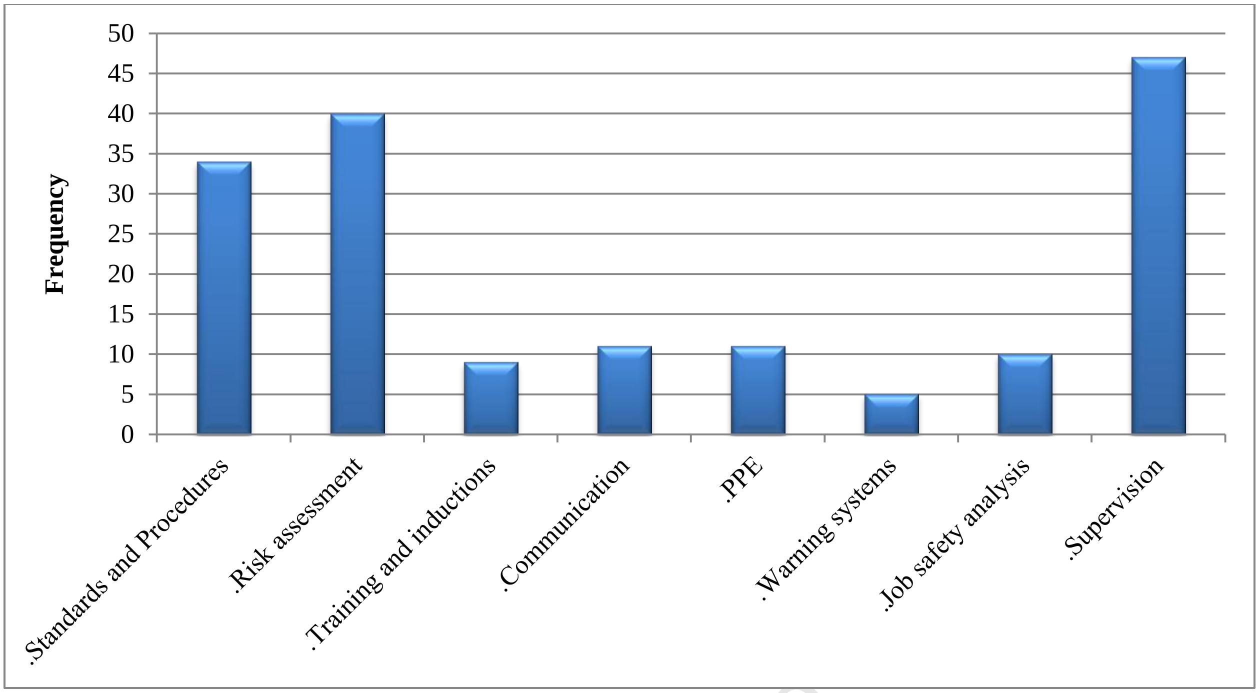

Figure 16: Distribution of accidents according to the nature barriers broken

4.2 Causal Analysis

This section serves as an introduction to the causal factors identified in this study. It starts with a summary of the results (Table 1) followed by appropriate comparisons with other studies.

Unsafe acts were identified in 98.9% (90 out of the 91) of the accident reports analysed. This comes as a no surprise since the mine is so labour intensive. The most common form of unsafe acts identified are *routine violations* (identified in 45% of all cases) followed closely by *mistakes* (43% of all accidents analysed) and then *slips and lapses* (30.8% of all accidents analysed). Workplace and systemic factors were implicated in 97.8% of cases analysed. The most prevalent workplace factor identified is the *physical environment* (39.6% of all accidents analysed), closely followed by the *behavioural environment* (34.1% of all accidents analysed). *Unsafe work practices*, *fit-for-purpose equipment* and *competent people* were also identified in this study as significantly contributing to accidents.

Table 1: Accident causes by framework categories from the analysis of 91 accident reports.

Framework Category	Frequency	Percentage
Systemic Factors		
Management of Change	11	12.1
Leadership	47	51.6
Training and competence	7	7.7
Contractor management	8	8.8
Risk Management	9	9.9
Housekeeping	9	9.9
Design	8	8.8
Maintenance management	7	7.7
Hazard identification	18	19.8
Monitoring and auditing	5	5.5
Strategic decision	0	0.0
Work Scheduling	4	4.4
Emergency response	0	0.0
Workplace Factors		
Competent People	18	19.8
Fit For Purpose equipment	16	17.6
Physical environment	36	39.6
Behavioural environment	31	34.1
Unsafe work practices	14	15.4
Direct Causes		
Slips and Lapses	29	30.8
Mistakes	39	43.0
Routine violation	41	45.0
Deviant violation	2	2.2

The identification of the physical environment as a major contributory factor was not a surprise due to the harsh working conditions underground. This is similar to results obtained by Lenné et al (2011) and Patterson and Shappell (2010), from the analysis of different accident reports from Australian mines, and Sanmiquel et al (2010) for Spanish mines. In the case of Lenné et al (2011) and Patterson and Shappell (2010), physical environment was involved in 55% and 39% respectively of all accidents, while in the case of Sanmiquel et al (2010) physical environment was involved in about 58% of all accidents.

Table 1 shows that *leadership* was the most common systemic factor identified in this study. Other systemic factors identified in this study as significantly leading to accidents at the mine are *hazard identification*, *maintenance management* and *management of change*. Factors such as *emergency response* and *strategic decision* were not identified in this study as contributing to any of the accidents analysed.

The involvement of systemic factors in this study was higher than the studies of Lenné et al (2011) and Patterson and Shappell (2010), both of which concerned the Australian underground and surface mines. This is partly due to the fact that in the HFACS framework used by Lenné et al (2011) and Patterson and Shappell (2010), *leadership*, which is the most prevalent organizational factor identified in this study, is a separate level in the HFACS system.

The percentage of causal factors in Table 1 in each level of the causal section of the framework (i.e. direct causes, workplace and systemic factors) does not add up to 100%, because in most cases, two or more factors were identified under the same level of the framework as contributing to the same accident. For example, a worker not wearing the right personal protective equipment (reported as a *routine violation*) might also have made a wrong judgement (reported as *mistakes*) concerning the safety distance between humans and hazards.

4.3. Unsafe acts

In this section, the unsafe acts identified in this study are analysed in a more detailed manner. The section starts by giving examples of specific unsafe acts identified under the broad categories (slips and lapses, mistakes and violations) of the framework. This is then followed by an analysis of the unsafe acts distribution according to factors such as agencies, type of employee, age, experience and time of day.

4.3.1 Distribution of unsafe acts

As stated earlier, this study identified unsafe acts in almost all the accidents analysed. Figure 17 shows the overall distribution of the unsafe acts identified.

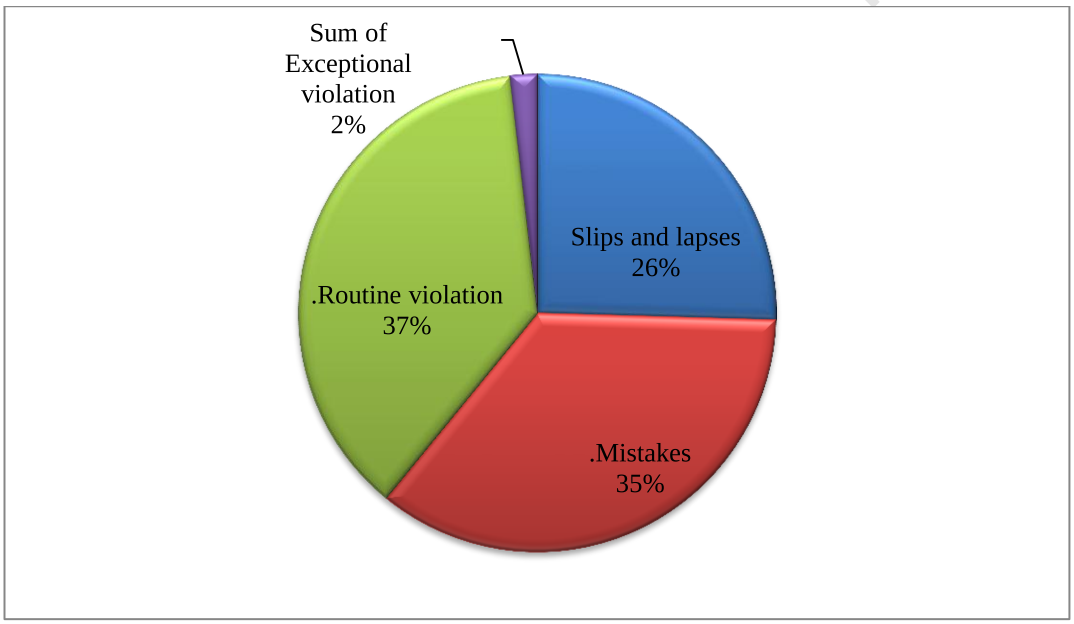

Figure 17: Overall distribution of unsafe acts

As can be seen from Figure 17, violations (*routine* and *exceptional/deviant*) constitute the most common unsafe acts, followed by *mistakes* and then *slips and lapses*. The most common violations included the following: non-usage of PPE, failure to conduct pre and mid-shift *barring*, use of wrong tools, failure to conduct risk assessment on tasks and working (usually coupling and decoupling) on moving machinery.

The most common mistakes recorded were inadequate risk/situational assessment and inadequate communication. Inadequate risk assessment usually led to situations in which miners took the wrong position for a task, used equipment below its capacity and or made decisions that exposed them to hazards. Since miners work in environments which are not always predictable, their ability to discern when conditions are safe and when they are not is very critical to safe operation.

Slips and Lapses had the least occurrence when compared to violations and mistakes. The most common cases of *slips and lapses* recorded were lack of alertness and not being able to avoid hazards because of not seeing them. The occurrence of these slips was not surprising due to the extreme conditions to which workers were being exposed and the length of time worked during shifts.

4.3.2 Distribution of unsafe acts according to agencies

This section analyses the distribution of unsafe acts across the different accident agencies (see Figure 15). This information could help in developing specific strategies for particular types of accident causing agencies. For example, if a particular type of violation leading to fall of ground is understood, measures can be put in place to address it. This approach is better than using a general solution strategy to address all kinds of violations.

