Cross-sectional Analysis of Incident Causations within the South African Civil Construction Industry

by

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Declaration

By submitting this thesis electronically, I declare that the entirety of the work contained therein is my own, original work, that I am the sole author thereof, that reproduction and publication thereof by Stellenbosch University will not infringe any third party rights and that I have not previously in its entirety or in part submitted it for obtaining any qualification.

March 2020

Abstract

The civil construction industry in South Africa contributes greatly to the occurrence of work-related incidents in the country, often leading to injury or fatality. In order for South Africa to reduce the high incident rates in this industry, it must first become aware what is causing these incidents. The study sets out to provide information regarding the causation of incidents within the South African civil construction industry, identifying leading incident causation factors in terms of *human errors*, *workplace factors* and *organisational factors*. Relationships between these incident causation factors develops understanding of the failure pathway which leads to an incident occurring.

Understanding incident causations can be done through the analysis of incident reports. The incident reports are gathered from three South African civil construction companies who shall remain anonymous. Each individual incident report is analysed using an incident causation framework (ICF) adapted from Jude Bonsu's work on the South African mining industry (Bonsu *et al.*, 2016). A cross-sectional analysis is then done across all incident reports, whereby leading incident causation factors and relationships between incident causation factors are identified.

Prior to performing analysing the incident reports, motivation is given of the need for this study in the South African civil construction industry. The motivation is given through the comparison of incidents between this industry and the South African mining industry. The results of this comparison found that the South African mining industry has successfully reduced both injury and fatality frequency rates, whilst the civil construction data had no statistical significance. Lack of statistical significance indicated a lack of control over incidents. The South African civil construction has managed to reduce injury frequency rates; however, they were experiencing rates far higher than those of the mining industry.

The findings of this study presented that common leading incident causations were occurring for the three companies. For all three companies; *mistakes* are found to be the leading *human error; controlled work environment* (CWE) the leading *workplace factor;* and *hazard identification* the leading *organisational factor*. Relationships were also established that linked the *workplace factors* to the *human errors* that they cause and

organisational factors to the *workplace factors* they cause. The relationships were analysed, and it was found that reasoning could be given to the relationships occurring between each of the incident causation factors.

The research concluded that it had both achieved the objectives set out as well as provided benefits that can be applied to the South African civil construction industry. Recommendations were also made to promote further studies and application of this study to the South African civil construction industry.

Opsomming

Die siviele konstruksiebedryf in Suid-Afrika dra grootliks by tot werkverwante voorvalle in die land, wat dikwels lei tot beserings of sterftes. Om Suid-Afrika se hoë aantal voorvalle in hierdie bedryf te verlaag moet mense eers bewus word van wat hierdie voorvalle veroorsaak. Hierdie studie beoog om inligting te verskaf rakende die oorsake van voorvalle in die Suid-Afrikaanse siviele konstruksiebedryf, deur die vernaamste oorsaakfaktore in terme van *menslike foute*, *werksplekfaktore* en *organisatoriese faktore* te identifiseer. Die verwantskappe tussen hierdie oorsaakfaktore ontwikkel begrip van die oorsake wat lei tot 'n voorval.

Om die oorsake van voorvalle te verstaan, moet verskillende voorvalverslae ontleed word. Voorvalverslae van drie Suid-Afrikaanse siviele konstruksiemaatskappye wat anoniem sal bly is ontleed. Elke voorvalverslag is geanaliseer en ontleed met behulp van 'n insident oorsaak raamwerk wat aangepas is uit Jude Bonsu se werk binne die Suid-Afrikaanse mynbedryf. Daarna word 'n dwarsnit-analise oor alle voorvalverslae gedoen, waaruit leidende oorsaakfaktore en verwantskappe tussen voorvaloorsaakfaktore geïdentifiseer word.

Voordat die voorvalverslae ontleed word, word 'n motivering gegee vir die behoefte aan hierdie studie binne die Suid-Afrikaanse siviele konstruksiebedryf. Die motivering word gegee deur die voorvalle tussen hierdie bedryf en die Suid-Afrikaanse mynbedryf te vergelyk. Uit die resultate is bevind dat die Suid-Afrikaanse mynbedryf die beserings- en die sterftefrekwensiesyfers suksesvol verlaag het, terwyl die gegewens vir die siviele konstruksiebedryf geen statistiese betekenis gehad het nie. 'n Gebrek aan statistiese betekenis dui op 'n gebrek aan beheer oor voorvalle. Die Suid-Afrikaanse siviele konstruksiebedryf het dus daarin geslaag om die frekwensie van beserings te verminder, alhoewel hul egter koerse ervaar wat veel hoër is as die mynbedryf.

Die bevindinge van hierdie studie het aangedui dat die mees algemene oorsake van voorvalle by al drie maatskappye voorkom. Vir al drie maatskappye is gevind dat; *foute* die grootste *menslike oorsaak* is; *beheerde werksomgewing* die grootste *werkplekfaktor* is; en *gevaaridentifisering* die leidende *organisatoriese faktor* is. Verwantskappe is ook bewerkstellig wat die *werkplekfaktore* koppel aan die *menslike oorsake* wat dit

veroorsaak en *organisatoriese faktore* met die *werkplekfaktore* wat dit veroorsaak. Die verwantskappe is geanaliseer en daar is gevind dat daar ‘n redenasie is vir die verwantskappe tussen elk van die oorsaakfaktore.

Die gevolgtrekking uit die navorsing is dat dit beide die uiteengesette doelstellings bereik het, sowel as voordele bied wat binne die Suid-Afrikaanse siviele konstruksiebedryf toegepas kan word. Aanbevelings is ook gemaak vir verdere studies en om die toepassing van hierdie studie binne die Suid-Afrikaanse siviele konstruksiebedryf te bevorder.

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Glossary

Acronyms

ALSI	JSE All Share Index
CCI	Civil Construction Industry
COIDA	Compensation for Occupational Injuries and Diseases
CONM	JSE Construction & Materials Index
CP	Competent People
CTF	Culture Transformation Framework
CWE	Controlled Work Environment
DMR	Department of Mineral Resources
FEM	Federated Employers Mutual Assurance Company
FFPE	Fit For Purpose Equipment
GDP	Gross Domestic Product
HFACS	Human Factor Analysis and Classification System
ICF	Incident Causation Framework
ICM	Incident Causation Model
ICMM	International Council on Mining and Metals
ILO	International Labour Organisation
JSE	Johannesburg Stock Exchange
MCSA	Mineral Council of South Africa
MHSC	Mine Health and Safety Council
MVA	Motor Vehicle Accident
OHS	Occupational Health and Safety
PPE	Personal Protective Equipment

PWC	Price Waterhouse Coopers
SWP	Safe Work Practice

Chapter 1.

Introduction

1.1. South African civil construction background

The civil construction industry plays a vital role in the economic growth and development of a country (Oladinrin *et al*, 2012). As a developing country, much of South Africa’s growth and development is dependent on the ongoing maintenance and improvement of infrastructure (Ackoff, 1990).

To better understand the South African civil construction industry there are two significant influential aspects; financial and current incident statistics. As with all industries in a capitalist economy, whether they are fully-fledged or developing, it is ultimately financial sustainability and success that underpins the state of the industry and so too influences the future growth. Thus, it is financial aspects that are used as a means of understanding the importance of the civil construction industry to the country and the people of South Africa. Secondly, industry-specific incident statistics and their impact provide reasons as to why methods are required to reduce the occurrence of incidents. If these incident statistics are viewed and analysed, it becomes evident that the industry’s growth is undermined by the frequent fatalities and injuries to South African civil construction employees (Joubert *et al*, 2005).

1.1.1. Financial background

South African civil construction is an industry with a steady 4% contribution to the South African Gross Domestic Product (GDP) (Okoro *et al.*, 2016). In any economy, but particularly in a developing one, any contribution to the national GDP is of significance However, civil construction has suffered a general decline in the Johannesburg Stock Exchange (JSE) share price from 2014 to 2016 (PWC, 2016). Figure 1.1 shows the reduction of approximately 50% in the JSE construction and materials (CONM) index, from the beginning of 2014 to the end of 2016 (PWC, 2016). The figure demonstrates that despite a difficult economic climate during this period, the JSE All Share Index (ALSI) remained constant while conversely, the CONM index declined substantially (PWC, 2016). Figure 1.1 demonstrates a slight rise in the JSE CONM index for June 2016; however, this rise is not substantial in indicating positive future profitability for the industry. It is possible that survival in a tough industrial climate resulted in companies possible turning to cost-cutting measures to protect their bottom lines but which may have impacted on employee safety.

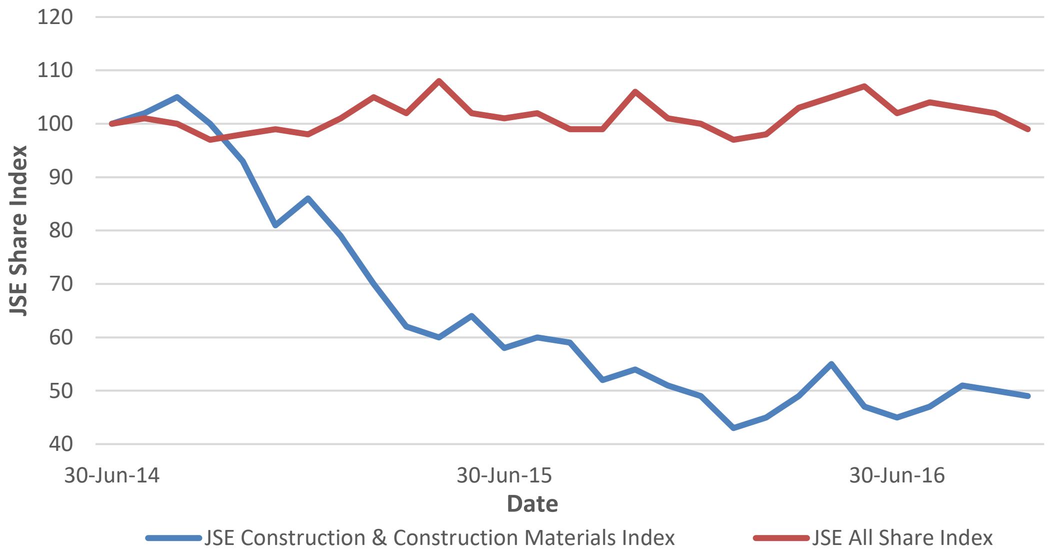


Figure 1.1: Comparison of JSE ALSI vs JSE Construction & Materials Index
(PWC, 2016)

This economic downturn and the entry of foreign construction companies into the sector led to a highly competitive civil construction market (Joubert *et al*, 2005). To add to the growing competition, many historically disadvantaged individuals took the opportunity to establish new companies through the Broad-Based Black Economic Empowerment Act (Oyewobi *et al*, 2014). The influx of these new civil construction companies alongside the appearance of established foreign firms in an industry in a country facing a general economic downturn creates a difficult environment with negative impacts on the profitability of established companies and is a threat to the survival of smaller recently developed companies. According to Price Waterhouse Coopers (PWC), with government's commitment to sustainable development, the industry has a platform for future projected growth for those companies which can adapt to the competitive market (PWC, 2016).

According to Oyweobi, the South African Government's policy on future sustainability will primarily aid in helping the economic growth of larger companies, due to an already established dominance of the market (Oyewobi *et al*, 2014). In a 2016 study undertaken by PWC this includes growth of the industry, compliance with laws, and health and safety as key risks impacting on future industry growth (Ugwu and Haupt, 2007). Health and Safety has a direct impact on productivity and company sustainability. For this reason, it is noted that these are of very high concern with regards to future development (Ugwu and Haupt, 2007). With regards to the South African civil construction industry incident statistics, significant reductions in incidents and the simultaneous improvement in employee safety can positively impact the sustainability of the industry. This positive impact can contribute to the growth of the South African civil construction industry.

1.1.2. Incident statistics

The International Labour Organization (ILO) estimates that the construction industry is responsible for a large proportion of the total international occupational fatalities (International Labour Organization, 2015). This estimate is supported with findings that construction activities cause approximately 30% of occupational fatal injuries worldwide (Okoro *et al.*, 2016). For South Africa the statistics show similar evidence. The incident statistics for the South African building industry were gathered from the Federated Employers Mutual Assurance Company (Pty) Ltd (FEM). For this study, civil construction is defined according to the following FEM subclasses:

- Civil engineering;
- Steel reinforcement construction;
- The erection/dismantling of scaffolding.

These subclasses apply to the entire region of South Africa thus the totals reflect all FEM recorded injuries in the building industry within South Africa. While it is possible that some incidents go unreported or in some cases may be reported to institutions other than FEM, for the purposes of this study the FEM statistics are used.

'Building' refers to all industries involved in the building sector, of which civil construction is a subclass. Figure 1.2 illustrates the number of injuries for the civil construction industry compared to the total number of building-related injuries, the data for which is given in Appendix B1 (FEM, 2018). Evident in Figure 1.2 is the high contribution from civil construction to the number of injuries occurring in the building industry. With a contribution of 36.71%, 2007 was civil construction's most successful year in terms of having made the lowest contribution to total building-related injuries. In 2010 civil construction contributed 43.05% of building-related injuries, making it the worst year in terms of percentage contribution of incidents. The number of injuries in the civil construction industry remains fairly constant from 2011 to 2016.

The number of injuries occurring may be due an industry practice of approaching a situation with a reactive response. A reactive response refers to the company holding the individual involved in the incident directly responsible thus absolving the employer and excusing the employer's need to improve and implement safety procedures and provide a safe working environment. A more detailed investigation is required to see where the employer can take responsibility for particular incidents occurring.

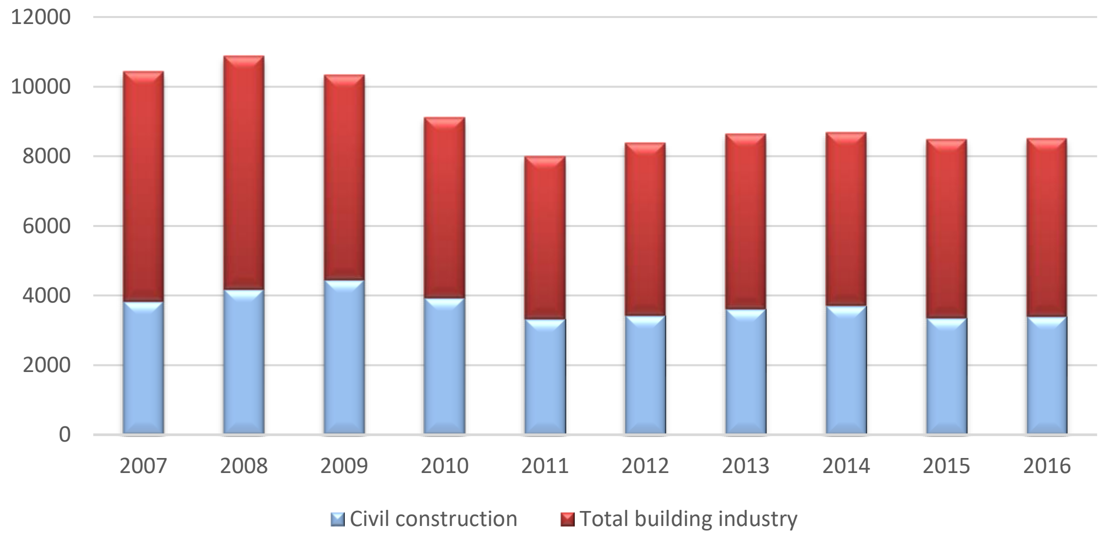


Figure 1.2: Occupational injuries within South Africa
(FEM, 2018)

As previously mentioned, fatal incidents within the civil construction industry account for a large proportion of international occupational fatalities and should therefore be a major concern to the industry (Okoro *et al.*, 2016). Figure 1.3 illustrates the total number of fatalities for both the civil construction industry and the building industry as a whole, the data for which is supplied in Appendix B2 (FEM, 2018). From Figure 1.3 it is evident that civil construction is responsible for roughly 50% of building industry-related fatalities annually. Many of the years studied demonstrate a steady increase in the number of fatalities compared to the previous year. Figure 1.3 presents periods of increase and decrease in the number of civil construction fatalities, showing a lack of efficient methods of preventing incidents. As with the injury statistics previously discussed, increased knowledge of the causations behind occupational fatalities will help to reduce the number of fatalities occurring.

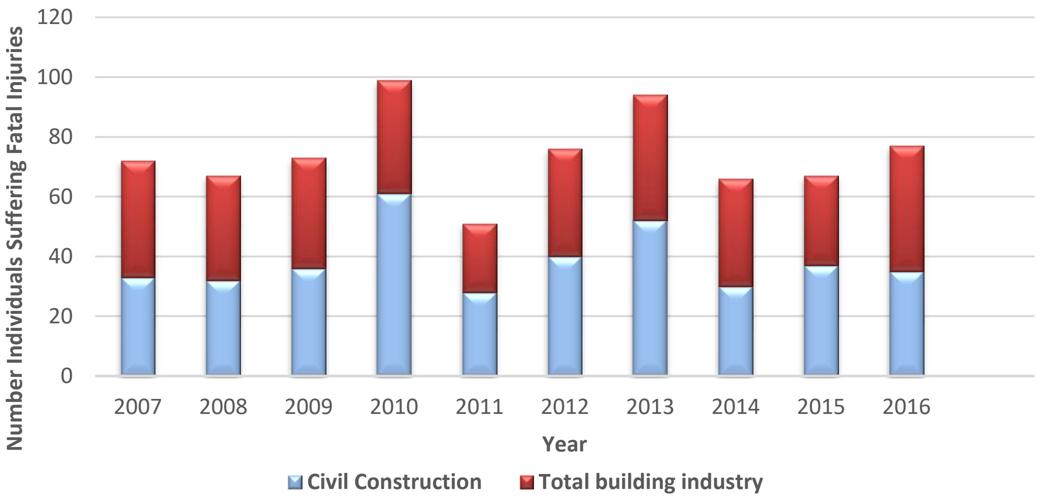


Figure 1.3: Occupational fatalities occurring within South Africa
(FEM, 2018)

Figure 1.4 shows the incident frequency rates for South African civil construction incidents per year, the data for which is supplied in Appendix B3. This figure shows both injuries and fatalities as the two incident types. The number of employees and number of incidents data used was gathered from the FEM statistics (FEM, 2018). For calculating these frequency rates, the data is normalised for 100 employees using *Equation 1.1*:

$$Frequency\ Rate = \frac{Number\ of\ incidents \times 200000}{Total\ hours\ worked} \tag{1.1}$$

For this formula the 200 000 represents the number of hours worked by 100 employees each year (8 hours a day × 5 days a week × 50 weeks a year).

A high spike in the fatality frequency rate in 2010 could be attributed the 2010 FIFA Soccer World Cup hosted by South Africa. With the construction of five brand new stadiums and approximately R17.4 billion invested in new infrastructure, the construction industry was highly active during this period (Future *et al*, 2010). With the FIFA Soccer World Cup approaching, time constraints would most likely have been in place, probably causing a rush in work and lowered adherence to safety precautions within the workplace (Future *et al*, 2010).

The frequency rates for fatalities presents common findings as indicated in Figure 1.3. Injuries demonstrate steady decline in frequency rates from 2007 until 2016. This steady decline reflects positively for the civil construction incident reduction; however, the injury frequency rates remain very large ranging from 2.41 (2016) to 4.02 (2007). An injury frequency rate this large remains highly concerning over the industries ability to control the occurrence of injuries and protect their employees. For fatalities the frequency rate fluctuates year-on-year just as the number of fatalities presented in Figure 1.3 demonstrated. Figure 1.4 demonstrates that fatality frequency rates have not decreased consistently from 2007 to 2016, indicating that the variation in the number of fatalities is not due to increased workforce numbers. The high injury frequency rates and rapidly inconsistent fatality frequency rates supports the requirement for methods which reduce the number of civil construction-related incidents occurring.

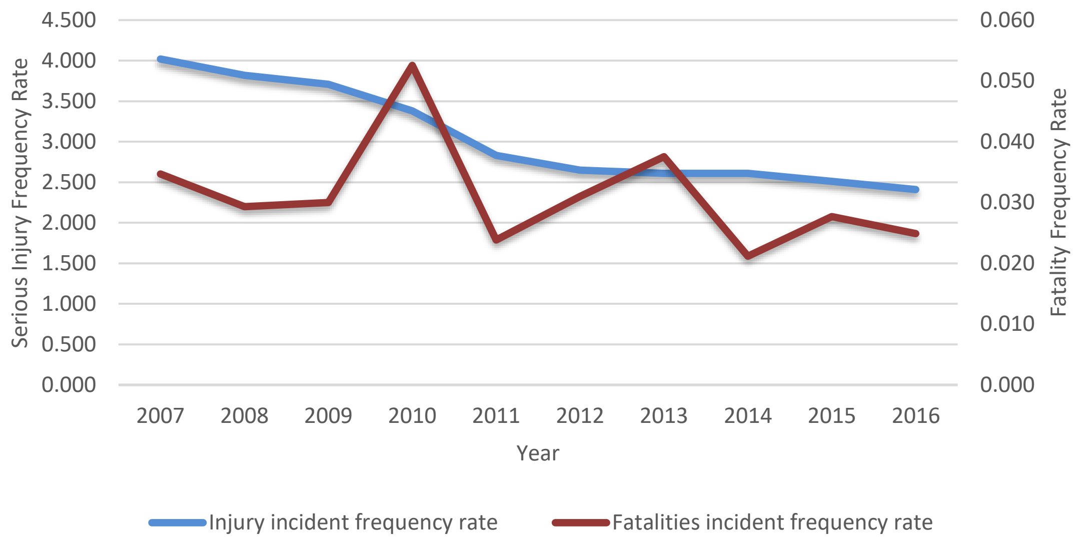


Figure 1.4: Incident frequency rates
(FEM, 2018)

Figures 1.2, 1.3 and 1.4 have demonstrated the current condition of the South African civil construction industry in terms of injuries and fatalities. The incident statistics and financial importance established for the civil construction industry indicate the impact this industry has on South Africa. A proactive approach for dealing with these incident statistics is to assess the process of investigation into incident occurrences. Investigation into the causation of incidents creates the opportunity for the development of means to effectively preclude incidents from occurring.