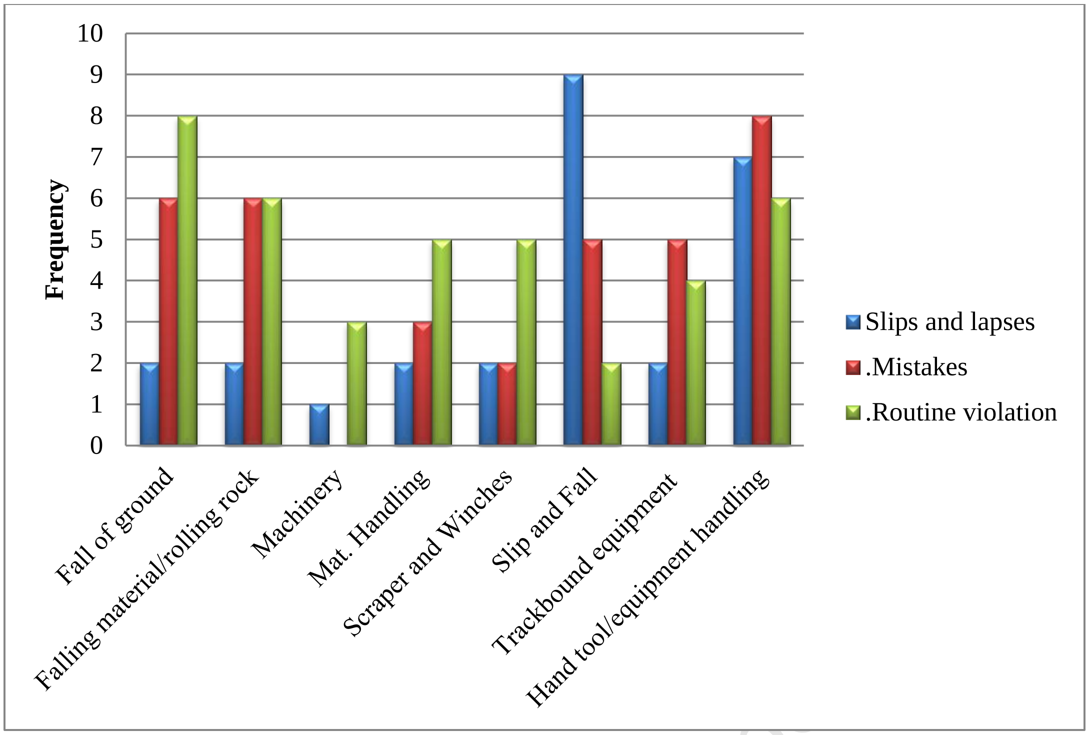

Figure 18: Distribution of unsafe acts across different agencies

At a glance what can be seen from the graph (Figure 18) is that different kinds of human errors contribute differently in each of the agencies. A face value lesson that can be learned is that a single solution to address all kinds of accidents will not work. A deeper analysis of the unsafe acts associated with these agencies is therefore needed.

Fall of ground accidents are prevented in the mine by the *barring* down of loose rocks and the installation of safety nets. Failures to obey these rules were the most common types of violations identified in this study as leading to instances of *fall of ground*. Another prevalent violation under this agency is the use of wrong equipment for *barring*. Inadequate *barring* activities were the most common mistakes leading to *fall of ground*. Inadequate risk assessment on how safe it is to stand during a *barring* activity is a common mistake identified with *fall of ground*. In this study the most common slips and lapses identified occurred under situations in which a worker unknowingly stood under an unstable roof due to lack of warning.

While the most common violation leading to accidents involving *machinery* was standing at unauthorized places, the most common slips and lapses identified are unknowingly standing in the path of machinery. Most violations identified in accidents involving *scraper and winches* include working on equipment in motion, the use of wrong tools and the non-usage of personal protective equipment.

While the main violations identified in accidents involving *manual handling of materials* are non-usage of personal protective equipment and improper lifting techniques, the main mistake identified was failure to communicate. Loss of concentration is the most common example of slips and lapses identified with *manual handling of material* accidents.

Most *slipping and falling* accidents occurred as operators were walking, escaping another hazard or performing a task (hence these acts are classified under *slips and lapses*). During such situations, the victims became vulnerable to the presence of trip hazards in their paths. Inadequate risk assessments also lead to workers either choosing to stand at trip hazards which also lead to incidents involving *slipping and falling* (hence classified as mistakes). Violations usually had an exacerbating effect on slips rather than being the cause: an example is not wearing PPE which increased the gravity of injuries occurring from slipping rather than causing them.

The manual nature of tasks performed by operators implies the use of hand tools and equipment such as crowbars, drilling machines, etc. While the most common mistakes associated with *hand tool/equipment handling* are poor positioning and failure to ensure that tools were fit before use, the most frequent violations included the use of wrong tools, operating tools without authorizations and not following procedures for using tools. Situations in which slips and lapses were involved included inadvertently holding the cutting part of a tool and not having an adequate grip on a tool.

Accidents resulting from *falling materials/rolling of rocks* were caused by violations such as non-usage of personal protective equipment and use of wrong equipment. Poor risk assessment was the most common mistake leading to the leaving of materials in positions where they were likely to fall.

As stated earlier, all incidents involving *track bound equipment* occured either during re-railing or coupling and uncoupling. The main violation identified under this agency is working on trucks in motion. Failed communication and inadequate risk assessment (wrong positioning) were identified with this agency.

4.3.3 Distribution of unsafe acts according to type of employee

Figure 13 showed that a significant number of incidents involved employees of contractor companies; the analysis under this section (Figure 19) to investigate the difference in the distribution of the unsafe acts committed by company employees and contractor employees.

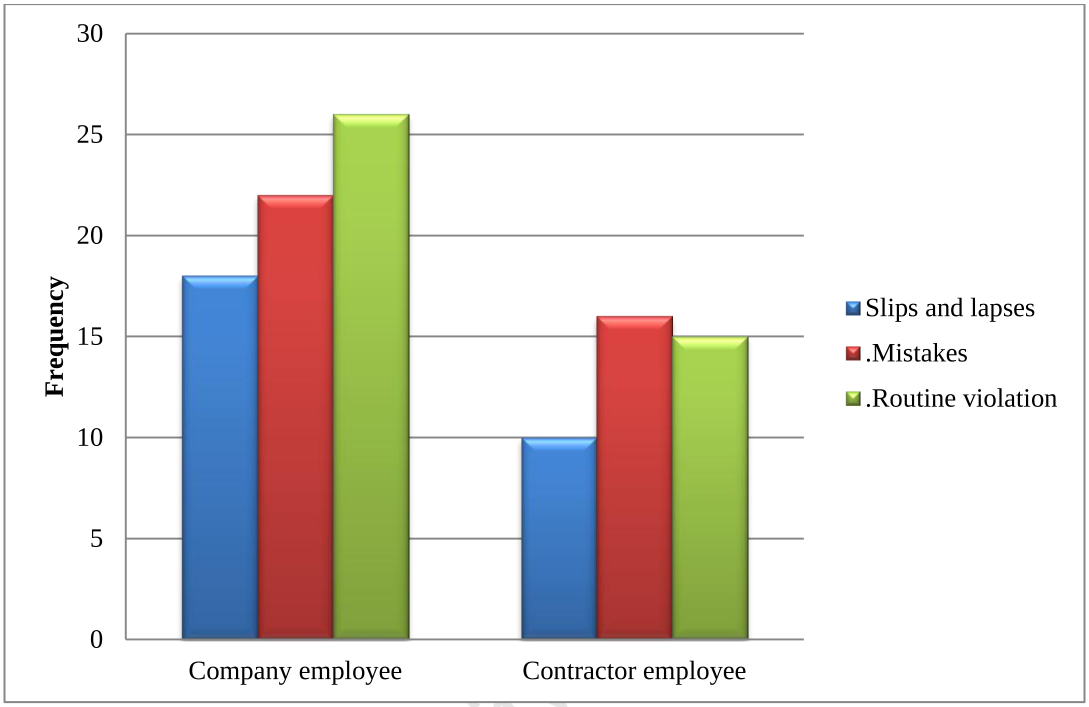

Figure 19: Distribution of unsafe acts across the different type of employees

The results presented in Figure 19 show that while violations are the dominant form of unsafe acts of employees, mistakes are the most unsafe acts of contractors. These results support the assertion that different approaches may have to be used when addressing unsafe acts by employees and contractors. The results seem to suggest that organizations may have to focus on the level of competence of the personnel of contractor companies assigned to tasks.

4.3.4 Effects of age and level of experience on unsafe acts

The analysis in this section seeks to determine the effect of operator variables such as age and experience on unsafe acts. Figure 20 shows that both mistakes and violations reduced with increasing working experience.

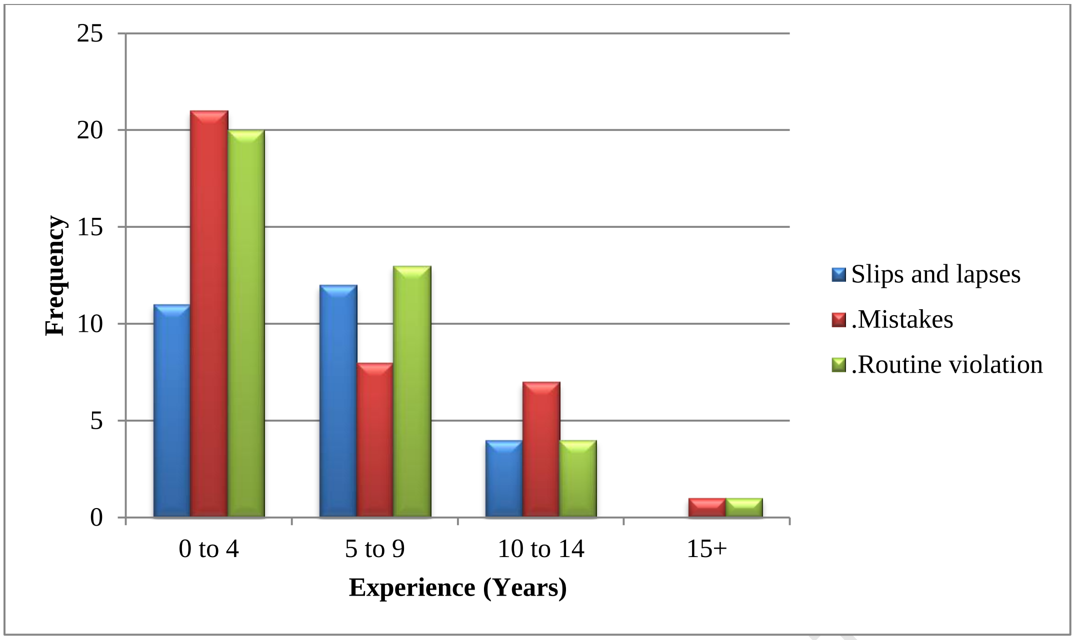

Figure 20: The distribution of unsafe acts according to work experience of perpetrators.

Slips and lapses also showed a generic decrease with experience. Although there was a slight increase from 0-4 years to 5-9 years, it was followed by subsequent decreases for workers with experience 10-14 years and those with experience 15 years and more. Figure 20 also shows that people with less than 4 years of experience were involved in more unsafe acts. Similar results were found by Kecojevic et al (2007) when they conducted a study on machinery accidents in United States mining industry. Their study showed that personnel with less than 5 years' experience are involved in most machinery accidents. Sanmiquel et al (2010) also reported in his study of mining accidents in Spain that over 42.5% of the accident victims had experience of less than 4 years. These results seem to suggest that workers with little experience are much prone to unsafe acts as compared to more experienced ones. This may be due to the competence that one gains with maturity. However, the author of this study is aware of the fact that the relatively low number of unsafe acts identified amongst workers with higher work experience may also be due to the fact that as a worker gains more experience at the workplace, there is usually a change in role that moves the worker further away from hazardous tasks.

The distribution of unsafe acts with age (Figure 21) shows an increase in all unsafe acts from age bracket 21 to 30 to age bracket 31 to 40 years; this is followed by a progressive decrease in all unsafe acts up to age bracket 50+. The graph seems to suggest that employees in the 31 to 40 age bracket are the most liable to various forms of errors. Another interesting observation is that while mistakes are the most dominant unsafe acts for the lower age groups (21 to 30 and 31 to 40), violations are the most dominant unsafe act for the higher age groups (41 to 50 and above 50). This seems to suggest that while younger workers have problems with decisions, older workers have problems with compliance. The study of Sanmiquel et al (2010) also recorded that those involved in 26.9% of accidents are between the ages 30 to 39 while those involved in 26.4% of accidents were between the ages 45 to 54. This seems to suggest that workers within the ages of 31 to 40 (approximately 30 to 39 in Sanmiquel et al work) are most vulnerable to accidents. The author of this study is not ignorant of the possibility that this unsafe act-age profile could also be due to the fact that the workplaces used as case study may just have higher numbers of workers within that age group, hence this observation can only be put in the right perspective knowing the age distribution of the workforce.

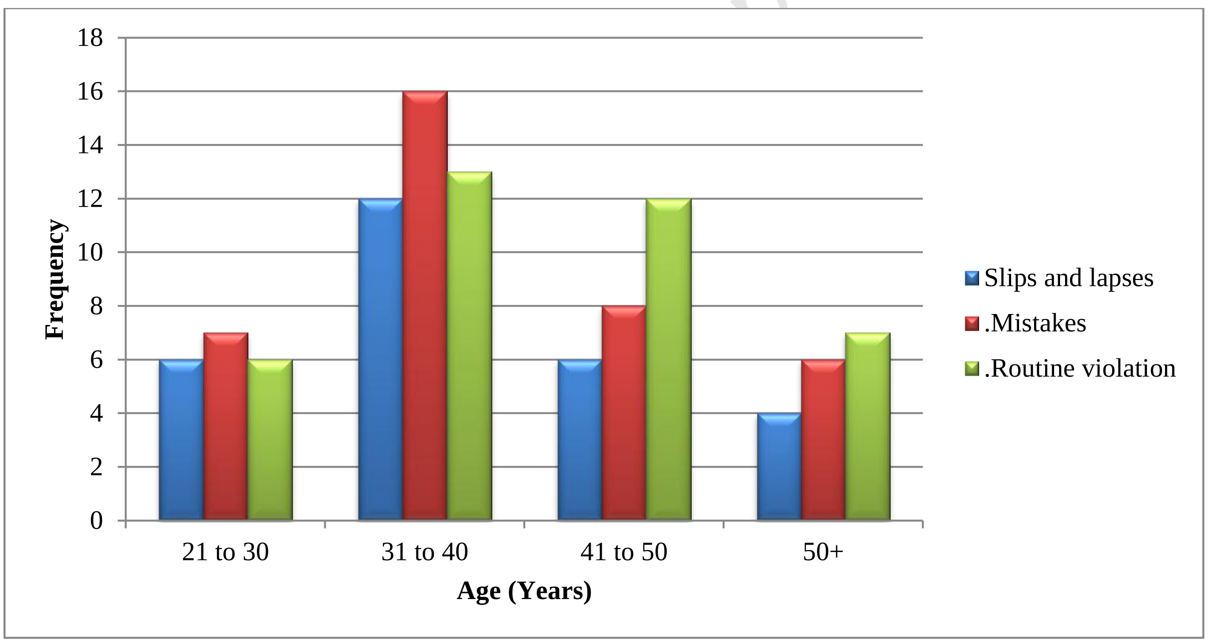

Figure 21: The distribution of unsafe acts according to age of perpetrators.

4.3.5 The distribution of unsafe acts according to time of day

The distribution of unsafe acts across different times of the day was generated to investigate the possibility of the existence of higher error liability at particular times of the day. The timing of the day was divided into 8 groups (see Figure 22) of 3 hours each. One time zone, 15:00 to 17:59 did not appear on the chart due to its zero frequency of unsafe acts. This is because that period usually did not have any activity taking place. The timing was arranged to synchronize with the shifts run by the company used in the study. The latter operates two main production shifts namely the morning and night shifts. The morning shift is from 6 am to 3 pm while the night shift from 10 pm to 5 am. There are occasional afternoon maintenance shifts.

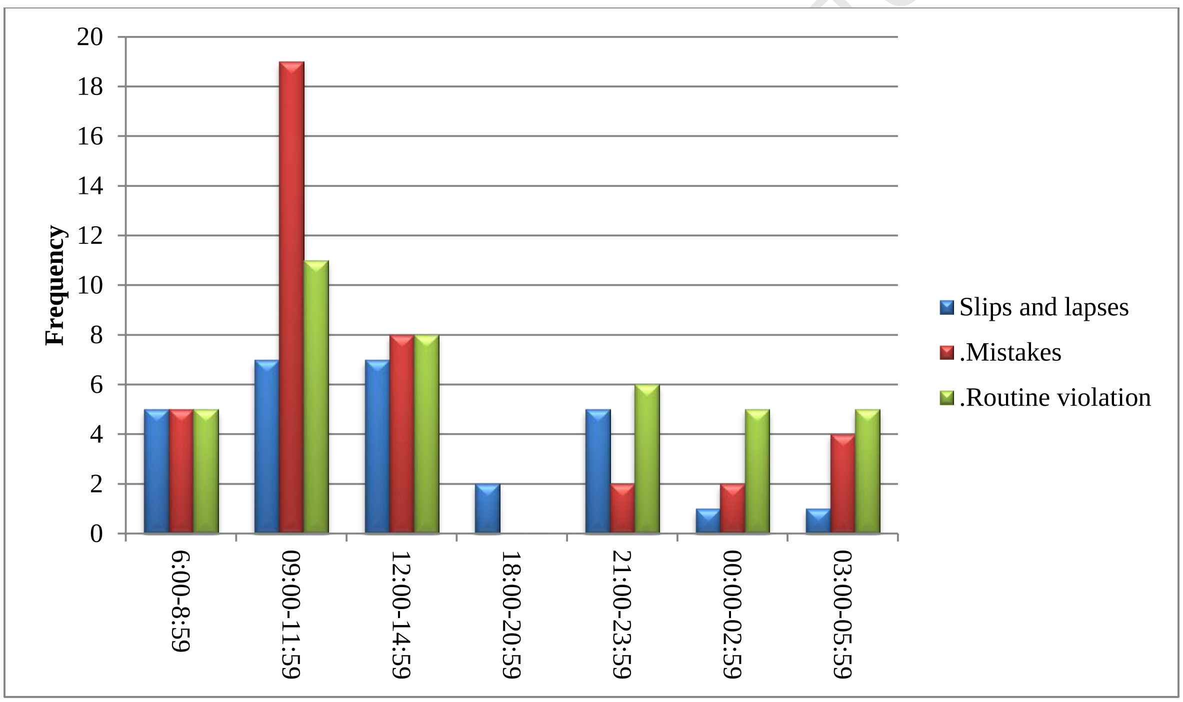

Figure 22: The distribution of unsafe acts according to the time of day.

The analysis of the effect of time of day on the propensity to commit unsafe acts proceeds by comparing what happens in the morning shift to what happens in the night shifts. A snap shot view of Figure 22 shows that far more unsafe acts occur in the morning shift (from 6:00 to 14:59) compared with the night shift (~ 21:00 to 5:59). This is partly due to the fact that most work is done in the morning shift. The time range with very low unsafe acts (15:00 to 20:59) represents the occasional maintenance afternoon shifts.

A focus on the morning shift indicates that while *slips and lapses* increase with the progression of work, mistakes and violations are highest in the middle hours of the shift (9:00 to 11:59). A possible explanation is that different psychological processes contribute to each unsafe act. Slips and lapses as explained earlier are caused by attention or memory failure. Workers are more vulnerable to this error because they get tired as time progresses within the shift. Mistakes are caused by error in judgement, while violations are caused by deliberate decisions not to comply. The author of this study believes that the trend observed for mistakes and violations is influenced by the involvement of supervisors or leaders. This is because inspection and task observations which are done by supervisors and leaders usually occur at the beginning and end of shifts, hence mistakes and violations may increase in mid-shift. Also a common example of violation identified in this study was failure to perform mid shift *barring*. This may also be a reason for the high levels of violations recorded from 9:00 to 11:59 (i.e. mid-shift).

The night shift showed very little variation in violations but a reduction in slips and lapses as the shift progressed.

4.4. Workplace Factors

This section explores the workplace factors that contributed to the unsafe acts shown earlier (Figure 17), or exacerbated their effects. This is done mostly by providing background information on the workplace factors identified in this study. As demonstrated by Table 1 and Figure 23, the *physical environment* was the most common workplace factor identified in this study as contributing to accidents. The most common examples of *physical environment* identified in this study include unstable geological conditions, poor illumination, confined space, and presence of trip hazards (obstructions, unlevelled grounds, wiring, and slippery floors).

The *behavioural environment* was the second most common workplace factor identified in this study as contributing to accidents (Figure 23 and Table 1). Most occurring situations of *behavioural environment* include failure to correct violation of rules, absence of supervision, encouragement to flout rules and failure to coordinate activities of workers. Instances of *fit-for-*

purpose-equipment, *competent people* and *safe work practices* were in the minority compared to the first two categories. Instances of *fit-for- purpose equipment* identified in this study include the absence of required tools, tools having incomplete components (e.g. tools without handles and pumps without valves) and malfunctioning equipment. Instances of *competent people* identified in this study include situations where training received did not adequately prepare workers for the tasks they perform, people yet to undergo on the job training and absence of training for a particular job.