1.1.3. Key concepts

In order of understanding the introduction to this study, an explanation of a few key concepts is given. The key concepts centre around the understanding of incident causation and incident causation frameworks.

Incident causation is a concept which categorises the actions that took place which led to an incident occurring. For this study incident causation is broken up into three factors; human error, workplace factors and organisational factors. The causation of incidents applies the principle that organisational factors are responsible for causing workplace factors, and workplace factors are responsible for causing human error. The human error is then the final event undertaken by an individual which resulted in the incident occurring. In order to assess incidents and identify the underlying incident causation an incident causation framework is required.

There are various incident causation frameworks which exist across multiple industries. Each framework attempts to find the most suitable way to assess incidents, using this assessment to find the incident causation factors. Different incident causation frameworks apply different methods and different incident causation factors in order to assess incidents. Models such as the Human Factors Analysis and Classification System (HFACS), the Domino effect model, James Reasons Swiss Cheese model and many others, have attempted to find the most accurate means to assess incidents.

The concepts discussed in this section are to provide an understanding of the required knowledge to understand the introduction of this. Detailed explanations of literature pertaining to this study is given in Chapter 2.

1.2. Research problem statement

Against the background of the incident statistics presented in Section 1.1.2, this study hopes to provide means to reduce the occurrence of incidents in the South African civil construction industry. More specifically, the study will attempt to find methods in which individuals can begin to understand incidents in terms of direct and underlying causations, where underlying causations are often overlooked by individuals in charge. Overlooking underlying causations focuses blame on the individuals directly involved in the incident, this approach to discipline merely shifts blame but does not solve the underlying causations. Underlying causations lie at a supervisory and management level. An incident causation framework (ICF) is adapted which can be used to identify causations at these levels. The problem will be tackled through examination of multiple incidents, gaining a cross-sectional analysis opposed to a singular incident analysis.

1.3. Research questions

The research problem devised in Section 1.2 leads to the primary research question, which is:

Can a South African civil construction ICF be introduced which is used to analyse multiple real-life civil construction incidents, providing links in the three levels of causation; human error, workplace factors and organisational factors?

Through research into this primary question, the following sub-questions need to be answered:

1. Is it necessary to produce an adapted ICF for the South African civil construction industry?
2. Can the adapted ICF provide the leading proportional contributors for each incident causation factor over multiple incidents?
3. Can the adapted ICF provide links between *human error* and *workplace factor*s over multiple incidents?
4. Can the adapted ICF provide links between *workplace factor*s and *organisational factor*s over multiple incidents?

1.4. Aims

With statistics supporting the view that this industry has one of the highest rates of harmful occupational incidents, the aim of this study is to provide an analysis of the incident causation within the specific context of the South African civil construction industry. Due to the nature of the work, civil construction sites present circumstances that may be a dangerous to employee safety.

Through the use of data analysis, the aim is to expose and highlight the number of incidents which occur due to specific causations and thereafter provide a link between the different incident causation factors. The incident data will be analysed using an ICF based on the Swiss Cheese Mark III model and Jude Bonsu's framework (Bonsu *et al.*, 2016). Analysing the incidents using the adapted ICF, causations may be identified across multiple incidents as opposed to viewing causation of singular incidents in isolation. The analysis will develop the proportional contribution made by the respective causations and the relationships between the causation factors.

Through this analysis into incident causation it is possible that common incident causations may be identified within the South African civil construction industry or within a specific company. The identification of common causation may aid in the future prediction of incident causation and subsequently, the prevention of such by allowing for further investigation into methods which aim to reduce the frequency of incidents occurring within the South African civil construction industry.

1.5. Rationale of study

Analysis of data regarding South African civil construction incidents is essential for this study. There is a reliance on three companies for this study to provide the required data. These companies will supply the required data regarding incidents which have occurred during the completion of their construction projects.

While the research aims to provide a deeper understanding of incident causation for the South African civil construction industry the results will have a direct effect on the three companies involved in providing data for analysis. These companies can specifically benefit from the analyses, while the research can also benefit the South African civil construction industry through viewing all three companies' data from a singular industry perspective.

The methods discussed provide the possibility of further research in the field of incident control. Through understanding of incident causation, controlling the number of incidents occurring becomes a simpler process. Further research may be done into methods which deal with each incident causation.

1.6. Research objectives

The main objective of this study is to find the common causation of incidents for the South African civil construction industry according to multiple factors. This will focus on finding causes using an adapted ICF which is to be fully established in subsequent sections. To achieve the main objective the following objectives must be achieved:

1. To perform a comprehensive literature study for the concepts pertaining to this study, including:
    - Controls
    - The 'Energy Damage Model'
    - *Human error*
    - *Workplace factors*
    - *Organisational factor*s
    - 'Incident Causation Models'
2. To provide valid reasoning why the South African civil construction industry requires this study using the adapted ICF.
3. To identify the leading proportional contributors to incident causation factors over multiple incidents in terms of:
    - *Human error*
    - *Workplace factor*
    - *Organisational factor*
4. To provide statistical information showing relationships between the following incident causation factors:
    - *Human errors* & *workplace factors*
    - *Workplace factor*s & *organisational factor*s
5. To validate this study and the use of the adapted ICF through detailed interpretation of the leading incident causation factors and relationships between incident causation factors.

1.7. Assumptions and limitations

The three companies will provide data that will be analysed for research purposes. The data for two of the companies will be analysed by two Honours students and then by the researcher. The third company's data will be analysed by the researcher, a Master's student. This data will consist of incident reports and will be analysed using the adapted incident causation framework. The analysis of the data for all three companies will create a dataset which will then be analysed providing the incident causation trends over multiple incidents. The limitation with this is the potential inconsistency between the analyses by the honours students and the researcher. In order to protect the data analyses from inconsistency, two provisions were set out. *Firstly*, the honours students and researcher will all work closely with Dr Wynand van Dyk to ensure accurate analysis of incidents. *Secondly*, the incidents analysed by the honours students will be re-examined by the researcher.

The ability to build a strong correlation between the incidents and their causations for the South African civil construction industry, depends on the number of accurate incident reports assessed. If an insufficient number of accurate incident reports are assessed, the data will not be able to be labelled as an industry-wide perspective. To develop strong trends in causation an estimated 60 incident reports are required. This number of incident reports provides the means for accurate findings into incident causation within the South African civil construction industry.

The incident reports were gathered from three reputable South African civil engineering construction companies. For this reason it is assumed that the incident reports are accurate in their examinations of the events which led to the incident occurring.

1.8. Ethical implications

Examining incident reports requires the researcher to apply ethical regulations which adhere to the privacy of the individuals and companies involved. Regulations have therefore been devised which allow the study to be conducted in a manner which upholds ethical principles.

The ethical regulations set in place for the research process are as follows:

1. Stellenbosch University has certified ethical clearance. The ethical clearance certification has been attached in Appendix C1.
2. Informed written consent was given by each company for their incident reports to be analysed and published within the study. The details of these reports included the events which led to the incident occurring.
3. All individuals and companies involved in the incident reports will remain anonymous.
4. Focus of the study is the events which led to the incident occurring and do not assess any data based on race, gender, income, education or any other aspect of the individual.
5. Access to all incident reports is only given to the researcher and the respective supervisors, Dr Wynand van Dyk and Dr Wyhan Jooste. The honours students will have access to the incident reports of the respective companies on which their research is based.
6. Analyses of the incident reports are based on facts, no personal opinion is taken into consideration. Findings of the study will thus not aim to favour the company or the individual but will remain neutral in content.

The study attempts to aid in the understanding of the causation of South African civil construction incidents. For this reason the study intends no negative impact on the companies involved and ensures to hold true to ethical principles. Improvement in the understanding of incident causation is the only desired outcome for this study.

1.9. Research methodology

The research methodology is to be covered in detail within Chapter 3. For the purpose of the study the basic outline of the chapter is as follows:

1. Introduction to the research process. Highlighting the ordered way in which the research was performed.
2. Providing detail of research into the topic. This section is covered through a literature review.
3. Describing the Incident Causation Framework used, primarily how it was developed and implemented.

4. Description of the collection and analysis of all data. Data collected was regarding three aspects:
    a. South African civil construction incident data
    b. South African mining incident data
    c. Individual incident reports collected from three separate companies
5. Summary of the chapter.

1.10. Research report outline

The study is broken up into various sections labelled as chapters. A brief layout and chapter contents is given below.

Chapter 1: Introduction

The introduction provides the rationale for the study. Initially, statistical representations are given to display both the economic importance of the South African civil construction industry and its current high incident rates. Following this, detail is given into the reasons why this study has been performed. In essence this section provides the reader with information required to understand the reasoning and means for the study.

Chapter 2: Literature study

The literature study builds the knowledge required to understand the material to be covered. Concepts covered in the literature study provide the core knowledge for following the research. The literature study begins with explaining what leads to incidents occurring and how to control incidents. After an understanding of incidents is developed the literature study covers aspects required to understand and apply the adapted ICF. In order for the reader to follow and understand the study the information given in the literature study is fundamental.

Chapter 3: Methodology

The methodology comprises of the research study, gathering of civil construction and mining incident data, gathering of civil construction incident reports and incident causation analysis of the incident reports. The methods discussed in the section outline the process of data analysis and how the data is displayed.

Chapter 4: Incident causation framework

The Incident Causation Framework aims to provide a detailed explanation into why the chosen adapted ICF is best suited to analyse the incident reports. Comparisons are drawn between the South African civil construction industry and the mining industry to provide reasoning for the requirement of control over incidents. In this section details regarding the adapted ICF are given which explain the different aspects and how the ICF is applied.

Chapter 5: Data analysis and results

Data analysis consists of analysing the incident reports using the adapted ICF in order to find common causations and links between causation factors. Graphical representations and analysis are given in Chapter 5. The data matrix is formed using Microsoft Excel, whereby each individual incident assessed is populated into a dataset. Finding causation proportions for each of the causation factors assessed, namely; *human errors*, *workplace factors*, and *Organisational factor*s is done in Chapter 5. Lastly, links are established between the causation factors.

Chapter 6: Conclusions and recommendations

Conclusions are given in terms of the research results found and contributions to the industry. The research results found aim to answer the research questions as well as objectives set out in Chapter 1. Conclusions drawn from this study may benefit the South African civil construction industry to control incidents by being able to provide recommendations.

Recommendations are given regarding possible future work which is based on this study in order to benefit the South African civil construction industry. Realisation of common causations provides the framework for further studies into the control of incident occurrence. Future work based on this study could provide further benefit for the South African civil construction industry.

1.11. Chapter 1 summary

Chapter 1 primarily focused on giving a brief outline of the study. Arguments presented in Section 1.1 are the reasoning behind the study into the South African civil construction industry. The research problem, research question, aims, rational and objectives, given in Sections 1.2 to 1.6, describe the reason for the study. Sections 1.2 to 1.6 also provide detail as to why this study makes a relevant contribution to the respective industry. Assumptions and limitations and ethical implications, Section 1.7 and 1.8, provide the reader with understanding as to what limited the study and the precautions taken to ensure the study retains ethical principles. Research methodology, Section 1.9, provides how the study was conducted. The outline of the report is given in Section 1.10 for each chapter.

Chapter 2.

Literature study

2.1 Introduction

An in-depth knowledge of relevant information regarding a research topic is vital in any study. The literature study aims to provide this knowledge to the reader. Various sections make up the literature study which help develop the understanding of what causes incidents and which makes up the adapted ICF. The knowledge gained through this section is applied throughout the study.

2.2 South African Occupational Health and Safety (OHS) Act

The Occupational Health and Safety Act 85 of 1993 (OHS Act) serves to protect an employee from any hazards that may occur in the workplace (*Occupational Health and Safety Act 85 of 1993*). The main initiative of this act is the prevention of any possible harm or injury to an employee due to physical damage (Booysen, 2010). The prevention of harm is focused on both the employees in the area, as well as any persons in the nearby vicinity. Apart from mines, all workplaces in South Africa (ranging from construction sites to regular office blocks) must by law, adhere to the OHS Act. In addition under Section 43 of the OHS Act the construction regulations of 2014 must be adhered to (*Construction Regulations 2014*, 2014).

The construction regulations of 2014 set out the need for a risk assessment. Regulation 9.1 of the construction regulations states that "[a] contractor must, before the commencement of any construction work and during such construction work, have risk assessments performed by a competent person in writing" *(Construction Regulations 2014*). Efficient risk assessment is then vital for all works in the construction field.

The South African Labour Guide (2018) provides guidance on any matter relating to labour regulations in South Africa. Risk assessment has categories (which may be applied for a construction-related project) set out by the South African Labour Guide which are; baseline risk assessment, issue-based risk assessment and continuous risk assessment. (Booysen, 2003). An explanation of each of these three categories is provided below.

Baseline risk assessment

Baseline risk assessment provides a high-level overview of possible risks. Assessed risks in this section are often very broad and establish a benchmark of the potential risks a certain project undertakes. This risk assessment establishes which risks would be considered the highest priority (meaning the highest concern regarding level of risk severity). This allows for the prioritisation of risk and assessing risk controls, which ensures that the control requirements for the particular risk level are met. The information gathered within a baseline risk assessment is used to set up risk profiles. These risk profiles set out the company's acceptable level of risk compared to the current risk levels.

Issue-based risk assessment

Issue-based risk assessment is concerned with evaluating risks at a higher level of detail than baseline risk assessment. This issue-based risk assessment provides steps in resolving a known risk, with the objective being to eliminate or reduce this risk. It focuses on research regarding methods of how to deal with the risk identified. Dealing with risk often involves the selection of the controls (discussed further in Section 2.3) required for the focused-on task. The findings of this assessment aim to provide methods of reducing or eliminating the risk within the system.

Continuous risk assessment

Continuous risk assessment is concerned with the final inspection of all tasks. Recommendations are made for the use of checklists in order to establish successful operations due to each requirement listed. Through inspection and detailed examination, this method can provide a reduction in error due to cancelling a procedure if adequate operation requirements are not met. It is the responsibility of a trained professional in the field to perform this assessment.

The OHS Act is set out to provide many of the guidelines for correct working procedures, although (due to an almost unlimited number of applicable working procedures) it is often perceived as an impossible task. Due to the impossibility of assessing every work procedure the guidelines are set out for tasks considered high risk in terms of incorrect working procedures. Adherence to these guidelines is mandatory as they set the foundation for the South African work safety protocol. These guidelines allow for risk assessment to become a more common practice within the South African civil construction industry. The risk assessment's purpose is to quantify the possible consequences of a risk that occurs. One of the more adequate methods for dealing with risk is the use of controls.

2.3 Controls

Controls are essentially safety barriers. One may refer to these as either controls or barriers dependent on the user's discretion. Controls are set in place for two purposes; in order to prevent incidents or to protect individuals in harmful situations (Hollnagel, 1993). Multiple layers of controls produce a system with the aim of preventing incidents and protecting individuals. Categorisation of controls identifies the method used for the control to aid in the system.

2.3.1 Control categorisation

Controls have two purposes, namely prevention and protection (Pinto, 2017). Prevention is the act of setting up controls which help reduce the possibility of an incident occurring. Incidents occur due to the release of uncontrolled energy from a system which if controlled the energy does the required work. Preventive controls keep energy from escaping the system in the event of an uncontrolled energy release. For the purpose of reducing the severity of damage done by the escaped energy, protection controls are put in place. Protection aims to act as a defence in reducing the harm or damage caused in an incident (Pinto, 2017). Protection will thus apply to any form of safety equipment which is used to minimise the effects of the uncontrolled energy transfer. Figure 2.1 (Image A), illustrates how preventive controls form a layer around the energy and Figure 2.1 (Image B) demonstrates how the protective controls form a layer around the individual. For example, although a stop sign may aim to prevent an incident, it will have no effect in reducing the severity of the incident's outcome. The same concept applies to a safety helmet, which does not prevent an incident but will reduce the severity.

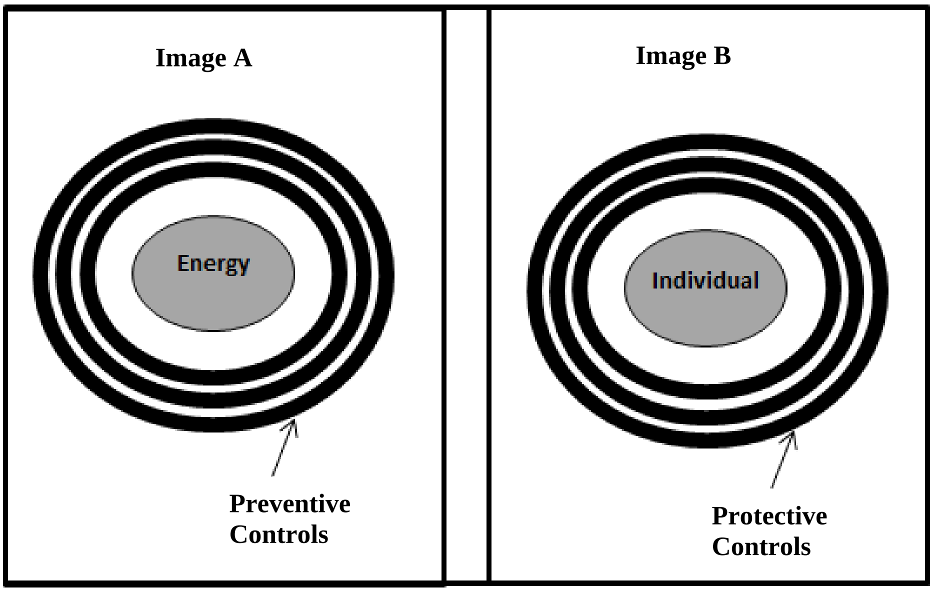


Figure 2.1: Representation of preventive vs protective controls

Erik Hollnagel (1993) suggests that controls can be divided into four categories. These categories are based on how the controls act in order to prevent or reduce harm. Categorisation is based on both the physical properties of the controls as well as the purpose the controls are put in place to perform. From categorisation a description is given on how the control performs the task of either prevention or protection. The four categories established by Erik Hollnagel (1993) are as follows:

Material controls

A material control is a physical object with the purpose of either prevention or protection. An example of a preventive material control could be additional support pillars which would ensure stability and prevent an incident from occurring. In terms of protective controls an example could be the safety equipment used (such as hard hats) which would reduce the severity of an incident if it should occur.

Functional controls

Preventive functional controls are ‘obstacles’ which must be completed to ensure that the individual is focused when completing the task (Hollnagel, 1993). An example is the use of a safety button with electrical equipment which prevents accidental start up. Protective functional controls act as safety fault mechanisms. These reduce the negative consequences of an incident. The notable difference between functional and physical controls is the lack of a physical barrier. Functional controls focus on slowing down a process in order for a higher level of thought to be applied.

Symbolic controls

Symbolic controls are made up of any vocal or visual warning used to indicate a possible hazard. In layman's terms, any form of warning system which conveys a message of danger may be considered a symbolic control. Symbolic controls may only be preventive in nature. An example of these preventive controls is signs which indicate overhead hazards as these create an awareness of danger.

Immaterial controls

Immaterial controls are based on the expected knowledge of the individual involved in a task and are preventative in nature. Various rules set out through mandates, laws and other restrictions need to be adhered to for the safe completion of a task. Relevant guidelines are communicated to the individuals performing the task based on these rules. People who regularly complete certain tasks do not necessarily need to refer to the respective guidelines as they are familiar with the practices. The biggest flaw in immaterial controls is individuals performing tasks in a manner of their choosing due to guidelines not being enforced (Hollnagel, 1993).

Erik Hollnagel's (1993) system, which is illustrated in Figure 2.2, classifies each control as either preventive or protective in nature. The preventive category consists of all the controls mentioned above, whilst the protective category consists solely of physical and functional controls. These categories of controls all form a level of safety which was used to develop a system known as 'defence in depth' (Saleh *et al.*, 2010).

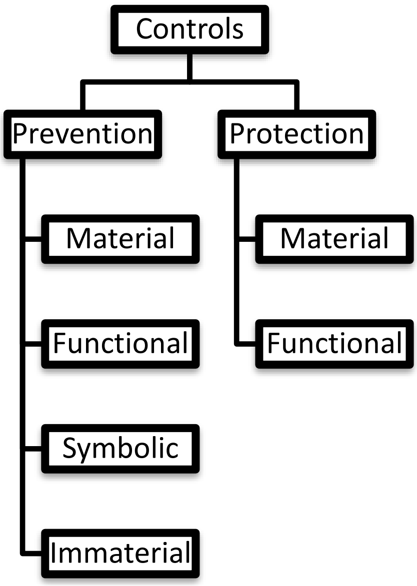


Figure 2.2: Control categorisation adopted from Erik Hollnagel (1993)

Defence in depth is a principle hypothesised by the US nuclear Regulatory Commission (Saleh *et al.*, 2010). Defence in depth refers to the multiple defence layers or controls which form a system. These layers are put in place to ensure the minimisation of the potential of the release of uncontrolled energy through a system failure. The energy source discussed is known as the hazard which is present within a system. When the control system does fail, hazards result as the source of the release of the uncontrolled energy and an incident occurs. This emphasises the level of importance in ensuring correct use of controls to form the system. Defence in depth promotes the use of a high number of layers which increases the level of safety (Saleh *et al.*, 2010).

2.3.2 Assessing controls

Each control must be adequate in terms of preventing or minimising the possibility of incidents (Katsakiori *et al*, 2009). Inadequate controls result in failures present in each layer causing the system to fail and an incident to occur. These failures within the controls are referred to as holes. If holes are present within the control a path can form which allows uncontrolled energy to travel through the system (Hudson, 2014). A physical representation of the controls is given in Figure 2.3, demonstrating that each of these controls can have holes; however, energy can only escape when these holes line up correctly. Therefore, effective controls are vital to ensure no holes are present.

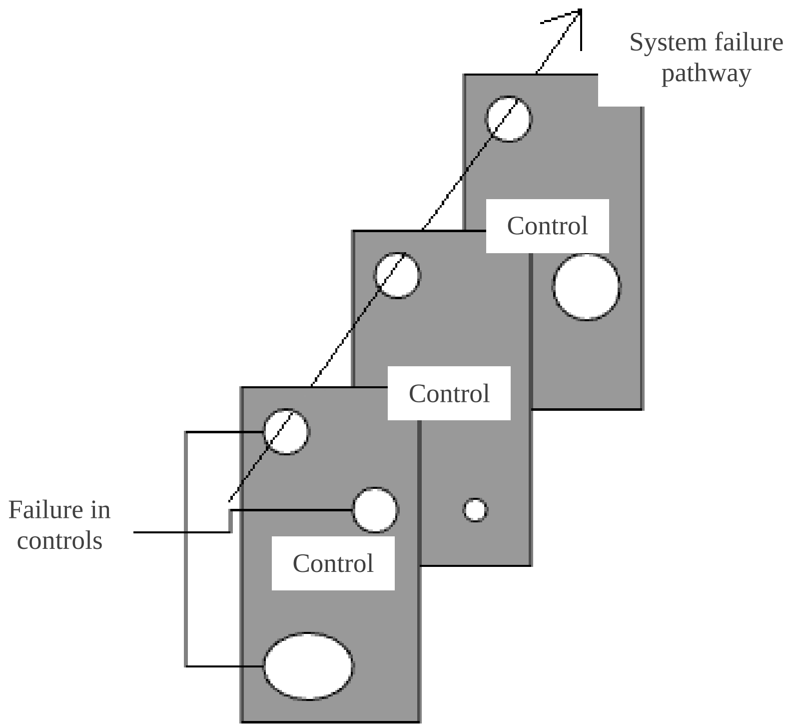


Figure 2.3: System controls and holes
(Reason, Hollnagel and Paries, 2006)

Through practical research, Dr Abel Pinto (2017) was able to assess his own criteria for establishing control effectiveness. The criteria are as follows:

Adequacy

This is the degree to which a control meets the design requirements. In the South African civil construction industry, the design adequacy refers to compliance with design regulations.

Reliability

Reliability considers the control's ability to fulfil its purpose. This is often given as a probability of the control being efficient.

Robustness

This is the capability of the control to withstand the environment in which it is contained.

Specificity

This is the control's ability to isolate itself from the required damage protection. Thus, it will not negatively affect other systems in the process of being effective.

These are the basic requirements to ensure that a layer of controls is effective. If Dr Abel Pinto's criteria are not met, holes form within the control (Pinto, 2017). To further understand how these holes form, a method known as the bow-tie diagram can be used.

2.3.2.1 Bow tie diagram

The bow tie diagram allows for a visual representation of the potential causes (initiating event) and consequences of an incident occurring (Aramis, 2007). This occurrence is due to a hazards energy which must be controlled. Inefficient controls which fail to contain energy result in the incident occurring. The bow tie diagram applies a visual representation of linking hazards, initiating events, controls and consequences involved in an incident.

The process of completing the bow tie diagram, as seen in Figure 2.4, will thus involve the following ordered steps (Cockshott, 2005):

1. Identify the hazard, the source of damaging energy.
2. Identify the initiating events which would occur. These are the events that can result in the loss of control of the hazard's energy.
3. Identify the first set of controls which may be set in place. These will be preventive controls aimed at preventing the escape of uncontrolled energy.
4. Identify the possible consequences of each initiating event and the preventive controls that failed to prevent the flow of energy.
5. Identify the second set of controls that must be set in place. These are protective controls aimed at reducing the amount of damage done.
6. The initiating event leads to the incident occurring through a failure of controls.

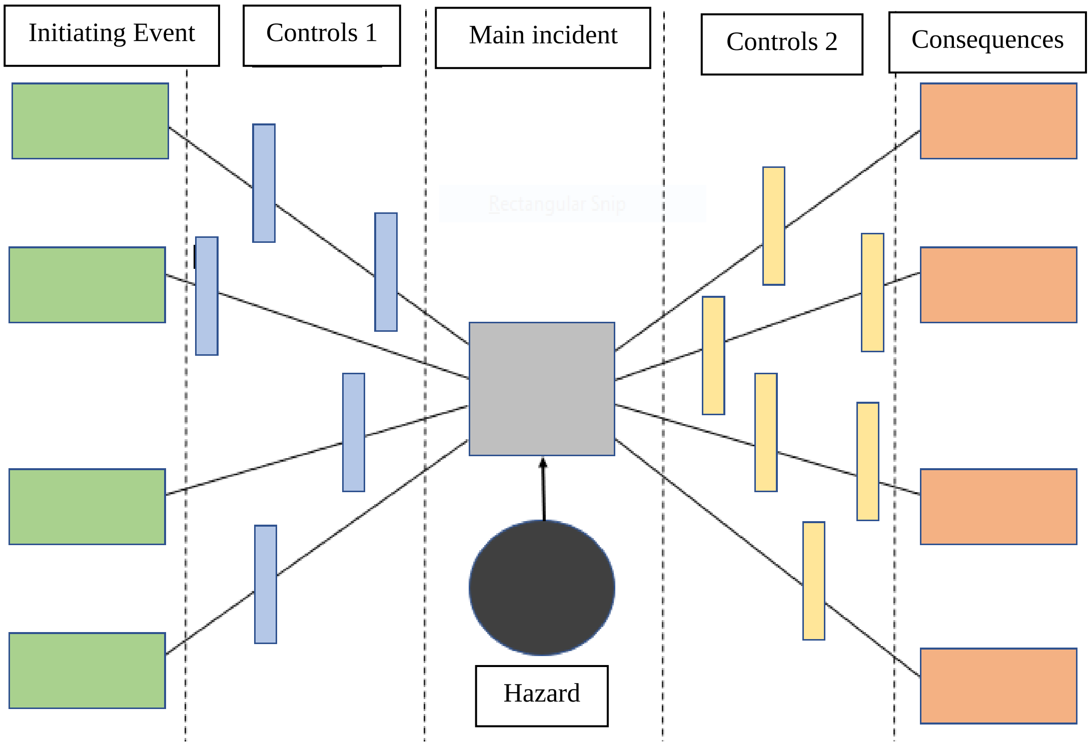


Figure 2.4: Controls bow tie diagram
(Rheinboldt, 2017)

Establishing controls demonstrates the first step in understanding the prevention of incidents. Further understanding of preventing the release of uncontrolled energy is given through understanding the energy itself. A model which explains the flow of energy and the ability to control said energy is the energy damage model. This model aims to build on controls in understanding the events which lead to an incident occurring.

2.4. Energy damage model

Borys (2000) states that for work to be done there must be energy present within a system. The source of energy is a hazard but if the correct controls are applied there is a successful transfer of this energy (Pryor, 2012). Successful energy transfer results in the correct work done and incidents do not occur due to an uncontrolled release of energy.

The Energy Damage Model recognises that exposure to a hazard can result in an incident occurring (Culvenor and Else, 1994). The larger the energy source, the larger the amount of potential harm that it can cause. Therefore, it is concluded that the size of the hazard's energy is directly proportional to the level of harm caused. The conditions that build up to the incident occurring (as a result of uncontrolled energy travelling through holes) are failures within each control, forming holes (Toft *et al.*, 2012). These incidents are problematic as they can often result in injury to employees or pedestrians. A hazard's energy needs to be released in one form or another; if uncontrolled an incident occurs and if opposing situations result in controlled energy release, correct work is done. To deal with all hazards is a seemingly impossible task as the number of sources of energy may be considered to be almost endless. To understand energy, categorisation may be used. Due to the large range of different criteria, energy categorisation is simplified within this research.

2.4.1. Energy categorisation

The term hazard is host to various definitions in different fields of research. For the sake of this research, a hazard is best defined according to Standards Australia (Pryor, 2012), which states that a hazard is a source of potential harm to an individual, property, environment or all aspects mentioned. Examples of the types of energy, as defined by Viner (1991), are as follows (SIA, 2012):

Potential energy

Potential energy is dormant energy which becomes active if triggered. This is primarily in the form of structural strain or gravitational energy.

Kinetic energy

Kinetic energy is dictated by the object's momentum. This form of energy is expelled through the energy of movement which takes weight and speed into consideration.

Electrical energy

Electricity is its categorised as its own singular form of energy. Exposure of an individual to electric currents may be detrimental to an individual's health.

With reference to the occurrence of incidents the above-mentioned energies are very relevant to the civil construction industry. There are, however, various other forms of energy. The listed forms of energy merely act as examples, or as a means of grasping the concept of energy. It is of primary understanding that all energy allows for the potential of an incident if not controlled correctly.

2.4.2. Energy damage model evaluation

Figure 2.5 is an adaptation of the energy damage model demonstrated by Viner (Pryor, 2012). The model is represented by a hazard and recipient relationship. When all controls are in correct working order there are no holes present thus the release of uncontrolled energy is prevented (Reason *et al.*, 2006). The first set of controls around the energy are the preventive controls. As stated previously if the energy escapes these controls it may result in an incident. As seen in Figure 2.5, the energy travels from the hazard to the recipient along the transfer mechanism (path the energy follows in order to reach the recipient) (Pryor, 2012). For the transfer mechanism to occur the holes within the controls must line up with one another. The next set of controls is the external controls which are also preventative in nature. These aim to stop the flow of escaped energy heading towards the recipient. If the energy flows through holes in the external controls the protective controls come into consideration. Protective controls are set in place to reduce the amount of harm done to the individual, in order to prevent an injury or fatality.

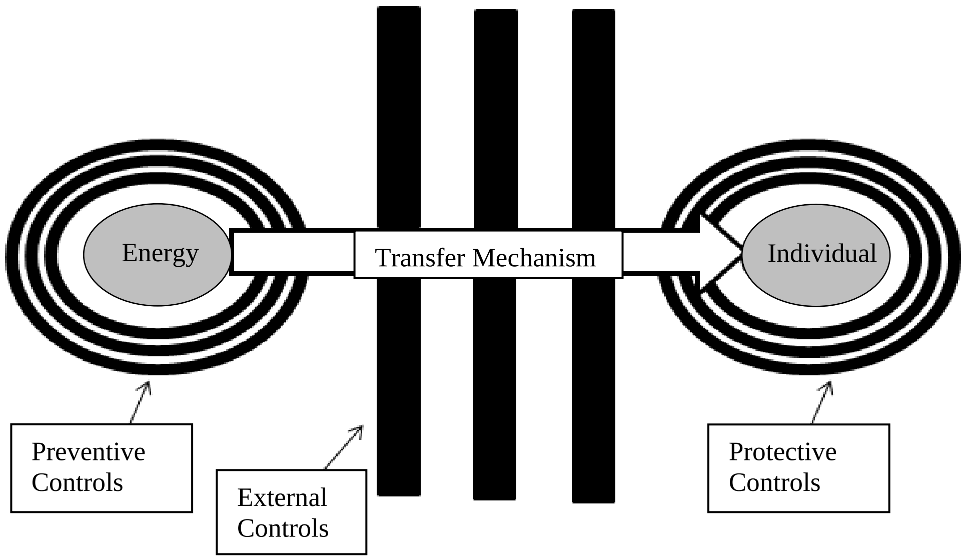


Figure 2.5: Adaption of Viner damage model
(Abas *et al*., 2013)

The amount of energy received above the recipients' threshold quantifies the level of damage done (Abas *et al.*, 2013). Level of damage is thus directly related to the amount of energy which is no longer under control. Thus, the size of holes within the controls through which the energy travels is directly proportional to the extremity of the incident. The amount of energy involved in an incident is directly proportional to the level of damage done. Thus, increased energy could lead to devastating and possibly fatal harm to an individual. Efficient methods for controlling the flow of energy should be established to minimise the potential of the release of uncontrolled energy.

To control energy, three methods may be considered. Each of these methods approaches the control of energy in a different manner. Ideally, a combination of these methods can be more proactive than the use of a single method. To understand these energy control methods, the following descriptions are given:

Minimisation of energy:

Minimisation of energy focuses on reducing harm through the use of two methods which involve either removing the hazard or reducing the hazard's energy. Dealing with a more controllable energy source (Hazard reduction) creates a more stable working environment. The first step is hazard identification which isolates the source of energy to establish the focus of the energy minimisation methods. To understand each energy minimisation method, the following examples are given:

Removing the hazard: *Ensure all objects and equipment not in use are not on site, eliminating chances of tripping over objects lying around.*

Reducing the hazard: *Uneven surfaces can be levelled to a more acceptable level, reducing the potential of tripping and reducing the hazard's energy.*

Improvement of preventive controls:

Improvement of preventive controls is gained by placing additional preventive controls or improving current preventive controls which are in place. Both methods of preventive control improvement reduce the possibility the release of uncontrolled energy (Improve controls). To achieve this an understanding of the controls required must first be established. One method of establishing the required controls is through the use of the bow tie diagram (discussed in Section 2.3.2.1). This diagram displays the controls which are set in place when an incident occurs, while simultaneously establishing ineffective controls. Once ineffective controls are established a decision can be made on whether new controls are required or if improvement of controls is substantial. An example of each of the preventive control improvement methods is given below:

Additional preventive controls: *Securing the entire area with sturdy guard rails when working at heights. This eliminates the potential of individuals falling and prevents the incident from occurring.*

Improving current preventive controls: *If only one row of guard rails is present, place a second row, improving on the control already added.*

Prevention of energy transfer:

Prevention of energy transfer is gained through the placing of additional protective controls or improvement of current protective controls (Improve controls). Protective controls prevent or reduce the consequences when there is a release of uncontrolled energy. Protective controls are the last resort in ensuring limited harm is done when energy loss occurs. To understand each energy transfer prevention method examples are given:

Additional protective controls: *Adding of a net when working at heights, ensuring that in the case where the employee falls the net is in place to catch them.*

Improving current protective controls: *Improving the design of personal protective equipment (PPE). Improved design offers more shock absorbing technology, restricting further damage when an employee is struck with an object.*

Apart from these three methods an additional design principle may be used. This design principle is known as safe design. The basis of safe design is the formation of a safe environment in which the worker operates rather than focusing on the reduction of *human error*. The safe design principle allows for correction before the escape of energy occurs, preventing the potential of energy to cause harm. Safe design focuses on the idea that regular maintenance should be set in place in order to reduce the possibility of a hazard occurring (Cowley and Borys, 2014).

2.5. Statistics of hazards involved in incidents

As established in the previous section a hazard is a source of energy which (if not controlled correctly) may result in an incident occurring. According to the previous (Energy damage) model an incident has occurred when there is an uncontrolled release of energy. The damage or amount of harm done in an incident is determined by the level of energy involved. The second factor which determines damage is the effectiveness of the controls to protect the individual from harm caused by the uncontrolled release of energy. Although these factors were established earlier, they are mentioned once more to contribute to the understanding of this section.

Figure 2.6 demonstrates the hazards energy release method and the specific number of incidents which have occurred due to this within the South African building industry. Specific data for the South African civil construction sector is unavailable, therefore, data is viewed for the South African building industry as a whole. A large proportion of the South African building industry's incidents are made up by the South African civil construction industry, meaning the data is still relevant in understanding which hazards most frequently contributed to incidents (FEM, 2018). Figure 2.6 demonstrates that the three largest proportions of incidents are a result of the hazards energy release methods: struck by, struck against and slips. Seen within Figure 2.6 these three hazards energy release methods are involved in 60% of all incidents. 'Struck against' refers the occurrence of an individual being knocked up against an object, whilst 'struck by' refers to falling objects striking an individual. Slips refer to individuals falling on site due to various factors. These slips should not be confused with the '*slip*' *human error* classification discussed in following sections.

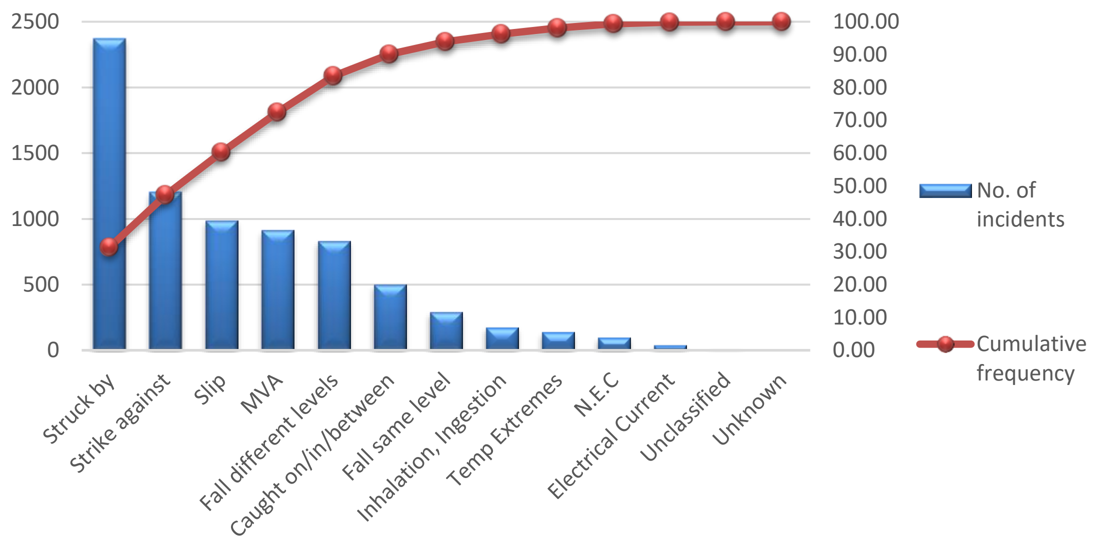


Figure 2.6: Number of incidents based on hazards energy release method
(FEM, 2018)

Fatalities are the most severe form of an uncontrolled release of energy. Figure 2.7 shows the number of fatalities attributed to the specific hazards in 2017. The top three hazards energy release methods which result in fatal incidents are motor vehicle accidents (MVA), personnel struck by objects and personnel falling between levels. As demonstrated in Figure 2.7, these three hazards energy release methods are involved in 88% of fatalities. From Figure 2.7 MVAs provide a disproportionally large number of the fatal incidents. To be more precise, in 2017 MVAs contributed to 62% of fatalities. MVAs are a reference to any incident where motor vehicles are involved.

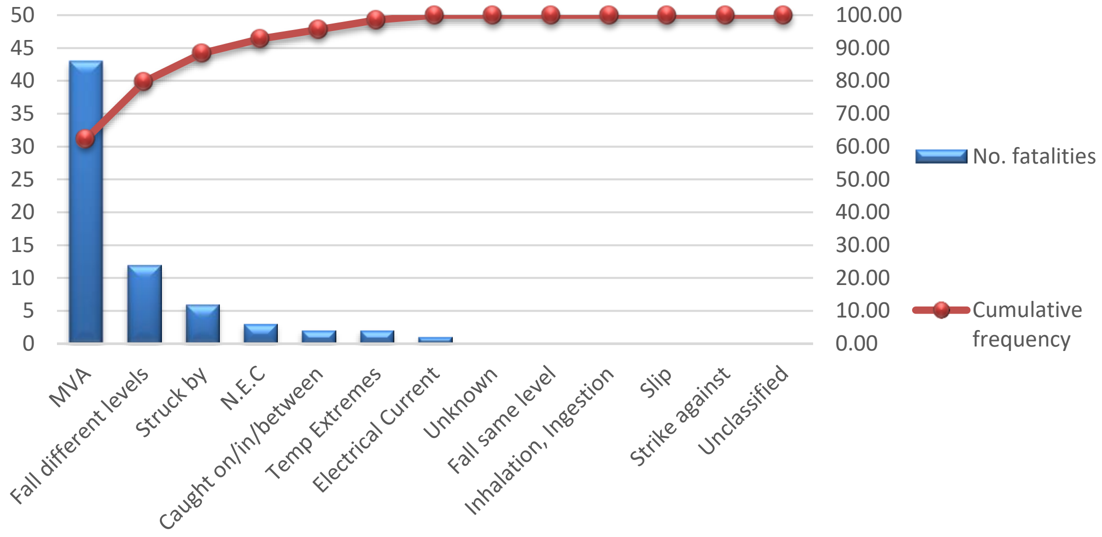


Figure 2.7: Number of fatalities based on hazards energy release method
(FEM, 2018)

A method for the reduction of the number of incidents is the principle of safe design (previously discussed in Section 2.4.2). Safe design in essence considers all potential hazards which are then planned for with sufficient controls. Through planning there may be a reduction in the probability of the uncontrolled release of energy. Supplying these statistics allows visibility on the hazards energy release most frequently involved in incidents. Understanding this allows for the finding of trends involving hazards which result in incidents. These trends may help develop an understanding of where more reliable controls are required. More reliable controls may then reduce the amount of uncontrolled energy flow, thus decreasing the frequency of incidents occurring.