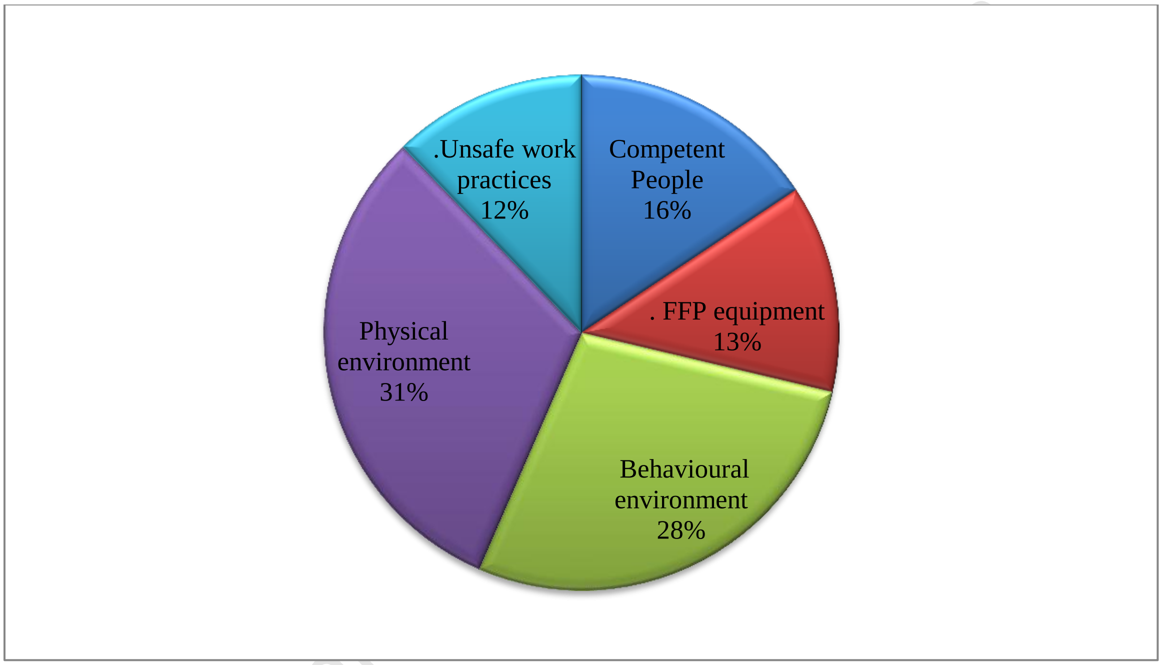

Figure 23: The overall distribution of workplace factors.

4.4.1. Workplace factors leading to unsafe acts

This section aims to establish links between workplace factors and specific unsafe acts. This is motivated by Reason's (1990) explanation of an unsafe act as being a symptom rather than the actual problem to be dealt with. This analysis, the author believes, will enable managers of mining companies to understand specifically how these workplace factors lead to the unsafe acts.

4.4.1.1. Workplace factors leading to violations

From Figure 24, it can be seen that the most common workplace factor identified with violations is *behavioural environment*. This means that most violations occurred because of the absence of a system that frowns upon violations by workers and different levels of leadership. Other workplace factors such as *physical environment*, *fit-for-purpose equipment* and *unsafe work practices* were barely identified as reasons for the violation of company's standards and procedures.

These results are similar to findings reported by Lenné et al (2011) where violations had a high association with *crew resource management* (i.e. lack of teamwork, failure of leadership and also how the social environment of the worker is managed). Further, on *behavioural environment*, Paul and Maiti (2008) reported that the presence of social support (from co-workers and leadership) reduces the possibility of workers having a negative attitude. These results illustrate the need for creating a work environment which does not support violations. The survey conducted by Laurence (2004) on the Australian mining industry clearly stated that writing more regulations is not a remedy for the problems on non-compliance. Masia and Pienaar (2011) also reported job insecurity and job stress as other factors which have an effect on the level of compliance of mine workers in South Africa to safety requirements. However, the author could not verify such claims since the accident reports used in the study were not designed to accommodate the effect of the factors reported by the latter.

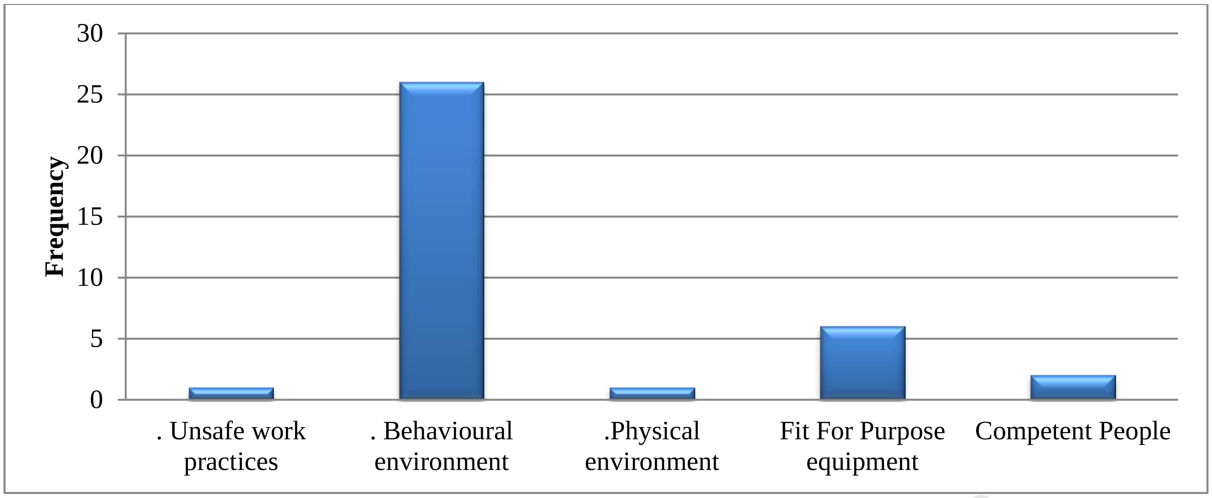

Figure 24: Workplace factors responsible for violations.

4.4.1.2. Workplace factors leading to mistakes

Figure 25 shows that the workplace factors identified with mistakes are much more diversified. While *competent people* and *unsafe work practices* were the two leading workplace factors, *fit-for-purpose equipment*, *physical* and *behavioural environment* are also significant.

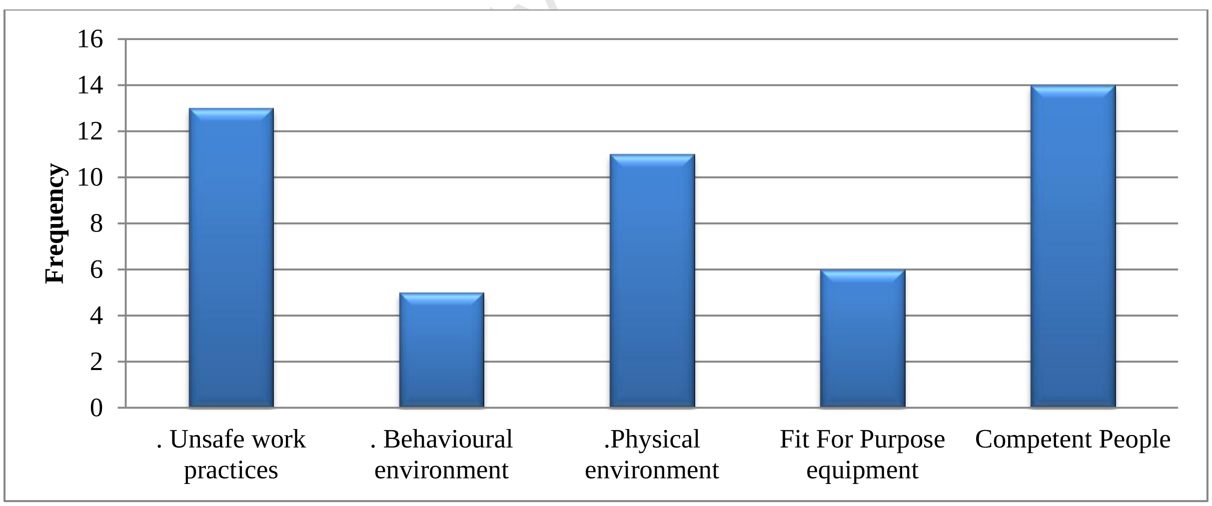

Figure 25: Workplace factors leading to mistakes

Most cases of *competent people* identified with mistakes in this study included lack of experience, inadequate skill level, not undergoing planned task observation and inadequate personnel. There situations obviously made mine workers vulnerable to committing mistakes.

Most instances of *unsafe work practices* identified with mistakes in this study included non-existence of standards for a specific task, and situations in which standards did not fully cover tasks. Such situations made workers vulnerable to mistakes. Most instances of non-existence of standards for a particular task (classified under *unsafe work practices*) identified in this study were accompanied by existing training procedures being inadequate to provide the needed competency (classified under *competent people*).

Confined spacing, poor illumination and ground conditions were the most common examples of *physical environment* identified with mistakes. These conditions usually exacerbated the effect of the *mistakes* rather than being the actual cause.

The presence of tools with capacity below the task requirement (short pinch bars), equipment not functioning properly, the absence of the needed tool and an incomplete set of equipment are specific examples of instances of *fit-for-purpose equipment* identified with mistakes in this study. In most cases, the absence of a *fit-for-purpose equipment* was enough to result in a mistake. *Behavioural environment* was cited in situations where uncoordinated activities and lack of communication led to mistakes.

Comparing this to the work of Lenné et al (2011), decision errors (synonymous to mistakes in this study) had significant causal relationships with technological environment (tools, equipment and rules) and adverse mental state (competence of the operator).

4.4.1.3. Workplace factors: Slips and lapses

From Figure 26, *physical environment* was the most common workplace factor identified with slips and lapses. The existence of the environmental conditions explained in Section 4.4 make victims liable to such slips and lapses. This result differs from those reported in the study of Lenné et al (2011) who found out that adverse physiological states (synonymous to health problems) had significant causal relationships with skill based errors (synonymous to *slips and lapses*). Very little was known about the effect of the state of the worker (such as psychological problems) as far as the tendency to cause *slips and lapses* is concerned. This was because the accident reports were not structured to capture those details. There was only a single situation where the health of a worker led to a slip. Situations such as modifications in equipment and equipment without handles are examples of the few occasions *fit-for-purpose equipment* led to slips and lapses. The results suggest that efforts need to be concentrated on the physical work environment if slips and lapses are to be reduced.

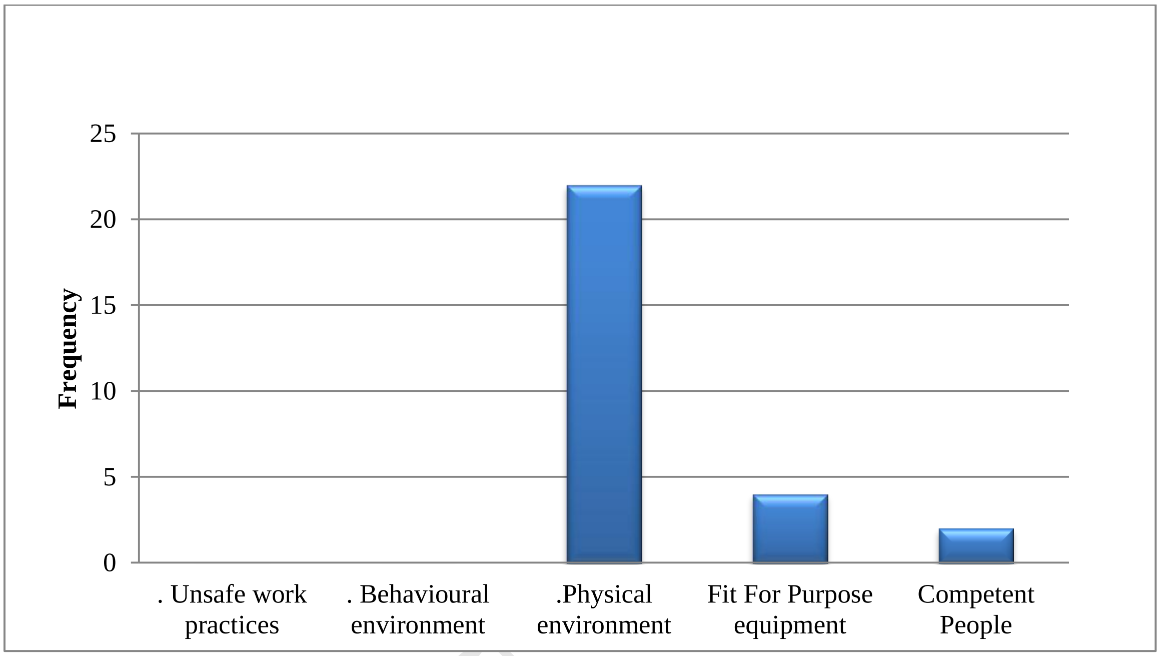

Figure 26: Workplace factors responsible for instances of Slips and Lapses

4.5 Systemic factors

This section takes a look at the systemic factors involved in various accidents. In this study, these systemic factors are considered to be the root cause of these accidents. Figure 27 shows the distribution of systemic factors identified in this study.

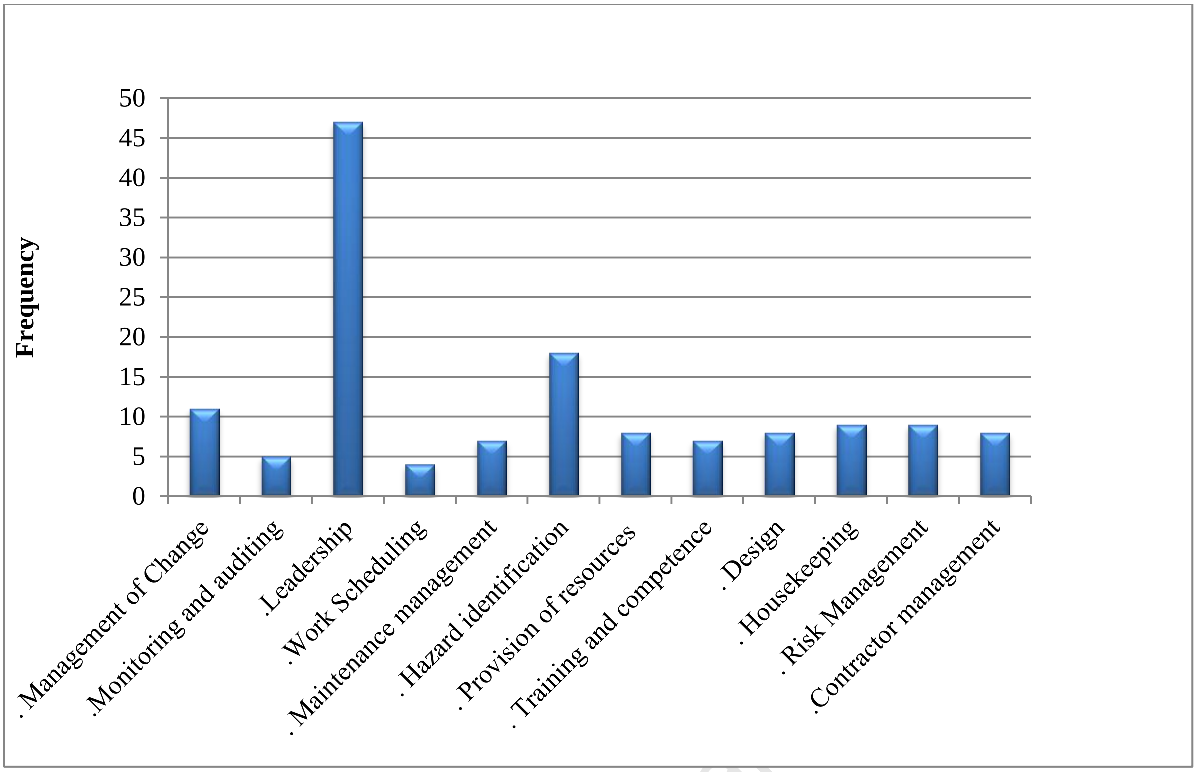

Figure 27: The overall distribution of systemic factors

The results (Figure 27) show that *leadership* was the most common systemic factor identified in this study as contributing to accidents. This is due to the already stated fact that most safety barriers put in place were not self-enforcing. Examples of poor leadership included inadequate supervision, the failure to train workers (conducting planned task observation), the failure to solve known problems and the failure to correct deviant behaviour.

Hazard identification is the second most common systemic factor identified in this study as contributing to accidents. This is said to occur when an accident happens even though the accidents victims followed company procedures. This was seen to be as a result of a deficiency in the hazard identification process during the formulation of the procedures.

Management of change, *training and competence*, *contractor management*, *risk management* and *design* are the other systemic factors identified in this study.

Specific examples of *management of change* include instances in which loss of qualified employees (either due to resignation or leave) and changes in task environment or task requirements) were not managed properly, leading to accidents.

Examples of *training and competence* were situations in which the training provided did not cover specific tasks, or untrained personnel assigned tasks.

Contractor management was cited in situations in which incompetent contractors were found performing tasks and in situations in which contractors were made to work without supervision.

Examples of *risk management* cited in this study included not dealing with known risk such as reported unsafe workplace, reported malfunctioning of equipment, and equipment shortage; and not ensuring the safety of the workplace before commencing tasks. Most instances of *design* included conditions such as narrow stopes (openings made in the extraction of ore) and improper equipment design.

The author believes that effective leadership could have been a solution to most of the other systemic factors identified such as housekeeping, risk management, some aspects of training and even provision of resources.

4.5.1. Systemic and workplace factors analysis

This section is aimed at establishing the link between systemic factors and workplace factors. This is usually done by explaining how the systemic factors may lead to the workplace factors. The author believes this would help in the strategic correction of workplace factors, in consonance with Reason's (1997) description of the Swiss Cheese Model which states that workplace factors are created by organizational or systemic factors.

4.5.1.1. Systemic factors identified physical environment problems

The results (Figure 28) show that the systemic factors that lead to *physical environment* problems can be categorized into two major groups. While *design* and *hazard identification* occur during the construction of the workplace, *poor housekeeping*, *risk management*, *maintenance management* and *change management* occur during day-to-day mining operations. While factors *design* and *hazard identification* usually created permanent conditions such as narrow stopes, factors such as *poor housekeeping*, *risk management*, *maintenance management* and *management of change* degrade an originally suitable working environment. Both of these make it difficult for workers to carry out tasks efficiently. This scenario depicts Reason's (1990) explanation of the varying nature of holes in various organizational structures that lead to accidents. While the first group of holes (*design* and *hazard identification*) lie dormant in the organization for a long time, the second group of holes (*housekeeping*, *risk management* and *maintenance management* problems) are usually created as production activities are carried out. This also confirms Reason's (1997) description of safety as not being something an organization has but what it does.

Examples of *leadership* identified in this study as a cause of situations of *physical environment* included the failure to correct known problems at the workplace and the failure to enforce thorough workplace inspection.

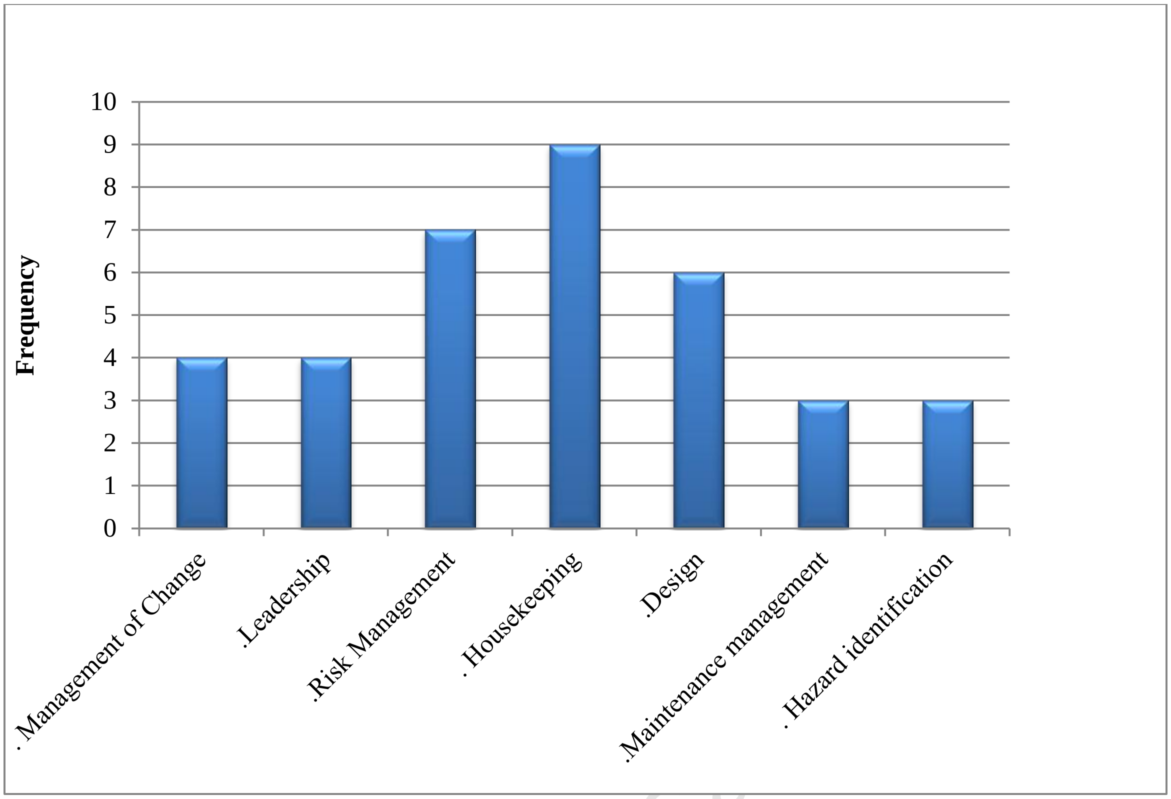

Figure 28: Systemic factors responsible for instances of physical environment problems

4.5.1.2. Systemic factors identified with behavioural environment problems

This section is aimed at elucidating the systemic factors identified in this study as leading to *behavioural environment* problems. The results (Figure 29) show that *leadership* is the most common systemic factor identified with *behavioural environment*. Poor leadership was identified at different levels, from section manager, shift boss, technical heads to team leaders. This shows signs of a problem of safety culture. The author believes the failure of these leaders to correct violations is the main reason for *behavioural environment*.