2.6. Decision-making

In order to complete a task various decisions are made, typically involving a decision-making process. All choices, whether they have large or small effects, are made by means of a decision-making process. The resulting decision holds certain consequences, which may either be favourable or unfavourable. Favourable consequences are the desired consequences of making a decision. These consequences in the South African civil construction industry involve construction going according to plan (Joy, 2000). Unfavourable consequences are the result of unforeseen circumstances. Unfavourable consequences may also be the result of not making a decision when one is required, resulting in possible time delays which have incident-related financial repercussions.

Decisions can further be classified into three categories:

Strategic decisions

A strategic decision is made at an executive level. The decision can be made in advance, allowing sufficient time for the decision-making procedure. The decision-making procedure is divided into the following steps (Ingram, 2018):

1. Find out all details and prior knowledge of the task requiring a decision. Provide an outline of the task requirements.
2. Identify all possible alternative policies. Listing alternatives allows for analyses of what is the most suitable option.
3. Through analysis of pros and cons identify which policy is most suitable to completing the task.
4. Using the previous point, select the desired policy. This option is chosen at the discretion of the administration group, however, step three above aids in building an understanding of possible outcomes.
5. On completion of each step, implement the policy to be adhered to when completing a task. Establishment of a working policy is required by this step.
6. Monitor the process, controlling it and reducing risks.

Strategic decisions involve an iterative process of considering all possibilities. Pros and cons allow for a level of knowledge regarding the possible consequences of each decision. This assessment allows for a timely analysis of alternatives which lead to the final decision. The effects of these decisions may be either long or short term but are more often found to have a long-term effect. Thus, they will have consequences in the future that may directly affect the company for which the decision is made.

Tactical decisions

Tactical decisions are decided at the point of transforming strategic decisions into actions. This decision-type falls to middle management. Tactical decisions are by nature less complicated than strategic decisions. Unlike strategic decisions, tactical decisions have a time constraint factor which affects the decision. The company is required to make decisions due to deadlines put in place for task completion. If the decision is not made in time for this deadline a required decision has been neglected, leading to negative consequences. The tactical decision-making process makes use of previous experience and learnt knowledge to influence the decision made.

Operational decisions

Also known as frontline decisions, these involve decision-making for day-to-day tasks. These decisions are made in an 'auto-pilot' frame of mind, meaning there is no in-depth planning. The more competent a person becomes in executing a task, the more the decision-making mode shifts from tactical (i.e. 'how to') to operational (i.e. 'auto pilot'). Bad work practices are often connected with operational decisions as past unfavourable practices being repeated dictates decision-making (Joy, 2000).

In performing basic tasks, operational decisions are most common. Operational decision-making in basic tasks often results in individuals not processing slight changes in the work situation. This lack of cognitive thought is a potential danger when the task is slightly altered as *human error* may then occur.

Correct strategic decision-making has the ability to affect the other two forms of decision-making. The strategic decision-making process can lay a foundation for further decisions, through the creation of appropriate policies. Tactical decisions will have to follow these policies set out in the strategic decision-making process.

Addition of more functional controls can be set out in the strategic decision-making process. The functional controls can then have a positive impact on the reduction of the number of incidents occurring due to operational decision-making (Hollnagel, 1993).

Through addition of controls within the process, *human error* is less likely to occur due to a lack of cognitive thinking.

Correct decision-making can be summarised as having the ability to avoid *human error*. Through the correct use of procedure, the possibility of *mistakes* and violations occurring is minimised. Accurate decision-making is the first step as a corrective measure for the reduction of *human error*.

2.7. Human error

Through the knowledge supplied in Section 2.3 and 2.4, an understanding has been developed into the theory of what leads to an incident occurring. Once understanding is gained that the release of uncontrolled energy is responsible for incidents, knowledge then needs to be developed as to what steps to set in motion the failure of controls and the release of this energy. To quantify this energy flow and the potential to do harm the term 'risk' is applied.

Risk is defined as the likelihood of harm occurring due to a hazard (Western Sydney University, 2015). Incidents are directly related to risk which is a function of both the size of the hazard in a system and the controls set in place to control the hazards energy flow. The first factor of risk is the hazard size which is determined by the amount of energy the hazard holds. The second risk factor is the controls set in place to prevent an uncontrolled energy release. When the risk is too high and an incident occurs, *human error* is the final action performed by an employee which results in an incident occurring.

The dominant hazards involved in *human error*, discussed in Section 2.5, have remained the same from years 2015 to 2017 (FEM, 2018). This repetitive pattern shows a lack of ability to control these specific hazards, therefore, an inability to cope with current risks. The civil construction industry is facing a particularly hard time to learn from incidents and set corrective actions in order to reduce risk (Lopez *et al*., 2010). The flaw with many investigations into the incidents is the lack of attention to visible trends. This lack of attention highlights an environment of not learning from the incidents that have occurred. Instead, a reactive solution is used in blaming the individual involved in the incident. This does not allow the development of why the individuals' actions resulted in the incident.

As *human error* is the last step which leads to the release of uncontrolled energy, understanding of incidents should be developed from this point. *Human error* can be categorised to develop visible trends involving incidents within the South African civil construction industry. If knowledge is developed on which *human error* is allowing incidents to occur, prevention of incidents becomes a more attainable goal.

2.7.1. Human error categorisation

Human error may be categorized under the following subheadings (Lopez *et al.*, 2010):

Slips

A *slip* error occurs primarily due to a design flaw which the worker does not consider at the time of the incident. These errors are also due to incidents in which the worker is not made aware of a change in design. They are usually distinguished by a temporary gap in judgement when performing an 'auto-pilot' action (Patterson and Shappell, 2008). Thus, slips are often associated with operational decision-making.

Lapse

The ideology behind this is an operational decision-making process paired with a design flaw, similar to the concept of slips. These forms of failure are due to a lapse in judgement because of memory loss in correct task completion processes. These involve a misunderstanding regarding the work's intention versus the performance when completing the work (Lopez *et al.*, 2010).

Both a *slip and lapse* may be due to an individual being exposed to what may not be considered an 'acceptable' amount of work (Patterson and Shappell, 2008). This is a task design flaw. An individual should not be exposed to excess work as this will create a decrease in concentration and, by doing so, promote the operational decision-making process. The basis of improving this work is to improve the design of a task. By improving the design of the task, there can be a reduction in the possibility of an error occurring.

Mistakes

Mistakes primarily occur as a result of the misapplication of knowledge. The individual attempts to deal with a situation in a way that is not acceptable. The worker has the right intentions and believes their plan will not fail, however, the plan does fail (Bonsu *et al.*, 2016). The individual has the correct platform to perform the task but often fails due to a lack of experience.

Violations

These *human error*s involve individuals going against set rules, assuming that the rules are clear to the individual involved before performing the task. Reasoning behind a violation may be an attempt to shorten the completion period of tasks, the reduction of the required effort, the underestimation of the risks involved, and the reduction of costs. Corrective measures required to deal with violations differ for each violation incurred (Mason, 2001). The following two subheadings categorise violations:

Routine violations

These violations are common practice. Workers will generally perform a task in a way practised by others. Regular practice of this task occurs even if the worker is not adhering to the correct procedure. This is often due to peer pressure resulting in common practices used (Mason, 2001). These violations often indicate a flaw in the work system as individuals are performing tasks however they choose. Lack of leadership and corrective action are visible when *routine violation*s are occurring. The workers are often aware that they are violating safety rules. With this knowledge they still go through with the task in the incorrect manner. In the case where the worker is not aware and just assumes he is correct, based on the other employees opinions, this is categorised as a *mistake*.

Deviant violations

Violations considered being out of the ordinary, are *deviant violation*s. They are violations committed by a select few and are not the ordinary practice of many. *Deviant violation*s do not indicate a trend within the workplace to performing tasks in an unwanted manner (Lopez *et al.*, 2010). These individuals take the method required into their own hands and attempt a task based on their own discretion.

2.7.2. Methods to reduce the occurrence of human error

Individuals must be made aware of any hazards faced when completing a task. The individual must also be aware of how to act in the case of a release of uncontrolled energy.

For this reasoning training is set out to educate individuals on hazards and how to respond to the uncontrolled release of energy. In some cases, training is considered an inefficient method as it creates an increase in operational decision-making (Joy, 2000).

Increase in operational decision-making may reduce the rate of *mistake*s, however, it will also increase the rate of slips and lapses. Instead, correction of task design flaws may be a more efficient method of reducing incidents. Ideally, correction of task design flaws can solve both the *mistakes,* and slips and lapses. A method known as Poka-Yoke is discussed in Section 2.7.2.1 regarding reduction in *mistakes,* slips and lapses.

To improve on violations an increased focus is given to the following of safety procedures. Safety procedures are set in place for the safety benefit of the employees involved in a task. This must be made clear to these individuals. According to a study conducted by Rebecca Lawton, the leading cause of violations is due to working more quickly, with inexperience and time pressure being the second and third leading causes (Lawton, 1998).

A quicker way of performing a task indicates a lack of concern to comply with safety procedure, as quicker methods often overlook various safety aspects. As the second leading cause of violations, inexperience is the direct result of insufficient training. If inexperienced individuals are trained correctly for all required tasks, there should be no instance where the individual is unaware of the correct work procedure. The third aspect of time pressure results in similar consequences to the use of quicker methods. Tasks are rushed, overlooking particular safety aspects.

2.7.2.1. Poka-yoke

In order to reduce the number of slips, lapses and *mistakes,* Dr Shigeo Shingo developed a method known as Poka-yoke (Dudek-Burlikowska and Szewieczek, 2009). Poka-yoke is a Japanese term which is translated as ‘Mistake Proofing’. The method makes use of devices that ideally ‘fool-proof’ a system. This is through the use of controls which perform repetitive tasks, where otherwise an operational decision-making process made by an individual is used (Tommelein and Ballard, 1999). The reduction in operational decision-making reduces the probability of slips and lapses occurring. The increased use of controls will also act in reducing the probability of a *mistake* occurring.

The idea of Poka-yoke is designing a system which is very basic to use. One such example is an on-site elevator not being operational unless the doors are closed. This reduces the possibility of the elevator being used in a dangerous manner.

Dr Shigeo Shingo categorises the Poka-yoke method as having two categories of regulatory functions (Shingo, 1986):

1. **Control functions**
   This method of regulation is known to be the more effective function of the two. It operates on a detection system which notices irregularities within a specific control. Once these irregularities are detected, motions are set in place to either correct or stop operations. Shigeo Shingo specifically demonstrated that if the system has the ability to correct inefficient controls, then shutdown is not required. If the system cannot correct itself, shutdown is required.
2. **Warning functions**
   This form of Poka-yoke control makes use of a warning system. The operation of this system relies primarily on phonic and/or visible warning signals, such as sirens or flashing lights. These signals indicate when an error occurs within a faulty control. The system does not shut down automatically or correct the faulty procedure. It will merely allow for the individuals nearby to be notified by the warning signals. Corrective actions or precautions are then utilised by the individuals, as set out by the system.

A system of blame placed on the individual involved in the incident may fail to resolve fundamental issues. A deeper investigation beyond *human error* may lead to finding accurate incident causations, which, if resolved, may greatly reduce the number of incidents. The deeper issues focus on w*orkplace* and *organisational factor*s (supervisory and management-level incident causations). A reactive response to incidents overlooks the *workplace* and *organisational factor*s and focuses on the *human error*. This research develops findings into the *workplace factor*s that may have been a contributing factor to the *human error* which occurred.

2.8. Workplace factors

Irrespective of a systems design level, it is part of human nature for *human error* to occur (Wiegmann and Shappell, 2001). *Workplace factor*s are the causation of incidents at a supervisory level and allow the *human error* to occur. Design preventing *workplace factor*s does have the ability to reduce the number of incidents occurring or the consequences of an incident. Human Factor Analysis and Classification System (HFACS) is a causation model that allows for the identification and prevention of incidents that may occur (Li and Harris, 2005). There are various other models which make use of *workplace factor*s; HFACS is merely an example of one such model.

Weigmann's paper refers to preconditions of unsafe acts which may be synonymous with *workplace factor*s (Wiegmann and Shappell, 2001). These preconditions contribute to an unsafe work environment possibly resulting in incidents. The HFACS model recognises adverse mental state, adverse physiological state, physical/mental limitations, crew resource management and personnel readiness as the *workplace factor*s (Wiegmann and Shappell, 2001). The authors of the HFACS paper consider their classification to be too complex for accurate identification of incidents (Bonsu *et al.*, 2016). This is evident as the classification system focuses on the mental state of individuals. Without in-depth information regarding these individuals this is difficult to examine and or to make any conclusions on.

The Nertney wheel is the preferred form for the classification of *workplace factor*s (Bullock, 1979). This is because it allows a far simpler examination of the *workplace factor*s. The four crucial concepts of the Nertney wheel are the establishment of personnel requirements, plant and hardware requirements and procedural and managerial control (Bullock, 1979). These four concepts allow for a means of analysing *workplace factor*s that are contributing to incidents. For the purpose of this paper, the *workplace factor*s have the same name as used in the Jude Bonsu incident framework (Bonsu *et al.*, 2016). These are *competent people* (CP), *safe work practice* (SWP), *fit for purpose equipment* (FFPE) and *controlled work environment* (CWE). The description of each factor is as follows:

Competent people

This requirement ensures that the correct people are employed to perform the desired task. Competent people (CP) ensure that the level of training and expertise of the individuals meets the required skill level of the desired task. The individual performing the task should be competent to do so.

Safe work practice

Safe work practice (SWP) ensures that the procedure used for the completion of a task considers all safety aspects, prioritising the safety of the employee above all else. If there is no procedure set out for the completion of the task, there is inadequate SWP (*Construction Regulations 2014*, 2014).

Fit for purpose equipment

Fit for purpose equipment (FFPE) ensures the equipment used is of an adequate standard and is suited to the completion of the task. An adequate standard of equipment ensures no malfunctions or any other issue whilst in use. Equipment prescribed in the construction regulations ensures the equipment used is suited to the task (*Construction Regulations 2014*, 2014).

Controlled work environment

A controlled work environment (CWE) ensures an adequate safety standard within the construction site. The key goal of CWE is a safe work environment for all individuals in terms of the both physical and behavioural environmental aspects. Physical aspects are with reference to the materials present that may pose a risk of harm to individuals. Behaviour is the way in which individuals conduct themselves, whereby correct leadership should ensure non-dangerous behaviour whilst working.

The *workplace factor*s can be simplified using the Nertney Wheel shown in Figure 2.8 (Bullock, 1979). All the *workplace factor*s must be considered adequate for their required task. If all these factors are adequate for task completion it creates a safe working environment (SWE). The concept of CWE encapsulates all the other *workplace factor*s as for a working environment to be considered under control all the factors (CP, SWP, FFPE) must be met. Each *workplace factor* is still an individual concept and CWE is considered its own concept in terms of the definition supplied.

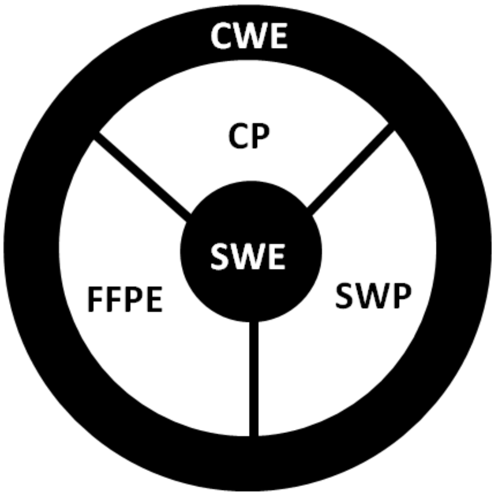


Figure 2.8: Nertney wheel adapted from Jude Bonsu
(Bonsu *et al.*, 2016)

As described, *workplace factor*s play a large role in the potential of an incident occurring. When there is an incorrect procedure used within the workplace, it creates holes in controls for the potentially damaging energy to travel through the system. *Workplace factor*s hold a key concept in understanding incident causation. For this reason they are taken into consideration when discussing the Incident Causation Models (ICM).

2.9. Incident causation models and frameworks

The South African civil construction industry has demonstrated a lack of ability or perhaps, willingness to learn from previous incidents (Lopez *et al.*, 2010). In order to change this, individuals must first understand the causation of these incidents. Incident causation is a systematic process which aims to identify causes of *human error*s, *workplace factor*s and *organisational factor*s involved in incidents. These incidents generally do not occur due solely to a single control failure but due to numerous controls which fail. Management of companies often make the error of focusing their attention on the on-site error (Bullock, 1979).

The on-site error is the visible act that resulted in the incident, i.e. the *human error* which occurred. An investigation further into the cause of the incident beyond the on-site error, may allow for the development of a deeper understanding of what led up to the incident. Further investigation brings attention to both *workplace* and *organisational factor*s. If these factors are understood, corrective measures may be taken on a supervisory and management level. Dealing with incidents at a higher level changes the response from a reactive to a proactive response. Without the use of an incident causation analysis, reactive disciplinary measures are taken, ignoring deeper problems within the company.

The use of an incident causation model (ICM) is fundamental in finding the different factors that led to the incident. When dealing with an incident, a causation model should be applied consistently throughout the workplace. The importance of applying an ICM consistently is to provide constant analysis of incidents and findings regarding common incident causation. The Swiss Cheese model is advised within the field of construction (Reason *et al.*, 2006). For the sake of this study the adapted incident causation framework (ICF) is based off both the Mark III Swiss Cheese model and Jude Bonsu's adapted model. The reasoning behind this decision is given through the explanation of numerous ICMs considered.

2.9.1. Domino effect model

Herbert W. Heinrich established the domino effect model as early as 1930 (Abdelhamid and Everett, 2000). Although this model has had many adjustments over the years, the main concepts remain relatively unchanged. Heinrich places emphasis on senior management as the key to ensuring prevention of incidents. The model predicts incidents as a chain effect of collapsing dominoes, whereby each domino represents a different aspect of the working environment. The theory divides incident causations up into five dominoes as defined below (Ghasemi *et al.*, 2013):

Domino 1. Social environment and ancestry

Domino 1 refers to the workers' undesirable traits gained through work experience. These traits may cause incidents due to the individual's stubbornness in performing a task in a manner which does not adhere to strict guidelines. The work procedure used is often related to the individual's social environment. This means that the lessons learnt through everyday interactions often dictate these decisions made.

Domino 2. Fault of person

Domino 2 continues from Domino 1 in that the fault of the person is developed through actions learnt within the social environment. Incorrect work practice from one individual can often spread to multiple individuals performing tasks incorrectly.

Individuals are influenced to perform tasks in a manner which does not conform to guidelines through the process of *routine violation*s. There is insufficient corrective action to fix this behaviour. Thus, behavioural trends spread from one individual to another.

Domino 3. Unsafe act or unsafe conditions

Domino 3 depicts conditions which arise from poor working conditions. Regulation of the manner in which tasks are performed should be in place in order to reduce the occurrence of unsafe acts. The association of unsafe acts is often with the SWP *workplace factor*. Dominos 1 to 3 are responsible for what causes the 'accident' (A term used in the Domino Effect model which is avoided in incident causation as it depicts fault of the individual involved. Focus is given to the term 'incident' rather than 'accident' in other sections of this study).

Domino 4. Accident

Domino 4 depicts the final event which occurs due to the above conditions. The final event is the resultant incident which may cause harm to one or more individuals.

Domino 5. Injury

Domino 5's injury refers to the consequences when an incident has occurred. Injury is the consequence of all the previous dominos knocking over the fifth and final domino. Injury can result in any form of harm to one or more individuals and may even be considered fatal.

Figure 2.9 is a visible demonstration of the domino effect model. Demonstrated in Figure 2.9 is that if Domino 1 falls, each domino collapses creating a chain effect resulting in injury. Heinrich stated that if one of these dominoes is removed the chain effect will not be possible (Toft *et al.*, 2012).

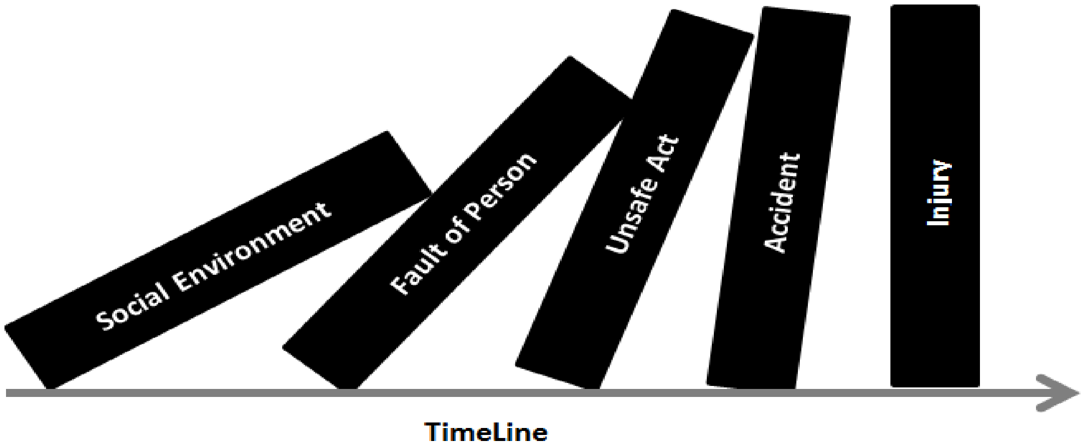


Figure 2.9: Domino model
(Hosseinian and Torghabeh, 2012)

Two findings were concluded in connection with this ICM according to Abdul Rahim Abdul Hamid (Rahim *et al.*, 2008). The first of these is that incidents are caused by people, thus *human error* is the cause of incidents. Whether this is direct or indirect, the human factor is a cause of incidents. Secondly, incidents are preventable with correct management of individuals.

The researcher believes that the opinions generated by this model are outdated and lack understanding. These findings indicate that the use of a reactive solution would be acceptable; however, this is not the case. The following are three arguments as to why the domino effect model is not considered accurate for assessing incident causation:

1. The domino effect model does not take an in-depth look into the causation of incidents. Viewing Domino 2 as ‘Fault of Person’ demonstrates that further assessment is not done as to what led to the *human error*. The study requires a model which takes a more detailed look into the causation of incidents, as incident causation is more complex than simply due to *human error*.
2. Heinrich states that if one domino is removed the domino effect is not possible (Toft *et al.*, 2012). This is inaccurate as the removal of one domino does not stop an incident from occurring. For example, if domino 2 is removed (fault of person) an incident can still occur as latent incidents do not contain any *human error*.
3. The domino effect model indicates that all incidents result in injury which is not accurate. Incidents are the release of uncontrolled energy, which may be released

in a form which causes material damage but does not harm any individuals. Near-miss is a category of incidents where no injury was caused in the uncontrolled release of energy.

The three points demonstrate why the Domino Effect model is not suitable to be used in assessing incidents for this study.

2.9.2. HFACS Model

The Human Factors Analysis and Classification System (HFACS) is a model originally developed to analyse *Human error* of incidents in the aviation industry (Wiegmann and Shappell, 2001). The developers of this model, Scott A Shappell and Douglas Wiegmann, were attempting to decrease the high incident rates present in the aviation industry (Shappell and Weigmann, 2000). HFACS was based on the Reasons 1990 model, showing how an incident causation model can be adapted for a specific industry (Wiegmann and Shappell, 2001).

HFACS not only views *Human error* as the direct cause of the incident but views it as a supervisory and managerial error. Applying *human error* as a direct cause, supervisory error and organisational error, the HFACS model uses the following four-level system for the examination of incidents:

1. Unsafe Acts - Occurring at a lower level, unsafe acts are the direct cause of the incident occurring. To categorise unsafe acts they are broken up into errors and violations.
2. Preconditions for unsafe acts – Conditions which exist and should be investigated as they may lead to an incident occurring. Preconditions are associated with the state of equipment used or state of the individual using the equipment. The state of the individual or equipment should be assessed as adequate before completing any task.
3. Unsafe supervision – The supervisor at this level has direct contact with the individual involved in the *human error*. Often an incident occurs due to a lack of direct leadership to ensure that guidelines are adhered to by employees.
4. Organisational influences – Management level decisions which may include elements such as protocol, task design, equipment used and employee guidelines.

> If managerial decisions provide an unstable foundation on which a task is performed, the probability of an incident is increased.

HFACS provides an example of adapting Reasons 1990 model to a specific industry. As an incident causation model HFACS is well structured and understandable. The two key issues in adapting HFACS for the civil construction industry are:

1. The model is defined for the aviation industry which has little in common with the civil construction industry. A more suitable industry model should be adapted for civil construction.
2. The direct cause, supervisory errors and organisational errors are not further categorised. The study aims to find the leading causation of incidents for each of these error levels. From this the study requires a model which further categorises the error to provide a deeper understanding of incident causation.

HFACS as a model is not suited to the study of incident causation in the civil construction industry. Other models are assessed which may be better suited to the study.

2.9.3. Wheel of misfortune

The wheel of misfortune is based on a concept known as Helmreich's concentric spheres (O'Hare, 2000). Figure 2.10 displays the wheel of misfortune which attempts to depict incidents as a sphere made of different layers, hence the concept of concentric spheres. Starting from the inside of the sphere indicated in Figure 2.10, the innermost sphere represents local actions, the middle sphere represents local conditions and the outermost sphere represents global conditions. The wheel of misfortune divides local conditions into task demands, interface and resources. Global conditions are divided into policies, philosophy, procedures, hazard unrecognised and hazards recognised (O'Hare, 2000).

Figure 2.10: Wheel of Misfortune
(O'Hare, 2000)

Each of the different layers is assessed detailing at each level what caused the incident. Local actions are categorised using the Rasmussen model as firstly an action, goal or strategy and then as either skill-based, rule-based or knowledge-based (Toft *et al.*, 2012). Global conditions focuses primarily on the recognising of hazards. Hazard recognition is the key concept for reduction in incidents according to this model. The middle sphere's primary categories are subdivided according to Roth and Woods (1998) cognitive triad as follows:

- **Task Demands** – Complexity, coupling, dynamism and risk.
- **Interface** – Displays, controls and communication.
- **Resources** – Physiological, psychological, skills and attitudes

For the use of this model the following key concepts are indicated making it unsuitable for this study:

1. Local actions categorisation is open to interpretation; there should be more rigid categorisation to allow for consistency.
2. Categorising of local conditions is very complex and is open for interpretation. Different users of this system may find different solutions for the same problem. The model is not suitable as a framework over multiple incidents due to a large room for error.

3. The model places zero emphasis on the control of energy within a system. Focus is on the identification of hazards not on the control of hazard energy.
4. The model's success in the aviation industry does not support it for the civil construction industry. As previously mentioned for the HFACS model, aviation and civil construction are very different industries.

Based on the categorisation of incidents used in this model, it is not suitable for the study of incident causation for the civil construction industry.

2.9.4. Swiss cheese model

James Reason developed the Swiss cheese model as a form of incident causation in the late 1980s (Reason, 2000).

The model acts as a means of evaluating incidents in terms of the incident causation. The Swiss cheese model is made up of various slices of cheese as demonstrated in Figure 2.11. Each slice of cheese represents an individual control such as those discussed in Section 2.3. Controls are in place to prevent any energy from slipping through the system and being released in an uncontrolled manner. The controls form a system of layers whereby increasing the number of controls or layers decreases the probability of an uncontrolled energy release.

Figure 2.11 depicts holes of various sizes which represent the failures in each barrier. The Swiss cheese model conceptualises that in the scenario where each of these holes line up, the energy can escape and the system is no longer under control. The now uncontrolled energy results in an incident occurring. These holes are sporadic and are constantly changing, and it is thus hard to predict where they may occur and how they line up (Reason *et al.*, 2006).

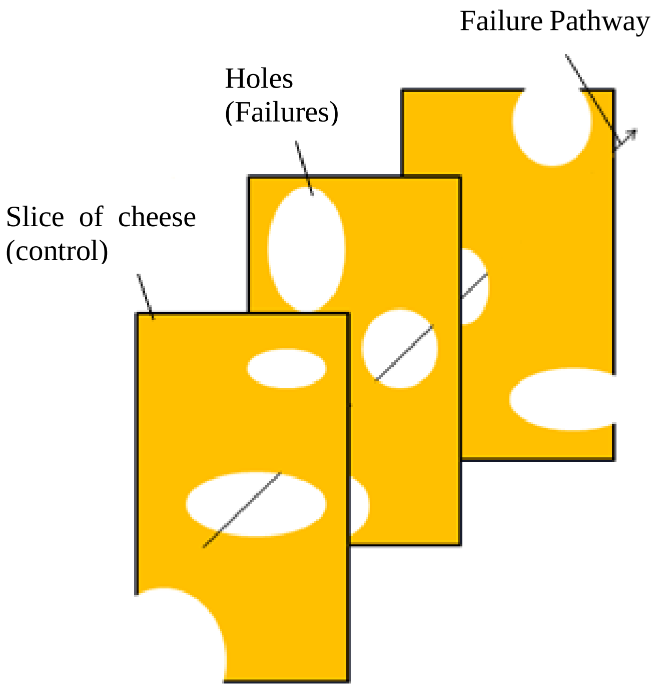


Figure 2.11: Swiss cheese model
(Hosseinian and Torghabeh, 2012)

Figure 2.12 depicts a visual representation of the Swiss cheese Mark III model which is an extension of the original Swiss cheese model. Synonymous with the original Swiss cheese model it makes use of controls set in place to prevent energy from escaping the system. The model aims to firstly identify the hazard which was the source of the energy and is involved in the incident. The next step is to identify which controls failed and the cause of their failure. The failed controls allowed for uncontrolled energy to travel along the failure pathway resulting in an incident.

Swiss Cheese Mark III depicts the process which is undertaken when an incident does occur. The model looks at the unsafe acts which occurred which are referred to as *human error*. After the *human error* is established the *workplace factor*s which were discussed in Section 2.8 are determined. SWP, CP, CWE and FFPE are the *workplace factor*s that are considered for this model. The final link is due to *organisational factor*s which occur at a management level, focusing on executive decisions regarding task design, protocol and employee guidelines. What went wrong within these steps will help depict the full picture regarding the incident causation.

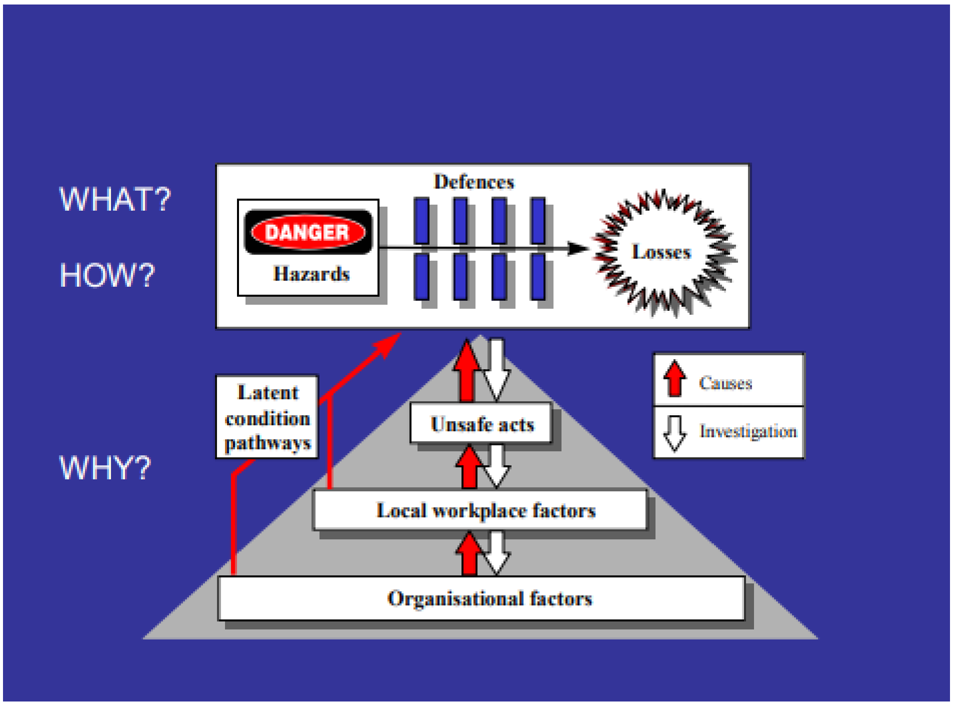


Figure 2.12: Reasons Swiss cheese Mark III model
(Reason *et al*, 2006)

Two types of failures, namely latent and active failures, cause these holes. Each of these is defined as follows:

Latent failure

The concept of the latent pathway is that the decision is made at an Organisational level and is directly visible from this action (Bonsu *et al.*, 2016). These are conditions caused by *workplace* and *organisational factor*s and are based on strategic decision-making. Often, they are decisions made which remain dormant and suddenly come into effect when activated due to a certain activity. Latent failures are often an unrecognisable form of failure until system failures occur (Reason, 2000). In some cases, the energy path is recognisable and there is no corrective action that has been used.

Active failure

Active failures are related to the time and place of the uncontrolled release of energy occurring as the system failure is immediately noticeable. Association is often made between active failure and *human error* as this is the immediate action which caused failure (Bentley, 2009). Active failures may be seen as a symptom of a system functioning incorrectly, thus stemming from *workplace and organisational factors* (Reason *et al.*, 2006). Active failure pathway is thus from the organisational level, through the workplace level and finally *human error* (Bonsu *et al.*, 2016).

Criticism of the model highlights the lack of explanation regarding the holes. There is no specification to identify a hole and the degree of failure of this hole. Thus, the size of the holes has no specifications and is not fully understood.

The Swiss Cheese Mark III model provides crucial concepts in the development of ICMs. The concept of controls and the linking up of failures (holes) to cause an incident is vital for understanding energy flow. Swiss Cheese Mark III provides a basis to adapt an ICF for this study. The researcher used the Swiss Cheese Mark III model along with Jude Bonsu's adapted framework to adapt a framework for the civil construction industry.

2.9.5. Adapted framework by Jude Bonsu

Jude Bonsu is responsible for the creation of an ICF for the mining industry, adapted from the Swiss cheese mark III model (Bonsu *et al.*, 2016). Jude Bonsu developed this framework as he believed that the model at present was 'overly complex and did not adequately account for all the factors that contribute to accidents in the mining industry' (Bonsu *et al.*, 2016). The civil construction and mining industries are very similar in practice. Due to these similarities, the framework developed for the mining industry can be adapted for the civil construction industry.

Jude Bonsu's framework maintains the core concept of the Swiss cheese Mark III model. The Swiss Cheese Mark III diagram, Figure 2.11, visually depicts this framework. Controls and the development of holes within these controls is a key concept maintained in Jude Bonsu's ICF. If these holes align, the energy can travel through these controls and result in an incident. This is synonymous with the explanation given in Section 2.9.4 on the Swiss Cheese model. The key sections of the framework focus on causal analysis, hazards and barriers (controls) (Bonsu *et al.*, 2016).

Causal analysis is comprised of three subsections, namely *proximal causes*, *workplace factors* and *systemic factors* (Bonsu *et al.*, 2016). Proximal causes are synonymous with the *human error* discussed in Section 2.7 and are the direct cause of an incident. Proximal causes are, therefore, part of the active failure pathway resulting in an incident. *Workplace factor*s are as defined in Section 2.8, and therefore keep the same classification as the *workplace factor*s used in Jude Bonsu's ICF. *Workplace factor*s are then the result of systemic factors.

Systemic factors refer to causation at the top level of an organisation. For this reason and the purpose of this study, these factors are synonymous with the aforementioned *organisational factor*s. The top level of decision-making is responsible for the systemic factors involved in an incident. Thus, systemic factors are found at the beginning of the failure pathway. Systemic factors are separated into the following reasons (Bonsu *et al.*, 2016):

- Training and competence
- Contractor management
- Design
- Management of change
- Hazard identification
- Monitoring and auditing
- Maintenance management
- Resource provision
- Strategic decisions
- Risk management
- Leadership
- Work scheduling
- Emergency response

Jude Bonsu's ICF was established using the Swiss Cheese Mark III model and adapted for the mining industry. From this knowledge an adaptation is made for a civil construction-specific ICF based on Jude Bonsu's ICF. This study uses the civil construction-adapted ICF to investigate multiple incidents occurring in the South African civil construction industry.

2.10 Chapter 2 summary

Chapter 2 has the objective of supplying the reader with the required knowledge to understand the contents of the study. Beginning with an introduction of the South African

OHS Act in Section 2.2, the chapter provides understanding of government rulings on how the South African civil construction industry must protect employees. Sections 2.3 to 2.6 supplied insight into crucial concepts in understanding the theory behind how incidents occur and the means to control incidents. Understanding the theory behind incidents gives the reader an understanding as to why an ICF can be crucial. Stipulating of *human error*s and *workplace factor*s, Section 2.8 and 2.9, demonstrate the first two causation aspects to be assessed using the ICF. Finally, Section 2.9 described an array of incident causation models and frameworks, explaining how the relevant framework was chosen. Section 2.9 also covers *organisational factor*s which is the third and final causation aspect.

Chapter 3.

Methods and data

3.1. Introduction

Chapter 3 discusses the data and the data assessment methods used for this study. Various ICFs were discussed in Section 2.9. However, for the purpose of this study the framework developed by Jude Bonsu based on the Swiss Cheese Mark III model, Section 2.9.5, provides the basis of the adapted incident causation framework (ICF) used (Bonsu *et al.*, 2016). Jude Bonsu's framework was adapted to suit the South African civil construction industry. Chapter 3 is focused on providing a detailed explanation of what constitutes assessable data, along with a discussion into how the adapted ICF was applied.

Figure 3.1 demonstrates the six separate stages of the investigation process. Stage 1 (literature study) consists of a research process in which an investigation was done into understanding the theory of incident causation and different incident causation models (ICM) and frameworks. Stage 2 describes the process of choosing the most suitable ICF/ICM. The chosen ICF/ICM was adapted to be used within the context of the South African civil construction industry. Stage 3 entails the data collection process, looking at what is considered suitable data for the study. Stage 3 also involved the process of finding suitable corporations to approach for the required data. The corporations were selected by the supervisor-in-charge, as these people could supply enough relevant information to produce detailed incident investigations.

Stage 4 motivates the requirement for this study using the adapted ICF and describes how the adapted ICF is applied. The motivation entails a section of data analysis, where comparisons are made between incident statistics for the South African civil construction and mining industries. Stage 5 contains the data analysis and discussion of results. This stage involves the assessment of the gathered incident reports and categorises the incident causations according to the adapted civil construction ICF. This allows for findings based on the different causation factors, namely *human errors*, *workplace factors* and *organisational factors*. Statistical analysis regarding the incident reports is used to give feedback on the common causations of incidents. Stage 6 ends off the study by drawing conclusions and making recommendations from these conclusions.

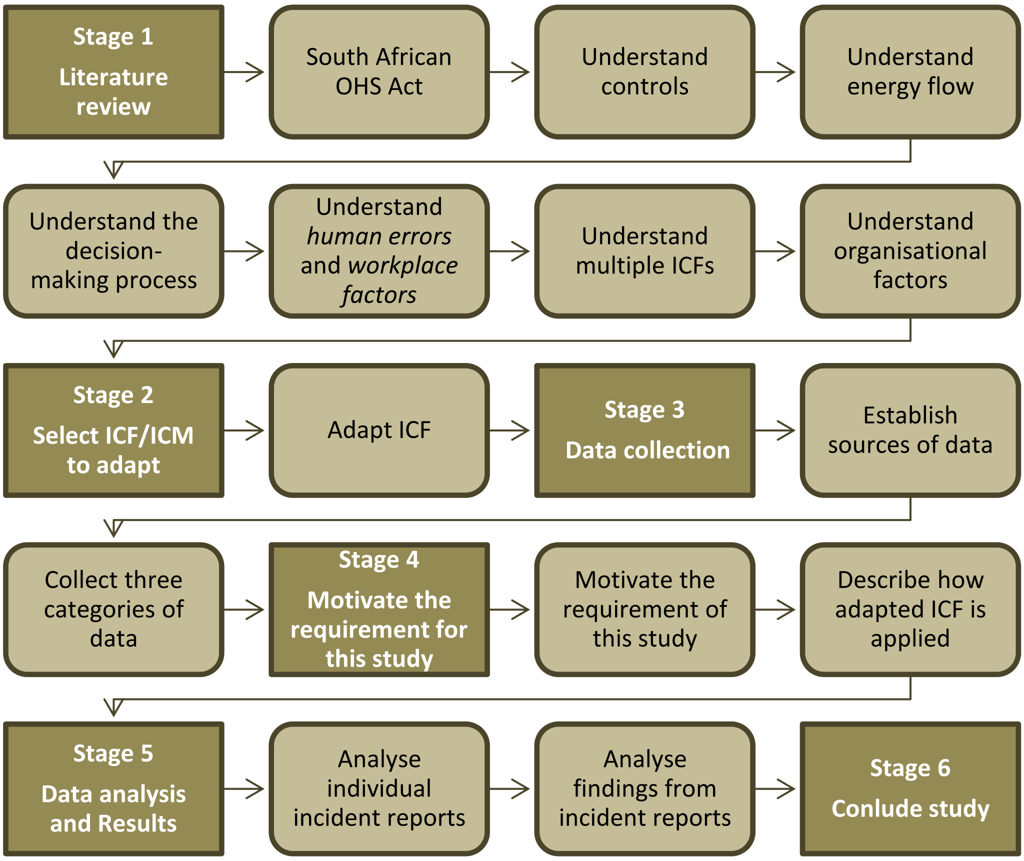


Figure 3.1: Research process

The first three stages of the study are discussed in the subsequent sections within Chapter 3. Stage 4 and 5 are introduced in Chapter 3 but are covered in greater detail in Chapters 4 and 5. Stage 6 is not discussed but is applied in Chapter 6.

3.2. Literature review

The literature review done in Stage 1 provides the foundation of this study. Understanding why incidents occur takes the first step in understanding incident causation. Once the reasoning behind why incidents occur is established, detailed descriptions are given to better understand ICFs/ICMs. To demonstrate the gathered knowledge to the reader a literature review is constructed in Chapter 2.