Situations such as *change management* and *work scheduling* were identified as causes of poor leadership in some instances. A specific example in this study is when unqualified people were assigned tasks by sectional leadership due to an exodus of qualified people. This poor leadership decision was adjudged by the author to have resulted from poor management of the change occurring in the system. A specific example of how *work scheduling* led to poor leadership is when the lack of adequate number of personnel on a voluntary shift led to inadequate supervision. *Monitoring and auditing* and *contractor management* were other systemic factors that led to instances of *behavioural environment*.

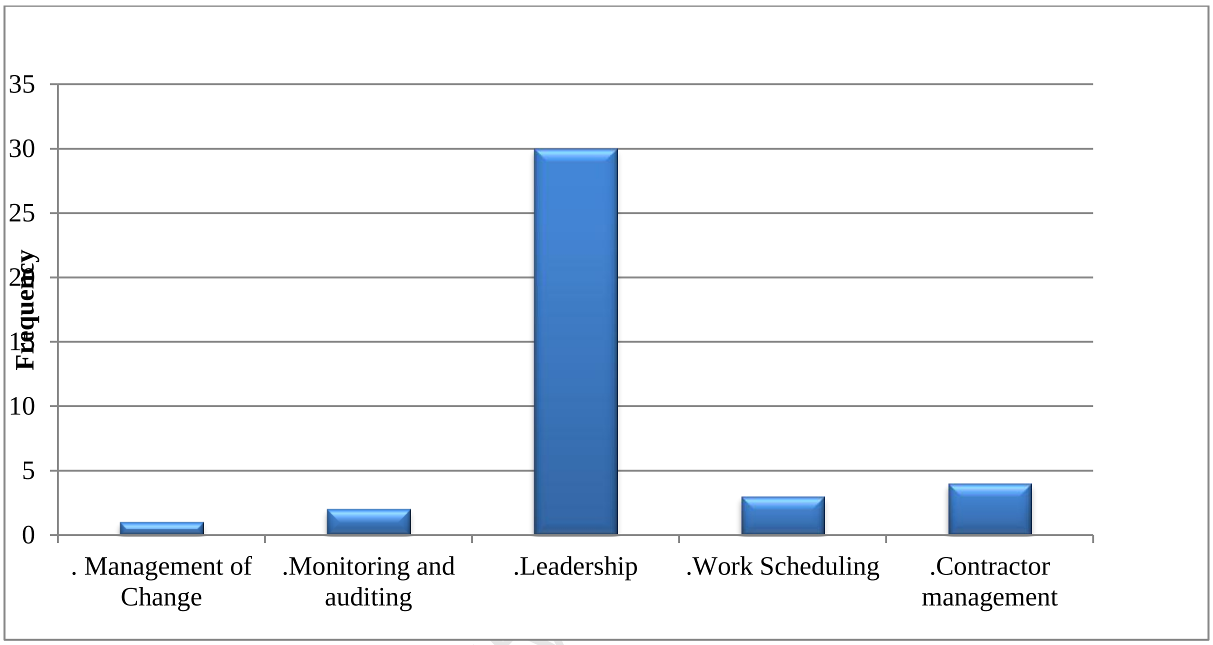

Figure 29: Systemic factors responsible for instances of behavioural environment problems

4.5.1.3. Systemic factors identified competent people problems

This section elucidates systemic factors identified as causes of *competent people* problems in this study. The results (Figure 30) show that *training and competence* and *leadership* were the most common systemic factors identified with instances of *competent people*. Common such situations classified under *training and competence* included inadequate training and the absence of training for particular tasks. These situations, in the opinion of the author made workers incompetent for the task assigned.

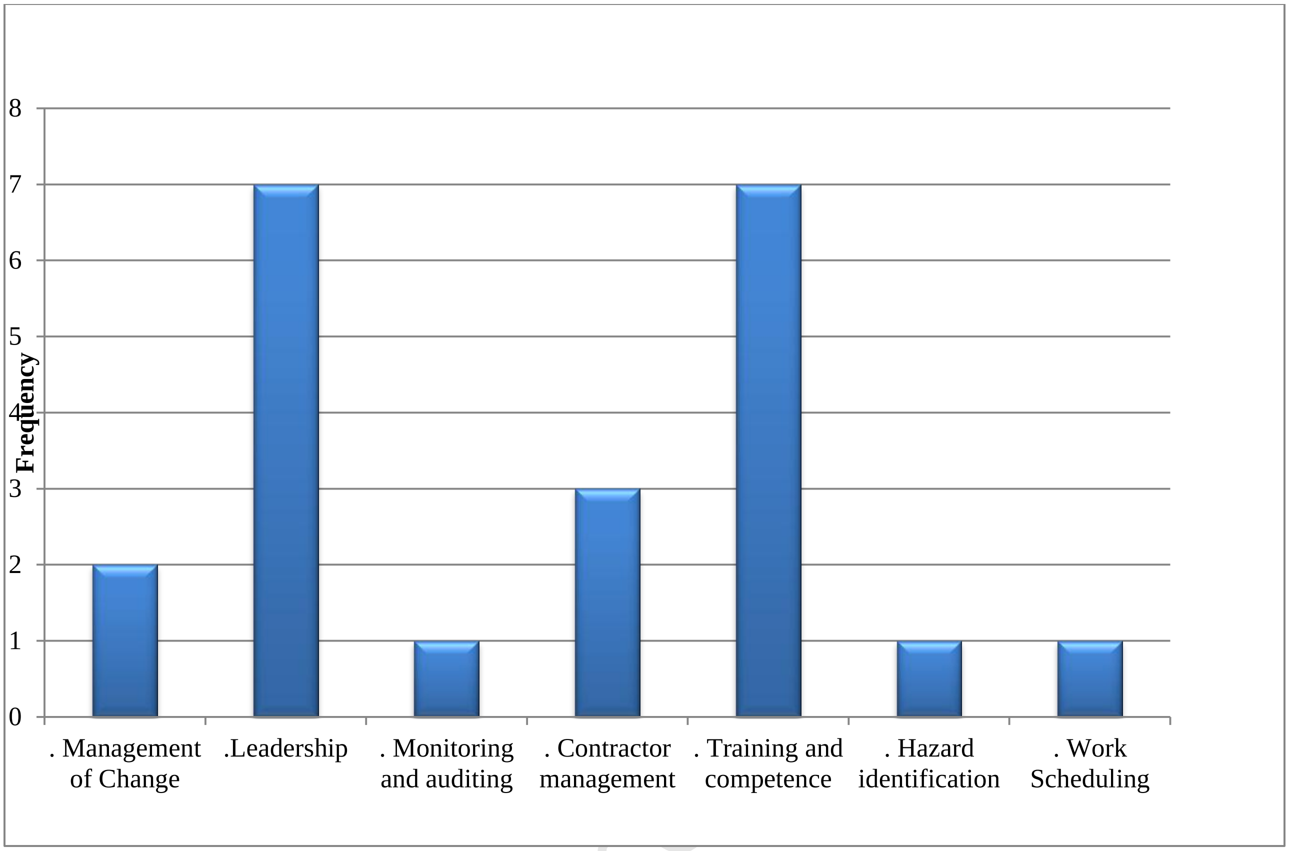

Figure 30: Systemic factors identified with instances of competent people problems

Examples of leadership lapses that identified with the absence of *competent people* included failure to conduct planned task observation and failure to supervise inexperienced workers. This was usually identified as leading to accidents involving inexperienced workers.

Other common systemic factors identified with *competent people* are *contractor management* and *management of change*. While incompetent contractors performing task was the main way *contractor management* lead to *competent people*, common examples of *management of change* included the effect of worker's official leave on the conducting of training of workers.

Monitoring and auditing, *work scheduling* and *hazard identification* were less common systemic factors identified as leading to *competent people*. An example of *monitoring and auditing* found in this study was the situation where shift leaders not providing adequate training to workers was not identified till it leads to an accident. This is seen as an indication of a poor monitoring system. A specific example of poor *work scheduling* was the presence of an inadequate workforce on voluntary shifts. This in the author's opinion reduced the workers ability (competence) to execute the task assigned to them. An example of *hazard identification* identified in this study is when workers behaved in a risky manner because of the absence of knowledge of a particular hazard in the operating procedures.

4.5.1.4. Systemic factors identified with fit-for-purpose-equipment problems

This section provides elucidation on systemic factors identified with situations of *fit-for-purpose equipment* problems identified in this study.