Knowledge is presented in a logical format in the literature review, whereby new concepts are explained and are understandable for readers from all academic backgrounds. The literature review begins in Section 2.1 by discussing the South African OHS Act which ensures the safety of all workers from potential hazards. The OHS Act enforces the control of all hazards and the use of a risk assessment in the South African civil construction industry (*Construction Regulations 2014*, 2014). Information in the OHS Act stipulates hazard control and the reduction of incidents as a key priority for all industries.

Section 2.3 begins to explain controls, which are set in place to control the hazard's energy. Controls describe ways to prevent incidents or reduce the harm caused through the restriction of energy flow. To understand the flow of energy, discussion of the Energy Damage Model is given in Section 2.4. Discussion of the Energy Damage Model subsequent to controls in the literature review is due to the necessity for the reader to understand how controls work before understanding the energy which needs to be controlled. Hazards are stipulated in the Energy Damage Model as the source of potentially damaging energy.

Hazards left without any form of effective control are responsible for the release of uncontrolled energy and lead to an incident occurring. Section 2.5 uses FEM statistics to describe which hazards are most frequently involved in incidents in South Africa. The statistics are also used to describe the frequency rate involved with particular hazards.

Section 2.6 outlines the decision-making process applied by individuals. Decision-making applies the basic operational process and is the first step in applying the correct controls to potentially damaging energy. Using the adapted ICF the decision-making process can be examined for particular incidents.

The adapted ICF evaluates incidents based on *human errors*, *workplace factors* and *organisational factors*. *Human errors* and *workplace factors* are discussed in Sections 2.7 and 2.8. *Organisational factors* are discussed in Section 2.9 within the descriptions of the various ICFs and ICMs. Each incident discussed is used to evaluate the best suited ICF/ICM to the current study, finding Jude Bonsu's adapted model to be the most consistent with the examination of the South African civil construction industry.

The literature review provides the reader with all the required knowledge to understand the remainder of this this study. The methods used to implement the South African civil construction adapted ICF is explained in detail in Section 3.3.

3.3. Incident causation framework

The ICF chosen to adapt for the South African civil construction industry was based on the research done in Section 2.9 (Stage 2). Jude Bonsu applied James Reason's Swiss Cheese Mark III model to the mining industry to establish a relevant ICF (Bonsu *et al.*, 2016). From Jude Bonsu's work, an ICF has been adapted for the South African civil construction industry.

Stage 4 motivates the use of this study and the use of the adapted ICF in Sections 4.2.1, 4.2.2 and 4.2.3. Comparison of the data gathered (Stage 3) for the South African civil construction and mining industries (Section 4.2.1) acts to possibly motivate the requirement for an improvement in incident control for the civil construction industry. Further motivation is given by describing effective incident control initiatives used by the mining industry (Section 4.2.2). Section 4.2 concludes by providing reasoning as to why this study using the adapted ICF can benefit the South African civil construction industry in terms of better understanding incident causation (Section 4.2.3). Explanation of how the adapted ICF is applied to individual incident reports is given in Section 4.3.

In order to analyse individual incidents, the adapted ICF firstly focused on the controls (described in Section 2.3) which failed or should have been in place. After establishing the controls for the individual incident, each incident was analysed to determine causation factors in terms of *human errors, workplace factors* and *organisational factors*. Each of these factors has been previously discussed within Sections 2.7, 2.8 and 2.9. Applying the method used in Section 4.3, all 66 individual incident reports are analysed to begin Stage 5 of the research process.

The analysis is done for multiple incidents across three South African civil construction companies creating an incident causation database. Analysing multiple incidents allowed for the establishment of a cross-sectional view of incidents, whereby incidents are not viewed in isolation. The cross-sectional view establishes the leading incident causation factors (*human errors*, *workplace factors* and *organisational factors*). A proportional analysis is done to find the proportional contributors for each causation factor, after which links are established between the separate causation factors.

3.4. Data collection and analysis

Stage 3 of the study is the collection of data which occurred as three categories of data. Category 1 is the collection of South African civil construction incident statistics from the FEM. Sections 1.1.2, 2.5 and 4.2 make use of the FEM data. In Section 4.2 the FEM South African civil construction incident statistics are compared to the South African mining incident statistics. The South African mining incident statistics were collected from the Minerals Council of South Africa (MCSA) and the South African Department of Mineral Resources (DMR). This is category 2 of the data.

Category 3 consisted of 66 incident reports from three South African civil construction companies. All incident reports are analysed using the adapted ICF to find common incident causations. Analysis of the collected incident reports is given in Chapter 5, which substantiates the use of the adapted ICF for the South African civil construction industry. Each category of data in the collection process can be substantiated in Sections 3.4.1, 3.4.2 and 3.4.3 respectively.

3.4.1. South African civil construction incident statistics

FEM established itself as a workmen's compensation insurance company for the building industry in 1936 (FEM, 2018). By permission of the Department of Labour Compensation Fund, FEM is licensed to provide Compensation for Occupational Injuries and Diseases Act (COIDA) cover to the building industry's employees (FEM, 2018).

All employers must register with COIDA to provide financial cover for their employees and for this reason FEM contains a large portion of civil construction incident data. Since FEM remains an optional service it does not contain records of all the data regarding civil construction incidents in South Africa. FEM provides individuals with relevant quantitative data regarding the number of employees, injuries and fatalities for the building industry.

The FEM separates their quantitative data into various subclasses based on work fields. From the FEM subclasses; civil engineering, the erection/dismantling of scaffolding/shuttering and the erection/dismantling of steel structures make up the civil construction incidents. All regions of South Africa are assessed for each of the above-mentioned subclasses. After these statistics have been gathered, they are compared to the South African mining incident statistics, in accordance with Stage 4 of the research process. The comparison provides a means to evaluate current incident trends in the South African civil construction industry. If it is found that the South African civil construction industries incident trends are unfavourable when compared to the mining industry, an argument can be developed for the use of the civil construction adapted ICF.

3.4.2. South African mining incident statistics

Category 2 data, which consisted of South African mining industry incident statistics, was gathered from the South African Department of Mineral Resources (DMR) and the MCSA (Minerals Council South Africa, 2018a; Department of Mineral Resources South Africa, 2018) . The use of two sources was due to specific annual reports missing from the DMR's dataset, therefore missing data was gathered from the MCSA. Comparisons were made regarding the statistics for each data source to ensure that they corroborated one another's statistics. The data gathered for the mining industry is of the same content as that gathered for the civil construction industry, also covering all regions in South Africa. The data collected is quantitative in nature, showing the number of each kind of incident which has occurred. Brief descriptions for each of these sources are as follows:

- **South African Department of Mineral Resources** (Department of Mineral Resources South Africa, 2018):
  The DMR is a branch of the national government with the goal of creating a globally sustainable and transformed minerals and mining sector. It is the responsibility of the DMR to protect the health and safety of communities and individuals affected by mining, whether they are local residents or employees. Mining companies in South Africa must compile an annual report regarding incidents and present this to the DMR. The DMR is responsible for consolidating this data into nationwide statistics regarding incidents which have occurred annually.

- **The Minerals Council South Africa** (Minerals Council South Africa, 2018a):

  Previously known as the Chamber of Mines of South Africa, the MCSA assists the mining sector through strategic support and advice. Support is given through the MCSA's membership of the International Council on Mining and Metals (ICMM), which aims for a safe, fair and sustainable mining industry. MCSA ensures that when an assessment of the mining industry is done by the DMR, the assessment is done in a previously agreed upon manner. The data used and assessed by both the DMR and MCSA has the same content, as the MCSA is set in place to survey the DMR.

After the collection of quantative incident data, the data analysis was performed using graphical representations to find incident trends for both industries. These trends in incident numbers and incident rates were used to develop the argument for an adapted ICF in the South African civil construction industry.

The comparison of the two industries develops the argument as to why an adapted ICF is necessary for the South African civil construction industry. The adapted ICF is then applied to assess the incident reports gathered.

3.4.3. Incident reports

Category 3 data consisted of incident reports for the South African civil construction industry. The incident reports were gathered from three separate South African civil construction companies who remain anonymous throughout the study. The content of the incident reports was details on the events which led to an incident occurring. The incident report sampling was performed by individuals involved in the respective companies. The student and supervisor were not involved in selecting the incident reports.

Incidents cover a range of injury types, namely; near-miss, lost-time, serious and fatal. Near-misses are incidents where there was an uncontrolled release of energy that did not result in any individuals being harmed. Lost-time and serious injuries are minor and major injuries. Fatal incidents are incidents where a worker has lost their life performing a work-related task, often detailing a lack of adequate protective controls on the civil construction site. All injury types involved in incidents are considered in the understanding of incident causation. The sampling is made up of 8 fatalities, 8 serious injuries, 25 lost-time injuries and 25 near-miss injuries.

Each individual incident report is significant for the overall analysis of the South African civil construction industry. An example of an incident report provided by a company involved in the study is given in Appendix D1. The three companies' incident reports have the same content as the report supplied in Appendix D1. Stage 5 of the study focuses on both the analysis of individual incident reports using the adapted ICF and grouping the findings into an incident causation database which is then analysed.

Section 4.3.1.6 demonstrates the analysis process of using the adapted ICF for the incident report given in Appendix D1. The incident reports provide an explanation of the events which occurred on the South African civil construction site that led to an incident occurring. Detailed incident reports provide the researcher with the required information to apply the adapted ICF for examination of individual incidents. The ICF's primary goal is establishing the relevant *human error*s, *workplace factor*s and *organisational factor*s involved in each individual incident.

In total 66 incident reports were collected and analysed; this gives a wide range to better understand incidents and eliminate the notion of reviewing incidents as singular events. Assembling the analysis of all individual incident reports provides a database. Analysis of the database provides the leading incident causations in terms of *human error*s, *workplace factor*s and *organisational factor*s over multiple incidents.

For the first analysis of the database *human errors*, *workplace factors* and *organisational factors* are all given in terms of the proportional contribution made by each type of the relevant factor (e.g. *Human errors* given in terms of the type of *human error*). Sections 5.3.1.1, 5.3.2.1 and 5.3.3.1 divide each causation factor into the proportional contribution made by each type of the specific factor.

In Section 5.3.2.2 each type of *human error* is given in terms of the proportional contribution made by the associated *workplace factors.* The equivalent concept is applied in Section 5.3.3.2, whereby each *workplace factor* is given in terms of the proportional contribution made by the associated *organisational factors*. Linking these incident causation factors provides relationships which can lead to better understanding of incident causation in the South African civil construction industry.

3.5. Research design

The research done in this study focuses on the analysis of incident causation for multiple civil construction incidents. To form the best level of understanding the study is done using a qualitative study supported by quantitative methods, the study design is thus a combination of both qualitative and quantitative methods.

Analysis is done to determine which incident causation factors are linked to another, as well as which causation factors result in the majority of incidents. The research done is for the purpose of getting an insight into civil construction incidents; it is investigative in nature thus qualitative. The qualitative research is supported by the data analysis which uses numerical methods.

Numerical methods provide the quantitative section of the study. Quantitative research is done using the structured ICF to analyse incidents and then classify the incident causation factors. Numerical proportions create understanding as to which incident causations provide the largest proportion of incidents for each of the three different factors (*human error*, *workplace factor* and *organisational factor*). The numerical proportions also detail relationships between the three incident causation factors by determining the proportion of the *workplace factors* which caused the specific *human errors* and the proportion of *organisational factors* which caused the specific *workplace factor*.

The qualitative study is thus developed and supported using quantitative means. The combination of both qualitative and quantitative means offers the strongest possible study design.

3.6. Chapter 3 summary

The methodology breaks this study up into six stages. Stage 1 is given through the literature review (Chapter 2) and builds core knowledge for understanding the contents of the study. Stage 2 uses the knowledge gained in Stage 1 to choose a suitable ICF to be used for this study. Minor changes are made to the ICF created by Jude Bonsu to adapt a relevant ICF for the South African civil construction industry. Stage 3 is the collection of the three different data categories. The three data categories accounted for gathering the South African civil construction incident statistics, the South African mining incident statistics and the incident reports from three South African civil construction companies. Stage 4 (found in Chapter 4) motivates and supports the use of the adapted ICF and the benefits made by this study in understanding incident causation. Stage 5 (found in Chapter 5) applies the adapted ICF, first analysing individual incidents and then combining all individual incident analyses into a database. The database is analysed to provide information on incident causation for the South African civil construction industry. Conclusions and recommendations are drawn from the study, making up Stage 6 (found in Chapter 6).

Chapter 4.

Incident causation framework

4.1. Introduction

The incident causation framework (ICF) developed by Bonsu (2016) was adapted to focus on the civil construction industry (CCI), ensuring that all incident causation factors analysed are relevant to this specific industry. The CCI has a large number of hazards which are unique to that industry. A number of the incident causation factors were therefore adapted slightly to account for hazards relevant to the CCI. Knowledge gained in other ICFs (Section 2.9) was used to adapt the framework to the CCI. The adaptation of these incident causation factors to the CCI is given in Section 4.3.1.3 to 4.3.1.5.

The adapted ICF is used for the analysis of multiple incidents that occurred in the CCI, whereby the multiple incident analyses are used to compile an incident causation database. The incident causation database allows for a cross-sectional view of incident causation over multiple incidents. Relationships between incident causation factors are identified using this cross-sectional view of multiple incidents. These relationships could indicate links between the incident causation factors and areas where the CCI can improve on current safety performance.

This chapter motivates the reasoning behind the use of the adapted ICF in the context of this study. After motivation for this study and the requirement of the adapted ICF has been given (Section 4.2), an explanation is given on how to apply the adapted ICF (Section 4.3). This chapter provides the reader with an explanation as to why this study differs from previous studies and aids the CCI as a means of potential reduction in the number of incidents occurring.

4.2. Motivation for using the incident causation framework

The first aspect of this section demonstrates the reasoning as to why the South African CCI requires improved safety, based on the South African CCI incident statistics. In order to promote the requirement for improved safety in the CCI, comparisons are drawn with the incident statistics of the South African mining industry.

The South African mining industry is known to be hazardous, with a large number of incidents and fatalities (Okoro *et al.*, 2016). Over the past decade, a significant amount of effort and attention was invested by multiple individual mining companies, labour unions, the industry as a collective and government in order to address the number of incidents occurring in the mining industry (Hermanus *et al.*, 2015).

Current mining initiatives which were set in place to reduce the number of incidents occurring are discussed in Section 4.2.2. Mining incident reduction initiatives are discussed to provide reasoning as to how the industry has attempted to reduce the number of incidents occurring. The last aspect discussed in this section gives reasoning as to how this study differs from previous studies (Section 4.2.3).

4.2.1. Comparison of South African civil construction and mining incident statistics

The work done in Section 4.2 has contributed to a separate study, a submission of an article for publication done by the author (Allsopp and van Dyk, 2019).

The civil construction incident statistics were collected from a wide spectrum of project sizes, ranging from small-scale construction projects to larger-scale and more time-consuming projects. Using the Federated Employers Mutual Assurance Company (Pty) Ltd (FEM) database’s subclasses, the South African civil construction incident data for the period of 2006 to 2016 was obtained and analysed (FEM, 2018). Incident data of the same nature was gathered for the South African mining industry from the South African Department of Mineral Resources (DMR) and the Minerals Council of South Africa (MCSA), this data was described in Section 3.4.2.

The South African mining industry and CCI incident statistics are compared, revealing that the mining industry's implementation of initiatives in recent years to reduce the high incident rates have been effective. If this implementation has been effective in the mining industry, the CCI can learn from this in order to introduce their own initiatives to reduce the number of incidents occurring. This study takes cognisance of the fact that there are fundamental differences between the mining and civil construction industries. However, it is argued that the comparison is relevant due to the large number of incidents in each industry. In civil construction an additional hazard is working on public roads. Mining does, however, have hazards which the civil construction industry does not, such as falling of ground which is the leading cause of incidents according to the DMR (Department of Mineral Resources South Africa, 2018). These industries were compared as they are two of the most hazardous industries internationally (Professional evaluation and certifcation board, 2019). If it is proven that one of these industries has made steady reductions in the number of incidents occurring, comparisons can be made to prove the other industry can make similar reductions.

Mining in recent years has adopted policies which highlight methods for incident reduction, through aspects such as the Culture Transformation Framework (CTF), to be discussed in Section 4.2.2 (MHSC, 2011). Even with these improvements, the mining industry is still one of the most hazardous industries in the world; however, as the hazards are always present, the mining industry has found means to control the energy in a more effective manner (Simpson *et al.*, 2012).

Comparison of the South African civil construction and mining industries begins with the fatality statistics, comparing the number of fatalities (Section 4.2.1.1) and then comparing the fatality frequency rates (4.2.1.2) for the two respective industries. After the comparison of fatality-related data, the injury frequency rates of each of these industries are compared to substantiate a further argument of industry safety. Both the mining and civil construction data are South African statistics as these are most relevant to the study.

4.2.1.1. Number of fatalities

Figure 4.1 shows the annual number of fatalities for both the civil construction (see Appendix B2) and mining (see Appendix E1) industries gathered from the sources given in Section 3.4. Figure 4.1 is crucial as fatalities provide an empirical argument to support the need for improved incident control. As seen in Figure 4.1, the number of civil construction fatalities displays no statistical correlation over time, as confirmed by the 0.97 p-value of linear regression which has been applied to the data (see Appendix F1). The mining industry displays a linear regression p-value < 0.05, showing that the trend is statistically significant at the 95% confidence interval.

Although there is no trend over time and it falls within the variation of distribution, the CCI saw 33 fatalities in 2007 and 35 fatalities in 2016, whilst the mining industry has managed to decrease its number of fatalities from 220 in 2007 to 73 in 2016 (p-value < 0.05). While the number of fatalities in the CCI has been found to be varied in distribution over the 10-year period, a stable reduction in the number of fatalities is simultaneously visibly demonstrated by the mining industry with a decrease of 67% from 220 in 2007 to 73 in 2016.

The argument does exist that the CCI has a significantly lower number of fatalities; however, the study aims to view whether the industry has been successful in reducing the number of fatalities over the time period. From Figure 4.1, the data demonstrates that the CCI has seen no significant reduction in the number of fatalities, thus fatality reduction methods in the CCI are not effective.

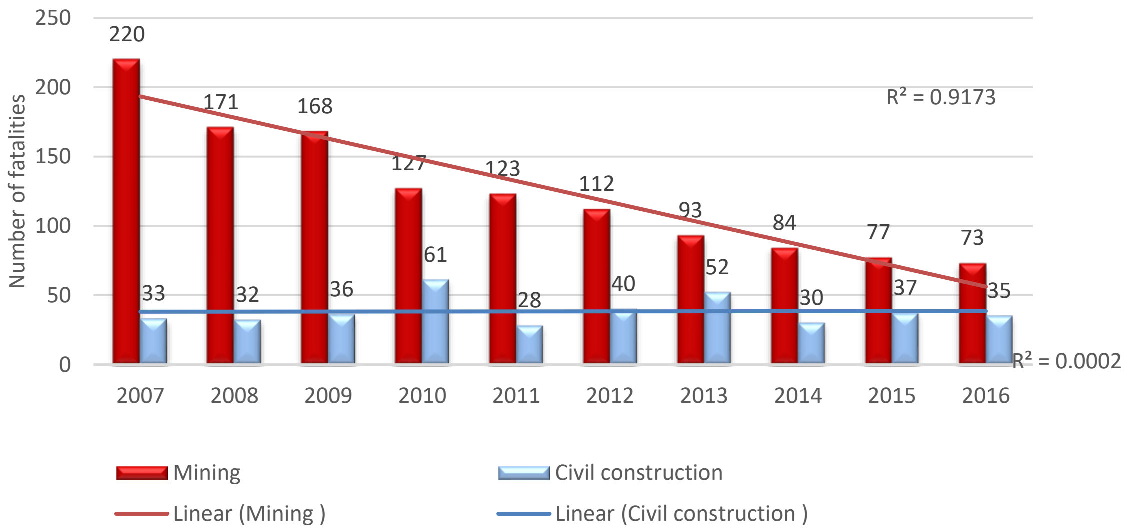


Figure 4.1: Annual number of fatalities for each industry
(FEM, 2018; Department of Mineral Resources South Africa, 2018; Minerals Council South Africa, 2018b)

Fatality frequency rates which normalise the number of fatalities by the number of employees in the industry, can be calculated using statistics gathered from the relevant sources. The fatality frequency rate uses the number of employees and can either support or reject previous statements regarding the two industries. The statement is supported if the mining industry fatality frequency rates also have a decreasing trend and the CCI fatality frequency rates also prove to have no trend or an increasing trend. Therefore, to build on from the number of fatalities, assessing the fatality frequency rates is the next logical step in the argument.

4.2.1.2. Fatality frequency rates

Figure 4.2 shows the fatality frequency rates for both the civil construction (see Appendix B3) and mining (see Appendix E2) industries, over the 10-year assessment period. The fatality frequency rate is calculated by standardising incidents per 100 employees and using *Equation 4.1*:

$$Frequency\ Rate = \frac{Number\ of\ incidents \times 200000}{Total\ hours\ worked} \qquad (4.1)$$ [1]

The CCI fatality frequency rate has a p-value > 0.05, therefore once again proving to be statistically insignificant. Conversely, the fatality frequency rate of the mining industry has a p-value < 0.05 (see Appendix F2), making the negative trend statistically significant at the 95% confidence interval.

In 2009, Figure 4.2 shows the mining fatality frequency rate decreasing below that of civil construction and remaining there until the final year of assessment in 2016. CCI reduced below that of mining briefly in 2011 and then rose again in the following year, although, according to Figure 4.1, the number of fatalities is still higher for the mining

[1] For *Equation 4.1* the 200 000 represents the number of hours worked by 100 employees every year (8 hours a day × 5 days a week × 50 weeks a year).

industry in 2016. Figure 4.2 creates the argument that the mining industry has not only had a consistently reduced fatality frequency rate, but that since 2009 it has also presented a fatality frequency rate lower than that of the CCI. As the hazards in these two industries are similar, the mining industry must therefore be capable of a higher level of control over incidents occurring within the working environment.

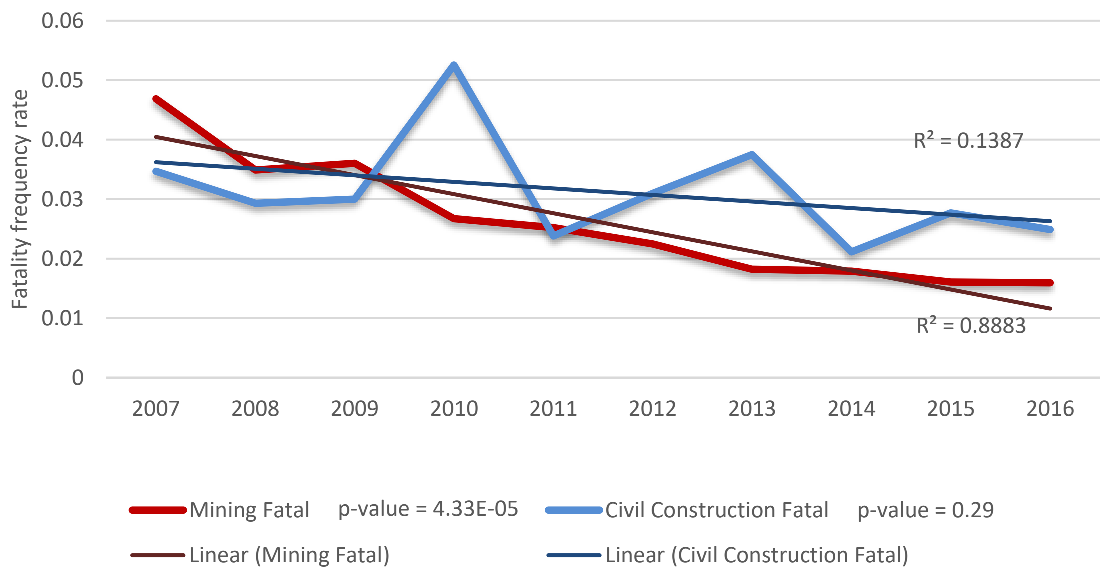


Figure 4.2: Annual fatality frequency rates
(FEM, 2018; Department of Mineral Resources South Africa, 2018; Minerals Council South Africa, 2018b)

In order to fully assess incidents, injuries which were not fatal are also considered. When a loss of energy control occurs, the only elements separating a fatality and an injury are a protective control or the magnitude of the energy involved, demonstrating the possible link between fatality frequency rates and injury frequency rates.

4.2.1.3. Injury frequency rates

The study of an industry's incidents is not only concerned with fatalities, but also analysis the frequency rate of injuries. To calculate the injury frequency rate the number of injuries is exchanged with the number of fatalities in *Equation 4.1* (see Section 4.2.1.1). The injury frequency rates for both the CCI (Appendix B3) and the mining (Appendix E2) industry were calculated and displayed in Figure 4.3. As the injury frequency rate for CCI is significantly higher than that of the mining industry, the two industries' injury frequency rates are plotted with separate axes. Both industries' data is proven statistically significant for the 95% confidence interval with p-values < 0.05 (see Appendix F3).

Figure 4.3 shows civil construction with an injury frequency rate for 2007 of 4.02, a high rate when compared to the 2007 injury frequency rate of 0.82 for the mining industry. A positive sign is the reduction in civil construction injury frequency rate from 4.02 (2007) to 2.65 (2012). The rate of reduction in civil construction injury frequency rates decreases from 2.65 (2012) to 2.41 (2016) over the 5-year period.

The civil construction injury frequency rate is more than three times greater than that of mining at any point in the 10-year assessment period. The much larger injury frequency rates indicate that employees in the CCI have a higher probability of suffering a workplace injury compared to employees in the mining industry. Even though the mining industry experiences a much lower injury frequency rate it has also experienced a negative trend. From 2007 to 2016 the mining industry reduced injury frequency rates from 0.82 to 0.61. Although the focus of the study is incident trends and the CCI has managed to reduce the injury frequency rate, the proportion by which the rate is greater than that of the mining industry is concerning.

The CCI experienced injured employees at a rate of 2.41 injuries per 100 employees in 2016 compared to the rate of 0.61 per 100 employees in the mining industry. Similar hazards are experienced by both these industries yet injury frequency rates for mining in 2016 are a factor of 3.95 lower than civil construction. Differences this substantial in injury frequency rates are a firm argument to improve the incident controls in the CCI, as increased injury rates may rapidly lead to increased fatalities.

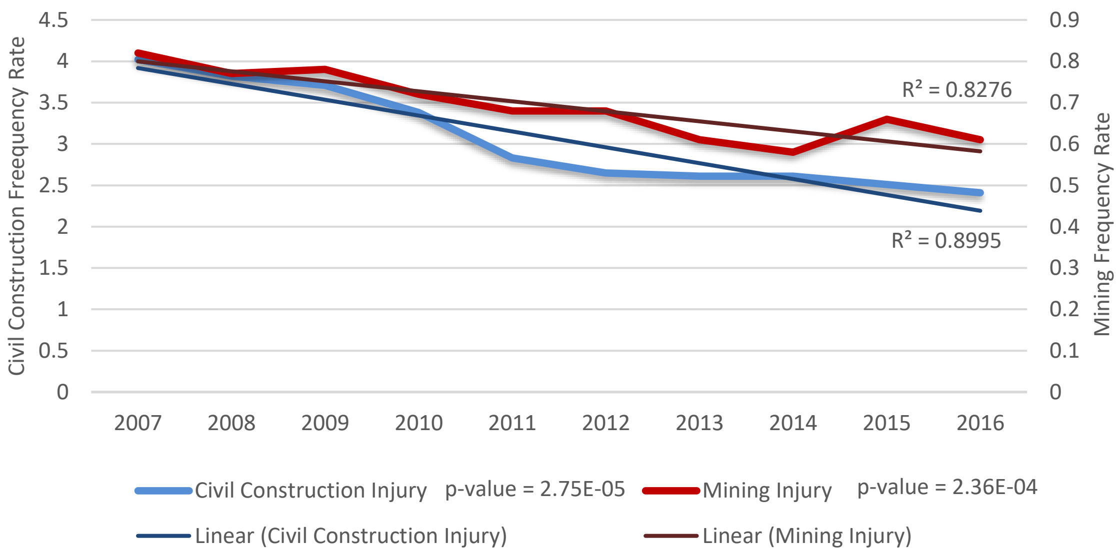


Figure 4.3: Annual injury frequency rates

(FEM, 2018; Department of Mineral Resources South Africa, 2018; Minerals Council South Africa, 2018b)

The CCI is highly unstable in terms of the number of fatalities and fatality frequency rates, resulting in no clear fatality trends being identified over time. Mining as an industry has demonstrated that the control over fatalities can be improved. One such initiative to improve incident control is the Culture Transformation Framework (CTF) developed by the Mining Health and Safety Council (MHSC) (MHSC, 2014). Although not solely accountable, the impact of such initiative can clearly be seen in the reduction of the fatality frequency rates in the mining industry. The mining industry, proven by both fatality frequency rates and injury frequency rates, has become a safer working environment for employees.

The fatality frequency rate was proven to be statistically insignificant for the 95% confidence interval, which means it provides little insight into future fatality frequency rates. The fluctuation of increase and decrease in the fatality frequency rate for CCI indicates that there is little control over the occurrence of incidents. The aim of this analysis, as illustrated by the mining industry statistics, is to create a 'burning platform' in the CCI to actively seek methods and adopt policies that will contribute to the reduction of injuries and fatalities.

4.2.2. Mining industry effective incident control initiatives

Figures 4.1, 4.2 and 4.3 illustrated the incident trends for the civil construction and mining industries. Fatalities in the CCI have shown no trend in growth or decay, whereas the mining industry has seen a reduction. The mining industry-wide initiatives have proven to be successful in the reduction of fatalities and injuries. Sections 2.2 gives brief details on known CCI-wide methods to control the occurrence of incidents.

The initiative applied in the mining industry to be focused on is the CTF. The CTF is chosen as available recorded mining incident trends demonstrate the positive role the CTF has played on the annual incident frequency rates for the mining industry (Department of Mineral Resources South Africa, 2018). The CTF was only developed in 2008, however incident reduction is seen from 2007 to 2008 and therefore cannot be glorified as the only means of incident reduction (MHSC, 2011). Focus is still given to the CTF as it played a role in further incident reduction from 2008 to 2016. Sustainable incident reduction is crucial to ensure favourable incident trends in the future.

The MHSC states that the CTF has a key focus of controlling risks at the source (MHSC, 2011), identifying how this framework is essential in preventing incidents. To understand how the CTF has made positive contributions it must be understood what makes up the CTF.

The CTF comprises of 11 pillars, each of which represents a different aspect of incident control. For the purpose of this study, the first six pillars are focused on, as the remaining pillars are only to be implemented after the year 2020 and are thus not relevant in the analysis. Brief descriptions of each of the six pillars under consideration are as follows (MHSC, 2011):

1. **Bonuses and performance incentives**: Zero harm to employees is the main priority, ahead of production and profit.
2. **Risk management**: Finding the source of potential risks, thereafter, managing future risks at the source.
3. **Leadership**: Encouraging leaders, workplace and organisational level employees, to lead by example in terms of promoting zero harm initiatives.
4. **Leading practice**: Find which OHS practices and approaches are successful and adopt these into the CTF.
5. **Diversity management**: No racism, genderism or any other form of discrimination.
6. **Data management**: Monitor and evaluate mine health and safety performance as well as the progress of the CTF implementation.

The CTF prioritises the safety of employees by focusing on the removal of risk, thereby creating a safer work environment. Reduction in risk is achievable through using the CTF to identify and control hazards which are present within the workplace. Understanding of the hazards allows for the correct selection of controls to be set in place. Both the CCI and mining industry have similar hazards which suggests that they should have similar level of controls in place (Tobergte and Curtis, 2013).

According to members of various South African civil construction companies there is a focus on the reduction of incidents occurring. However, the fact remains that according to the FEM statistics regarding the CCI, the industry has been unsuccessful in controlling the occurrence of fatalities and there is a large injury frequency rate. A possible reason behind the initiatives not being successful is the CCI focusing on incidents in isolation.

This study focuses on incidents as a collective, providing a cross-sectional view of incidents. The adapted ICF is used to analyse multiple incidents across three South African civil construction companies. The analysis of multiple incidents provides findings regarding the leading incident causation factors and relationships between the incident causation factors. Findings regarding these incident causation factors allows for the understanding of controls which need to be improved or put in place to prevent an uncontrolled energy release.

4.2.3. Potential improvements made by this study in understanding incident causation

The ICF developed by Jude Bonsu has been constructed to simplify incident causation compared to other ICFs (Bonsu *et al.*, 2016). The adapted ICF is able to account for many factors considered in the occurrence of incidents. The improvement this study has made compared to previous incident investigations is due to the approach it has taken in applying the adapted ICF across multiple incidents.

This study's analysis process allows for the cross-sectional view of multiple incidents, removing the focus from viewing incidents as singular events. The adapted ICF is used to analyse 66 incidents which have occurred across three South African civil construction companies. This analysis gives insight into the leading incident causation factors (*human errors*, *workplace factors* and *organisational factors*), as well as revealing relationships between the different incident causation factors. Findings regarding these incident causation factors allows for the understanding of controls which need to be improved or put in place to prevent an uncontrolled energy release.

Chapter 5 presents the analysis of the incident causation factors using the 66 incident reports analysed. The findings based in Chapter 5 demonstrate how the South African civil construction industry can improve its understanding of incidents, making incident reduction a more simplified task. To apply the ICF across multiple incidents a further understanding is required as to how to use this ICF.

4.3. Introduction to adapted South African civil construction incident causation framework

Section 3.3 gave a brief outline of how the adapted ICF is applied in this study. To understand the application of the adapted ICF, the aspects analysed and identified within this ICF must be understood. Detailed discussion is given in this section regarding the aspects analysed using the adapted ICF.

Uniform analysis is achieved by using only the adapted ICF in assessing incidents, providing a standardised method of assessing incidents. The ICF establishes each incident's causation factor, thereafter, combining all the incident causation factors to create an incident causation database.

4.3.1. Conceptualisation of framework

Conceptualisation of the framework begins through the adaptation of Jude Bonsu's mining ICF to suit the South African CCI (Bonsu *et al.*, 2016). The civil construction ICF is used to indicate aspects which played a role in an incident occurring.

Figure 4.4 provides a visual representation of how the ICF is applied to solving an incident. Each of the key aspects displayed in Figure 4.4 is discussed in Section 4.3.1.1 to Section 4.3.1.6. The basis of Figure 4.4 is to develop the understanding that causation originates from *organisational factor*s which subsequently lead to specific *workplace factor*s which in turn lead to specific *human errors*. Once the final *human error* has occurred, if there is a lack of effective controls present, there is a loss of control of energy, resulting in an incident. The focus of the adapted ICF is determining the *human error*s, *workplace factor*s and *organisational factor*s which occurred, and in the process establishing the hazard as the source of the uncontrolled energy and the controls which failed.

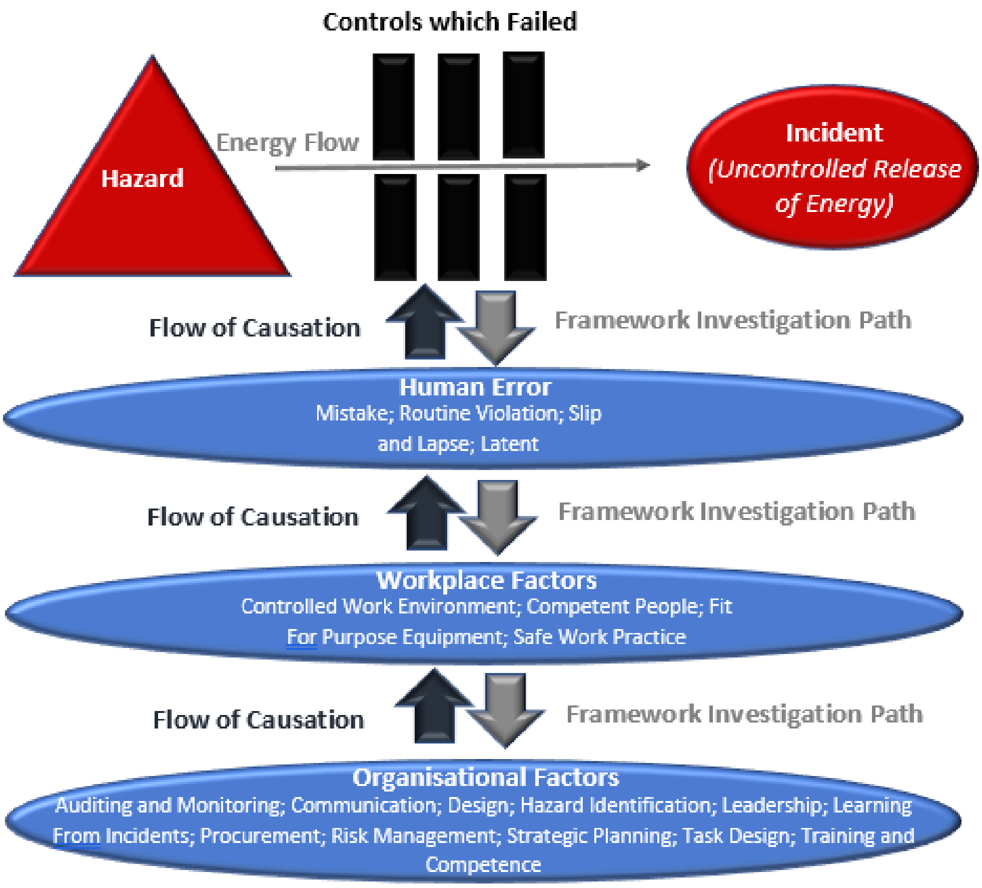


Figure 4.4: Visual representation of the adapted ICF
(Bonsu *et al.*, 2016)

The South African civil construction ICF aims to investigate retrospectively from the *human error* to the *organisational factor*s which lead to the incident occurring. The process of investigation begins through the establishment of the energy source or hazard involved in the incident.

4.3.1.1. Establishing the hazard

When an incident occurs there is an uncontrolled release of energy; hazards are the source of this uncontrolled energy. The understanding of hazards stems from the Energy Damage model, discussed in Section 2.4. Determining the hazard is a primary step in analysing the incident using the adapted ICF.

Tracking the incident back from the event which occurred to the source of energy determines the hazard. The magnitude of the hazard's energy is proportional to the harm caused when there is an uncontrolled release of this energy, unless a protective control is set in place to protect the individual. Hazards are made up of various objects and can range from mechanical devices such as bulldozers to simple exposed flooring edges. For a hazard to result in an incident there was ineffective control of the energy. Effective energy control would not allow a release of uncontrolled energy.

To prevent the uncontrolled release of energy or protect individuals from this energy, controls are to be set in place. Identifying the hazard is essential in ensuring the correct controls are in place.

4.3.1.2. Establishing controls

Controls discussed in this section correspond with the description given in Section 2.3. Failed controls are identified by establishing how the energy was able to escape (preventive control) or how the energy was able to cause harm once it escaped (protective control). Establishing that controls failed, resulting in an incident, indicates that controls must be improved to prevent incidents from occurring. Providing the understanding of what makes up both a preventive and protective control allows them to be identified in real-life incidents.

Preventive controls revolve around the prevention of damage, whilst protective controls revolve around restricting the damage done. An incident occurring indicates that the preventive controls failed and there was a release of uncontrolled energy. Protective controls are established when individuals are harmed, either due to protective controls being ineffective or not having been put in place.

Establishing both types of controls builds an understanding of the failures which resulted in the incident occurring. An incident occurs when there is an uncontrolled release of energy, however the three factors (*human errors*, *workplace factor*s and *organisational factor*s) lead to the uncontrolled release of energy. The first to be identified using the adapted ICF are *human errors*.

4.3.1.3. Establishing human error

To understand the identification process for determining the *human error,* reference is given to Appendix G1. For the correct application of Appendix G1 the user must first clearly distinguish the events which occurred and the controls which failed resulting in the uncontrolled release of energy. Appendix G1 provides the process of identifying the *human errors* involved in the specific incident.

Using Appendix G1 any of the following *human errors* are identified as causation factors for the specific incident:

- **Deviant violation -** A violation which does not commonly occur, practised by very few individuals.
- **Routine violation -** A violation which commonly occurs, practised by many individuals.
- **Mistake -** A gap in knowledge of the individual completing the task is apparent, or insufficient skill to complete task.
- **Slip/Lapse -** Task carried out correctly, incident still occurs due to design flaw, distraction or change in usual situation.
- **Latent failure -** No *human error* is present.

The *human error*s have been discussed previously in Section 2.7, however, to identify the *human errors* involved in a specific incident focus is given to Appendix G1. Table 4.1 provides a description of each step taken in Appendix G1 to identify the *human error*s involved in the incident.

Table 4.1: Human error flowchart description

Is there a Human error which occurred? (Description of active and latent failure is given in Section 2.9.4)	1. **Yes** - Active failure states there was a *human error* which occurred. 2. **No – <u>Latent Failure</u>.** Defined by the lack of human error.
Was there intent in the action?	1. **Yes** – Intention clear. The individual involved in the incident purposely disobeyed set rules or procedures. 2. **No** – Intention not clear. Individual was not purposely disobeying any rules or procedures.

Is this violation common practice? (Both described in Section 2.7)	1. **Yes - <u>Routine Violation</u>**. Occurs as common practice by many individuals. 2. **No - <u>Deviant Violation</u>**. Occurs infrequently, practised by very few individuals.
Was there a lack of knowledge? (Section 2.7 describes each human error)	1. **Yes - <u>Mistake</u>**. Gap in knowledge. Assumes can complete task, however, proven incorrect. 2. **No - <u>Slip/Lapse</u>**. No gap in knowledge. Provided correct application, however, an error still occurred.

Table 4.1 has described the process given in Appendix G1 for identifying the *human errors* involved in the incident. Identifying the *human error* over multiple incidents is the first step in determining the incident causation factors to be analysed. Identification of the *workplace factors* is the next step, as these factors led to the *human errors* occurring.

4.3.1.4. Establishing workplace factor

Descriptions regarding the different *Workplace factor*s have been given in Chapter 2.8. The descriptions given in this section aim to apply the *workplace factor*s to the CCI. Table 4.2, gives definitions for the 4 *workplace factor*s when applied to the civil construction ICF, very similar to those given in Section 2.8.

Table 4.2: Workplace factors used in South African civil construction ICF

Competent People (CP)	Individuals performing the task have competence in doing so, with the correct skill levels.
Fit for Purpose Equipment (FFPE)	Equipment used is fit for purpose and of good working order.

Controlled Work Environment (CWE)	**Physical work environment** ensures the workspace does not have physical conditions which could result in incidents. e.g. Workspace is overcrowded by individuals performing tasks. **Behavioural work environment** ensures that incorrect behaviour is not condoned in the workplace. e.g. Individuals ignore safety procedures set in place for the completion of a task.
Safe Work Practices (SWP)	There is a work procedure in place which provides adequate safety for the completion of the task.