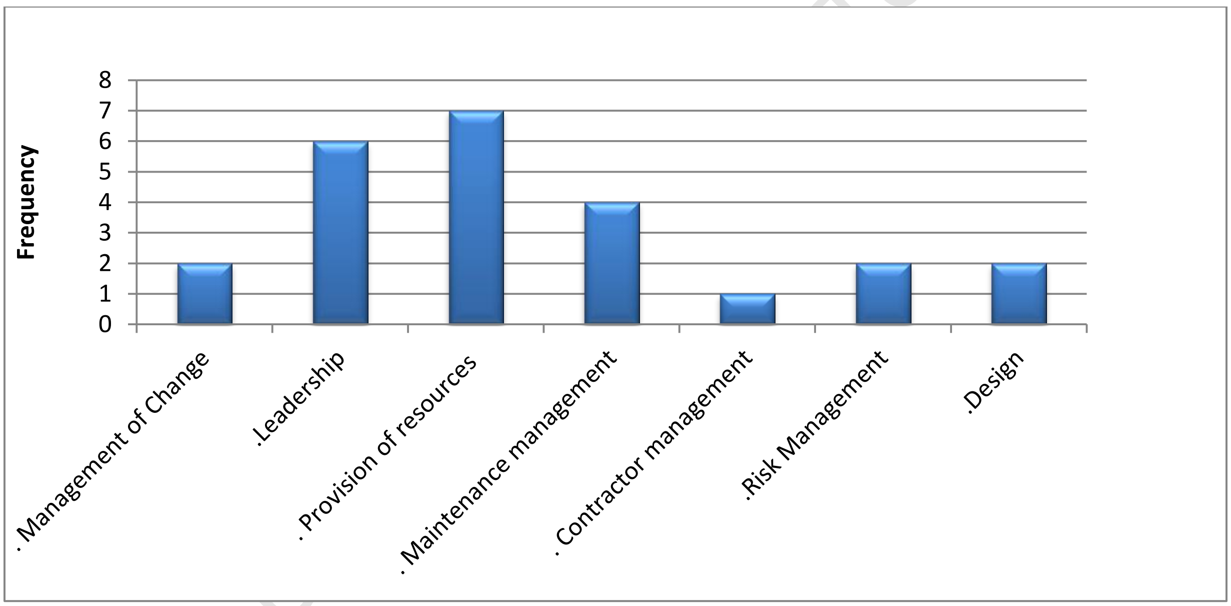

Figure 31: Systemic factors identified with instances of fit-for-purpose equipment problems

Figure 31 indicates that *resource provision* was the main reason for *fit-for-purpose equipment*. In most of these cases workers had no choice but to use available tools in order to accomplish the given task, because they were not provided with the right ones. The second most prevailing situation were scenarios in which leadership (mainly shift bosses and team leaders) did not report shortage of equipment or leaders gave workers wrong tools for a task that were below the capacity of the task to be accomplished. *Maintenance management* was identified as a significant contributory factor to issues of *fit-for-purpose equipment* in this study. The poor maintenance of existing equipment usually affected the ability of the tools to safely perform the respective task. Poor *design, management of change* and *risk management* each had minor contributions to the situations of *fit-for-purpose equipment* at the workplace. Examples of poor design of equipment identified in this study include equipment lacking handles and lack of protection against hazards while using equipment. Scenarios in which poor risk and change management were cited include situations where modifications on existing equipment/operation introduced new risks thereby leading to accidents and situations in which reported equipment deficiencies were not dealt with.

4.5.1.5. Systemic factors identified with instances of unsafe work practices

This section is aimed at providing the background information on the nature of systemic factors leading to unsafe work practices.

The most common cause of *unsafe work practices* is *hazard identification* (see Figure 32). This usually led to hazards not being catered for in procedures, hence putting workers at risk while performing tasks. This condition, the author believes, created situations in which existing work procedures did not protect workers from hazards.

Management of change and *monitoring and auditing* were identified in a few instances as contributing to *unsafe work practices*. *Management of change* was identified as a contributing factor to *unsafe work practices* when an initially adequate procedure became inadequate due to changes in the usual work condition (example working in a new section).

Monitoring and auditing was also cited when the author had cause to believe that the *unsafe work practice* was due to failure of monitoring of systems.

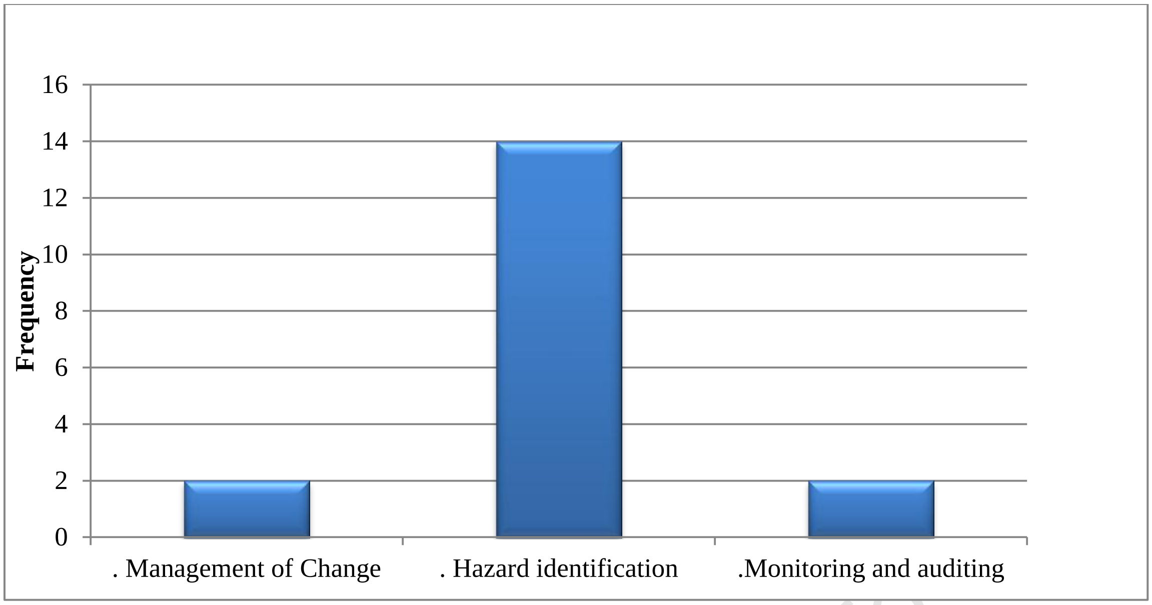

Figure 32: Systemic factors identified with instances of unsafe work practices

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To conclude, the results obtained in this study have clearly been displayed and explained. Though there has been an initial discussion of the results, the next chapter focuses on the detailed discussion of the results obtained.

CHAPTER 5: DISCUSSION

This chapter focuses on the interpretation of the results presented in the previous chapter. The chapter is divided into two broad sections. The first section is concerned with the interpretation of the results obtained from the accident characterization. The aim of this exercise is to provide meaning to the type of results presented in Chapter Four and possible reasons why these results may be different from results obtained in other studies. The second section (5.2) analyses the different levels of accident causality and the implications for the broader organizational safety. Arguments for the conclusions presented in Chapter Six are also developed.

5.1 Accident characterization

The characterization of accidents provided the basis for understanding the other results obtained in this study. The results show that the mode of operation in the mine used as a case study exposes workers to hazards. This is because most tasks are very manual in nature. Figure 12 showed that drilling and engineering tasks are the most accident prone tasks. These tasks are performed using hand held tools like drilling machines, crow bars and spanners which place them very close to the available hazards.

This view on exposure to hazards is reiterated by the types of *slipping and falling* accidents identified in this study. Most *slipping and falling* accidents analysed in this study happened when the victim was walking, signifying limited protection from physical hazards. This supports the author's view that a significant number of the accidents are due to the proximity between hazards and workers.

The level of exposure of humans to hazards in engineering tasks (e.g. maintenance) is somewhat the same across most industries. Reason (1997) stated that while some industries have been able to automate most functions, thereby moving workers further away from hazards, maintenance related activities remain one field where there still exists a significant level of contact between human and hazards. He argued that close contact between people and technical components make up the single largest human factor problem facing most hazardous technology.

An inference that can be drawn from this argument is that the activities at the mine under study which involve close contact between human, technological components of the system and hazards are partly responsible for the high involvement of human error in most accidents. This view is supported by results obtained in the barrier analysis section of this study (Figure 16) which showed that standards, risk assessment and supervision are the three barriers which were frequently breached. It can be deduced from this that safety at the mine being investigated is heavily dependent on either the workers' willingness to obey rules, the supervisors' ability to enforce the rules, and the worker's ability to perceive danger in their environment and avoid it.

This finding seems to support the suggestion made by Ashworth and Peake (1994) that current methods used in preventing *fall of ground* in underground mines in South Africa are inadequate, and that a technological solution aiding workers to determine whether or not a workplace is safe for operation is necessary.

However, the author also believes that mechanization and automation would not be a panacea to all the safety challenges faced in the South African mining industry. Reason (2000) described defence-in-depth (a desirable by-product of automation) as a mixed blessing. While defence-in-depth ensures that a single failure on the part of a worker does not lead to accidents, it provides a means for the accumulation of individual failures up to the point where situations get out of hand. This makes proper safety management procedures the sure way to manage safety in a firm.

In summary, the results from the accident characterization from this study have clearly shown the potential of the current work systems on the mine to serve as a precursor for many human induced accidents. The next sections proceeds to discuss the pertinent human factor issues identified in these accidents.

5.2 Accident causality

The analysis of accident causality showed that *violations* were the most common unsafe acts. This can be compared to the earlier study on mine incidents by Patterson and Shappell (2010) in Australia, where skill based errors (*slips and lapses*) formed the bulk of the unsafe acts committed. The high number of violations identified in the current study relative to that of Patterson and Shappell (2010) can be attributed to the difference in the two mining systems.

While the accident reports used in the current study were all from underground mines, the study of Patterson and Shappell (2010) used reports which had a balance of underground and open cut coal mines, underground and open cut metal/non-metal mines, quarries and preparation plants. Surface mining is usually mechanized, and preparation plants are mostly automated and this in a way helps to separate people from hazards. It is no wonder that the most common human errors encountered in Patterson and Shappell's (2010) study were inadvertent operations (*slips and lapses*).

Most *slips and lapses* identified in this study were deemed to be caused by the presence of a non-supporting *physical environment*. This is not really surprising considering the harsh environmental conditions to which workers are exposed. The effect of the *physical environment* on the performance of mine workers corroborates the studies of Sanmiquel et al (2010) and Patterson and Shappell (2010) which, although conducted in different countries (Spain and Australia respectively), identified the working environment as a major factor affecting the performance of mine workers. Although proper design could have improved the work environment in some incidents, most cases of *physical environment* were temporary situations created as operations were being carried out. This makes *housekeeping*, *maintenance management*, *hazard identification*, *risk assessment* and *change management* major issues to consider if the mining environment is to be made safer.

The accident causality analysis also suggested that poor leadership is the root cause of most the violations identified in this study. This is based on the fact that the most common workplace factor identified with most violations was *behavioural environment* i.e. an environment where people that broke the standards or procedures were not corrected either by co-workers, team leaders or shift supervisors. According to Reason et al (1998) this situation is due to the existence of conflicting goals. For instance, there can be a conflict between organizational goals in terms of rules and regulations (e.g. conducting mid-shift *barring*) and meeting a personal goal (e.g. achieving a production bonus). Ensuring that safe behaviour is psychologically rewarding is a viable option in addressing such a gross culture of impunity. Creating a social environment where wrong behaviour is eschewed and the concordance of individual and organizational goals is maximized were the recommendations by Reason et al (1998) to deal with violations inducing environments. Based on the current study, it can be deduced that lapses in leadership/supervision are the root causes of violations.

The author of the current study is of the opinion that high production pressures exerted on workers might have contributed to the high violation rates identified (note that this was not stated in any of the reports used in this study). One of the most common violations identified in this study is failure to do mid-shift *barring*. Workers were supposed to stop working and bar down any hanging or loose rocks. Workers are unlikely to conduct this *barring* operation if they are far behind completing the shift's work. In the analysis of the reports the current author came across instances of violations occurring in the presence of supervision. The fact that most of the violations identified in this study were routine or repetitive (see figure 17) also supports this view. This hints of the possibility of conflicting goals. This view is shared by Ashworth and Peake (1994) who conducted a separate research on the South African gold and platinum mining industry and the findings of an earlier study by Lenné et al (2011) which reported significant causal relationships betweem violations and adverse mental state. Adverse mental state as used in Lenné et al (2011) study describes situations of mental fatigue which may happen as a result of long hours of work.

The author also believes that the causes of *mistakes* identified in this study are more complicated and diverse than the other unsafe acts. This view is influenced by the fact that the study identified that the causes of mistakes were distributed across the five workplace factors (Figure 25). This seems to suggest that training is not a panacea to the liability of mistakes. The systemic factors leading to these workplace factors are also diverse as shown in figures 28 to 32 above. This situation may be due to the complex nature of mining hazards which make it difficult to predict exactly all possible scenarios of danger.

The most common mistakes identified in this study are poor communication amongst workers and poor risk/situational assessment. This is similar to the earlier findings of Patterson and Shappell (2010) and Ashworth and Peake (1994). The study of Patterson and Shappell (2010) identified procedural error, faulty risk and situational assessment as the most common decision errors (synonymous to mistakes). Ashworth and Peake (1994) also identified inadequate examination/inspection of the work environment as the cause of 21.4% of all accidents analysed. The author agrees with the reasons given by Ashworth and Peake (1994) for ineffective risk assessments by mine workers, which include inadequate methods of examination and the use of ineffective tools and inadequate training system. The study discovered that existing working procedures on *barring* are equivocal on how far to stand when *barring* rock or exactly what constitutes an unsafe environment. Tools used in *barring*, such as pinch bars, equally put workers in danger. This leads to the deduction that *hazard identification*, *management of change*, *provision of resources* and *risk management* are the systemic factors that need to be dealt with if mistakes leading to *fall of ground* are to be reduced.

The study of Lenné et al (2011) identified technological environment (synonymous to *fit-for-purpose equipment*) as the main cause of decision errors (mistakes). This tends to agree with findings of this study that the nature of the tools being used affect the quality of workers' judgement. Saleh and Cummings (2011) proposed the concept of defence-in-depth as a better way of dealing with hazards in mines. The merit and demerit of defence-in-depth have been discussed in Section 5.1. The author of this current study proposes the consideration of the use of technologies such as automation for making safe procedures (Teleka et al, 2012) and virtual reality training (Squelch, 2001; Etienne, 2008) to increase the level of safety against such complex hazards.

The role of leadership/supervision (seen as contributing 51.6% of all accidents analysed) has been discussed in detail in this study due to the number of instances it was identified as a causal factor in various incidents. Leadership as used in this study involves shift bosses, team leaders and sectional supervisors. Due to the administrative nature of barriers used by the firm, the role of leadership in the safety of operations cannot be overemphasized. Different levels of leaders are in charge of operationalization of various components of safety managements such as provision of resources (making sure equipment moves from storage to workers), enforcing rules, conducting risk analysis on new tasks and ensuring safe housekeeping. It is no wonder that leadership was identified as a root cause of most workplace factors. The level of leadership lapses encountered in various incidents hints of deeper systemic problems. The author believes a further investigation of factors that affect the performance of leaders is needed.

In conclusion, the study has clearly identified the complexity of accident causality. However the results suggest that most unsafe acts leading to accidents were actually influenced by workplace factors (section 4.4) that were in turn caused by system deficiencies (section 4.5). This implies that with positive safety measures and a constant commitment to safety, a safer workplace can be achieved. The next chapter draws the curtain on the study.

CHAPTER 6: CONCLUSIONS

This section presents the conclusion of the entire study. Appropriate key findings, significance, limitation of study and recommendations are also reported.

6.1 FINDINGS

These are the key findings of this study:

1. The nature of operations in the mine under study is such that humans are deeply involved in the daily operations, resulting in a high rate of human errors.
2. There is a major difference between the type of human errors occurring in mechanized mining and labour intensive mining.
3. Most of the violations identified are routine (repetitive). This seems to imply that there are some organizational factors (possibly production pressures) causing them.
4. Leadership failure remains a major challenge in any attempt to improve safety at the mine.
5. The existing measures used in dealing with mistakes at the mine are inadequate. Such mistakes are usually associated with fall of ground, use of hand tools and equipment.
6. Most root causes of slips were temporarily environmental conditions created by work processes.
7. A technique developed from the Swiss Cheese Model (Reason 1990, 1997) can be used to analyse incidents in the South African mining industry.

6.2 SIGNIFICANCE

1. A developed framework has been successfully used to analyse accidents from a platinum mine South Africa. This has led to the identification of factors which are of importance to the safety of the industry.
2. The results have been compared with other studies carried out for mines in other countries (Lenné et al, 2011; Sanmiquel et al, 2010; Patterson and Shappell, 2010) and in South Africa (Ashworth and Peake, 1994). Significant similarities and differences have been identified and discussed.

3. A foundation has been laid for the use of larger data set for a cross commodity (different type of mines and products) analysis. This will bring to light the broader picture of the systemic factors to be considered.

6.3 LIMITATIONS

1. As with all post-hoc analysis, the efficacy of the technique depends on the genuineness of the information in the accident reports. The author has no other means of cross checking such information.
2. The author also acknowledges the challenges that come with interpreting the results from a study using accident reports from just one company. However this is not seen as a major problem since the aim of the study was to demonstrate how a tool can be applied rather than providing factual statements about the South African mining industry.

6.4 RECOMMENDATIONS

1. The author of this current study recommends that the developed framework be tested with data from other mining commodities, most importantly the gold and the coal industries. These two industries are cited because of their contributions to annual fatalities.
2. The author also recommends that a survey be conducted amongst various kinds of leadership at the mines. This recommendation stems from the fact that most violations occurred either in the presence of supervisors or as a result of inadequate supervision. Since most safeguards against hazards depend on the enforcement by leaders and supervisors, the mines will be safer if leaders are able to enforce procedures and standards.

APPENDIX

Table A 1: Meta data Section

Incident	Time	Task	Place	Employee Type	Age	Experience	Job Title
1	13:30	Installing	Underground	Contractor	32	<1	Cheesa
2	7:20	Working on pump	Underground	Employee	52	3	Artisan
3	10:08	Make Safe	Underground	Employee	33	10	Artisan
4	21:40	Drilling	Underground	Employee	28	<1	Rock Drill Operator

Table B 1: Agency and Barrier analysis section

Incident	Description	Agency	Consequence	Broken/absent Barriers	Comment on barriers
1	The cheesa was walking in the center raise when a fog occurred during the installation of hydrabolts and rocks struck him on his skull, neck.	Fall of ground	Fatal	Supervision	Supervisors ordering wrong person to conduct inspection
2	Victim was struck by an LHD whiles sitting against the sidewall in roadway	Machinery	Serious injury	SOP	SOP not obeyed
3	*Barring* the chute at silo no.2 when the rocks dislodge and struck the pinch bar which tilted upwards and struck him on the side of his face.	Hand tool/equipment handling	Serious injury	SOP, Supervision, Job Hazard Analysis	Inadequate standards implying poor job hazard analysis. Supervisor fails in his duties
4	Drilling the face when a piece of rock that has dislodge, rolled and struck him on top of his left foot.	Falling material/ rolling rock	Serious injury	Supervision	Supervisor failed in his duties did not ensure that rules were obeyed

Table C 1: The Causal Section

	Proximal causes					
Incident	**Slip and Lapses**	**Mistakes**	**Routine violation**	**Exceptional violation**	**Non-human cause**	**Comment on choice**
1	0	0	0	0	1	He was working under an unsafe ground
1	0	0	1	0	0	He was not qualified by standards to do the rock inspection
2	0	0	1	0	0	He was sitting at an unsanctioned place
2	1	0		0	0	He didn't hear/see the LHD coming, he might have fallen asleep
3	0	1	0	0	0	Wrong positioning for the job
4	1	0	0	0	0	Stone that fell was obscured due to thickness of rock
4	0	0	1	0	0	Mid shift barring not done, it may have identified rock
5	0	0	1	0	0	Instead of using equipment for mid-shift barring he used his hand(Risky behaviour), no shortage of equipment

Table C 2: The Causal Section (Workplace factors)

	Workplace factors						
Incident	**proximal cause**	**CP**	**FFPE**	**PE**	**BE**	**UWP**	**Comment**
1	Non-human cause	0	0	1	0	0	Adverse ground condition
1	Routine violation	0	0	0	1	0	Chief rock engineer flouted the rules,
2	Slip and lapses	1	0	0	0	0	He was on medication, not fit for such task
2	Routine violation	0	0	1	0	0	Sat at the unsanctioned place because the designated place was very dirty
2	Mistake	0	0	1	0	0	No sign indicating the danger
3	Mistake	0	1	0	0	0	Using short pinch so he had to climb up
3	Mistake	0	0	1	0	0	Box design was limiting
3	Mistake	1	0	0	0	0	training didn't fully prepare him for that
3	Mistake	0	0	0	0	1	Existing standards weren't enough to identify all the risks

KEY

CP = Competent people. FFPE= Fit-for-purpose equipment, BE = Behavioural environment,

PE = Physical environment USP= Unsafe Work practices

Table C 3: The Causal section (Systemic Factors)

Systemic Factors				
Incident	**Workplace factors**	**Factor1**	**Factor 2**	**Comment**
1	Physical environment	R.M.	0	Adverse ground condition not managed properly
1	Behavioural environment	C.M.	L	Supervisor ordered the violation, it was because of inadequate stuff resulting from exodus of workers
2	Physical environment	H.K.	0	Poor housekeeping, cubicle has not been cleaned for a while
2	Competent people	C.M.	0	A medically unfit contractor working
3	FFP equipment	P.R.	0	Failure to provide workers with long pinch bars
3	Physical environment	D	0	Poor design of work environment
3	people	T.C.	L	Existence training inadequate, Failure by supervisor to conduct Planned task observation
3	Unsafe work practices	H.I.	MC	Existing standards weren't enough to identify all the risks. Platform installed without change management analysis

Key

R.M. = risk management, C.M. Change management, L = leadership, HK=housekeeping, P.R. = Provision of Resources, H.I. = hazard identification, D= design, T.C. = Training and Competence

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