Understanding which *workplace factor*s resulted in the incident occurring is established in Appendix G2. From Appendix G2 there may be multiple *workplace factor*s which correspond to a singular *human error*. Identifying all *workplace factor*s is vital, thus the questions in Appendix G2 do not rule out one *workplace factor* because another is chosen.

Establishing the *workplace factors* which led to the *human errors* is accomplished through the data analysis of all the incidents. The next step in the determination of causation is then to establish the *organisational factor*s which led to the specific *workplace factor* occurring.

4.3.1.5. Establishing organisational factor

The concept of *organisational factor*s was previously discussed in Section 2.9.2. *Organisational factor*s comprise of management systems set in place to restrict the possibility of an incident occurring. Flaws in the management systems create the *organisational factors* which lead to the *workplace factors* occurring. *Organisational factors* thus provide the first flaw within a system which leads to the uncontrolled release of energy.

Many of the *organisational factor*s used for the civil construction ICF were taken from Jude Bonsu's Incident Causation Framework (Bonsu *et al.*, 2016). To understand the *organisational factors* used for the adapted civil construction ICF definitions have been supplied in Table 4.2:

Table 4.3: Defined organisational factors for adapted civil construction ICF (Bonsu *et al.*, 2016)

Organisational Factor	Definition
Auditing and Monitoring	Lack of individuals constantly auditing and monitoring control systems to ensure that they are meeting the changing working environment and to ensure they are being adhered to.
Communications	Individuals performing the task do not understand correct safety protocol and do not communicate safety complaints to individuals in charge.
Design	Workplace or equipment is poorly designed and does not prioritise safety.
Hazard Identification	The hazard or magnitude of the hazard present has not been identified, therefore, controls set in place are non-existent or ineffective in dealing with hazard's energy.
Leadership	Deviant practices in the workplace are occurring due to inefficient supervision to correct behaviour.
Learning from Incidents	Lack of quality of investigations into previous incidents and relaying these findings to employees.
Planned Maintenance	Lack of regular equipment maintenance or substandard maintenance of equipment leading to failure.
Procurement	Incorrect or substandard equipment is purchased or necessary equipment has not been purchased.
Risk Management	Not managing or dealing with identified risk through the use of effective risk control methods.
Strategic Planning	Organisation has prioritised specific goals over the safety requirements for employees.
Task Design	Task instructions have not identified all risks, in failing to do so insufficient risk control methods are present.
Training and Competence	Workers do not have the correct skill to complete a task or their competence was not checked before the completion of the task.

Multiple *organisational factor*s may result in a specific *workplace factor* occurring. For the purpose of determining all relevant *organisational factors*, a checklist has been established for deciding which *organisational factor*s resulted in the identified *workplace factor* occurring. The checklist used for identifying the relevant *organisational factors* is given in Appendix G3, ensuring that the adapted ICF identifies all *organisational factor*s involved.

After analysing each of the 66 singular incident reports using the adapted ICF, trends in incident causation may be found by viewing the multiple incidents as a whole. The findings will focus on the proportional contributions of each incident causation factor as well as developing links as to the *workplace factors* that caused the specific *human errors* and the *organisational factors* which caused the specific *workplace factors.*

To better understand the ICF used it is vital to see an example of analysis. The analysis combines the assessment of all the aforementioned data.

4.3.1.6. Example of incident analysis

To demonstrate how the adapted ICF is applied, the analysis of the incident report given in Appendix D1 is explained. Appendix D1 is an incident report received from Company 1. All three companies' incident reports provide the same details regarding the incident. The analysis of this incident report demonstrates to the reader the analysis process used when applying the adapted ICF to a singular incident.

The analysis of applying the adapted ICF to an incident report follows the steps given in Figures 4.5, 4.6 and 4.7. The analysis seen in Figures 4.5, 4.6 and 4.7 is extracted from the database of all analysed incident reports, thus each incident followed the same steps for analysis as displayed.

Steps 1 to 6 shown in Figure 4.5 look at the administrative details taken from the incident report. Administration detail is information regarding case number, date and time, day of the week, time of the day, type of incident and the location of the incident. This information is given to provide the context as to when the incident occurred and the severity. Step 7 summarises the events that led to the incident occurring, helping to identify the hazards which released energy and the controls which failed. Each of the steps demonstrated in Figure 4.5 forms the basis of understanding the conditions which led to the incident occurring. This basis of understanding leads to further steps in identifying the factors which led to the incident occurring.

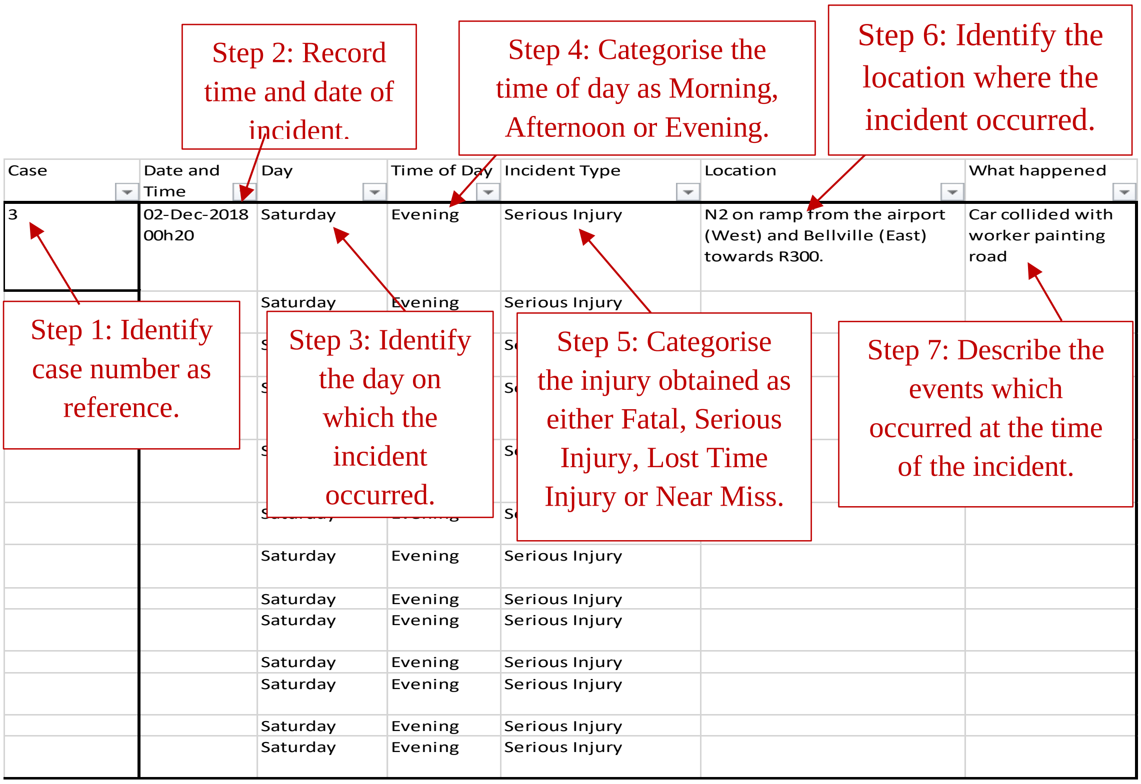


Figure 4.5: Analysis of company 1, case 3 (a)

Figure 4.6 shows steps 8 to 12 which identify the proximal causes of the incident occurring. The source of energy, the hazard, is identified in step 8. Identification of the hazard shows where the energy release originated from, this can lead to step 9, the identification of the controls which failed or should have been in place to control the energy. Description is given in step 9 as to why the control failed, whilst step 10 discusses whether the identified control was preventive or protective in nature. Identifying the controls shows where the organisation did not implement effective methods in controlling the hazard.

Step 11 identifies the *human errors* which led to the control failing and the incident occurring. The method to determine the relevant *human errors* is given in Appendix G1 as discussed in Section 4.3.1.3. Identification of the *human errors* determines the final factor responsible for the incident occurring, the reasoning for each *human error* identified is given in step 12. The remaining factors are to be established in Figure 4.7.

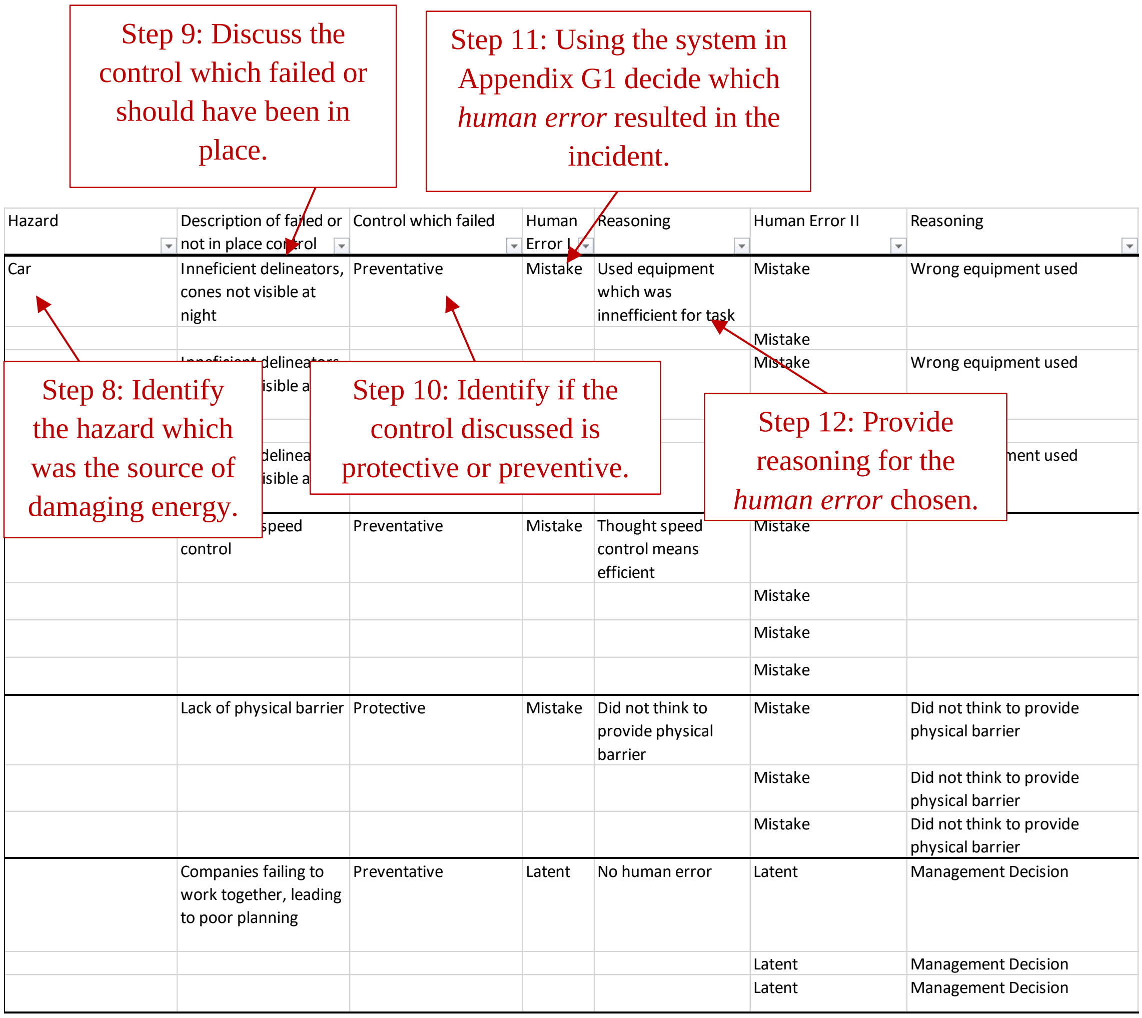


Figure 4.6: Analysis of company 1, case 3 (b)

Figure 4.7 shows how the adapted ICF identifies the *workplace factors* which caused the relevant *human error* (step 13) using the method given in Appendix G2. When the *workplace factor* identified is CWE, step 14 identifies whether this is due to the physical or behavioural work environment and is repeated for all instances of CWE. Step 15 provides the reasoning as to which *workplace factors* occurred for the specific *human errors*. Steps 13 and 15 are repeated to establish all *workplace factors* as these may be multiple for each *human error* identified.

Step 16 uses the checklist given in Appendix G3 to identify the *organisational factors* which caused the relevant *workplace factor*. Reasoning for each *organisational factor* is given in step 17. Steps 16 and 17 are repeated for the entirety of Appendix G3 to identify all *organisational factors* responsible for the relevant *workplace factor*.

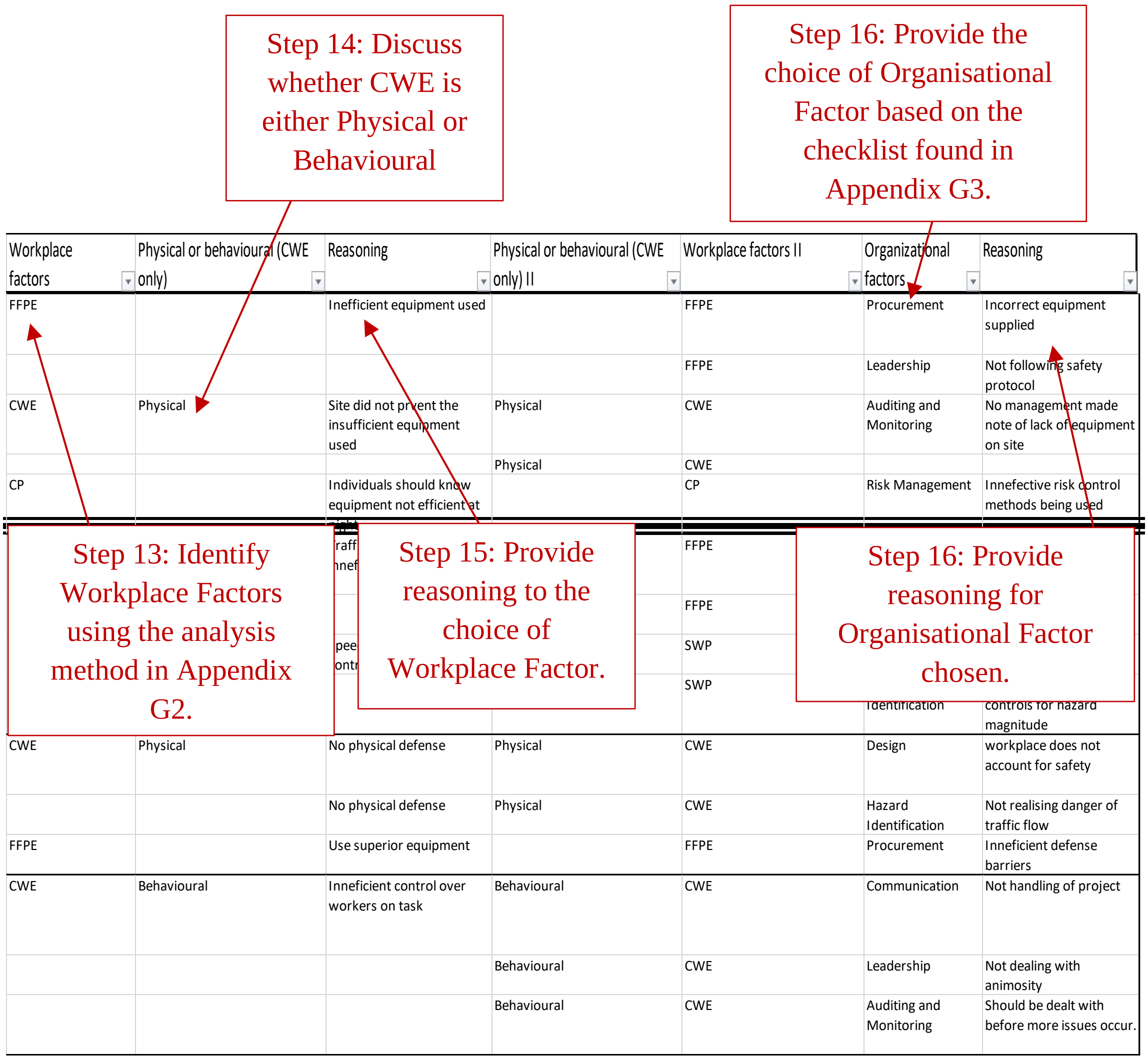


Figure 4.7: Analysis of company 1, case 3 (c)

All 66 incident reports are analysed using the adapted ICF. All analysed incident reports form the database from which the analysis is done for the incident causation factors. Grouping the individual incident analyses into a database allows a cross-sectional analysis of incident causation. The cross-sectional analysis gives insight as to the leading incident causation factors and builds relationships between these factors. The analysis of the incident causation factors is given in Section 5.

4.4. Chapter 4 summary

Chapter 4 set out to motivate the South African civil construction industries' requirement for this study using the adapted ICF and to describe all the aspects to understand the use of the adapted ICF. Section 4.2 covered aspects which motivated the study and Section

4.3 described the adapted ICF. A means to control and reduce the occurrence of incidents in the South African civil construction industry was proven to be required through the comparison with the South African mining industry in Section 4.2.1. This demonstrated that the mining industry has greatly reduced the occurrence of fatalities and fatality frequency rates, whilst the civil construction industry has statistically insignificant results in this regard. The injury frequency rates demonstrated the very high frequency rates occurring in civil construction; however, there seems to a be a reduction taking place. Section 4.2.2 provides means that the mining industry has applied in receiving such positive results in incident reduction. This leads to Section 4.2.3 which aims to provide the civil construction industry with its own means of understanding and reducing incidents. It describes how this study could benefit the civil construction industry in this regard through the development of understanding incident causation across multiple incidents, finding relationships between incident causation factors and the leading incident causations. Section 4.3 finally described all the aspects used in the adapted ICF and how to apply this ICF to an incident report. The reader will have gained valuable understanding of how the ICF is used for this study.

Chapter 5.

Data analysis and results

5.1. Introduction

Analysis of the 66 incident reports using the civil construction-adapted ICF creates a database made up of all the incident causation factors which contributed to the incidents. Once the database is populated, graphs are used to compile a cross-sectional analysis of incidents. The cross-sectional analysis views all 66 incidents (5 fatalities, 27 lost-time injuries, 8 serious injuries and 26 near-miss incidents) as a database which represents the South African civil construction industry, as opposed to viewing each as individual events. The cross-sectional analysis provides an insight into the leading incident causation factors, as well as relationships between the incident causation factors. The database comprises of 191 *human errors*, 284 *workplace factors* and 485 *organisational factors* for the 66 incidents.

Analysis of incident causation factors reveals the primary *human error*s, *workplace factor*s and *organisational factor*s causing incidents. Once the primary *human errors, workplace factors* and *organisational factors* are identified, it is a simpler process to reduce the occurrence of incidents due to these factors. Determining relationships between the incident causation factors identifies the type of *workplace factor*s which cause the specific *human error*, thereafter, the type of *organisational factors* which cause the specific *workplace factor*. By improving the specific *organisational factors*, linked *workplace factors* will reduce and subsequently the linked *human errors*.

The information provided in Section 4.2 motivates the requirement for a means to better understand incident causation for the South African civil construction industry. The data analysis and results given in this section aim to provide that understanding of incident causation.

5.2. Data assessment

To understand the analysis of incident causations, each of the three companies is initially assessed individually to demonstrate similar results across them; the reasoning for this is motivated in Section 4.2.3. Tables 5.1 to 5.3 describe the different aspects highlighted in the analysis for each of the three factors (*human error*s, *workplace factor*s and *organisational factor*s), briefly discussed in Section 3.4.3.

The primary analysis of *human error* is the proportional analysis, whereby the total *human error* is demonstrated as the proportional contribution made by each *human error* type. Table 5.1 demonstrates the two other parameters from which *human error* is assessed. These two parameters aim to demonstrate the frame of mind of individuals performing a task at the time of the *human error*.

Table 5.1: Human errors analysis parameters

Time that Injury Occurred	1. Morning: *From 04:00 to 11:59.*
	2. Afternoon: *From 12:00 to 19:59*
Day that Injury Occurred	1. Monday
	2. Tuesday
	3. Wednesday
	4. Thursday
	5. Friday
	6. Saturday
	7. Sunday

The analysis of *workplace factor*s begins with the proportional analysis, separating each *workplace factor* into its contribution to the total number of *workplace factor*s. After the proportional analysis, the *workplace factors* are assessed according to their proportional contribution in causing each type of *human error*. Table 5.2 represents these parameters as the *workplace factors* are assessed according to each type of *human error*. Relationships are provided through this proportional analysis which depicts the *workplace factors* which commonly cause the specific *human error*. The relationships providing links between *human errors* and *workplace factors* give insight into the flow of energy resulting in the occurrence of incidents.

Table 5.2: Workplace factors analysis parameters

Human error	1. *Latent* (No human error)
	2. *Mistake*
	3. *Slip and lapse*
	4. *Routine violation*
	5. *Deviant violation*

*Organisational factor*s are the last factor analysed and are the first factor to lead to the flow of uncontrolled energy. This relationship was demonstrated previously in Figure 4.4. The proportional analysis for this factor separates each *organisational factor* into its proportional contribution to the total number of *organisational factor*s.

After the proportional analysis, relationships are given for the proportional contribution of *organisational factors* which caused the specific *workplace factors*. These relationships provide insight as to which *organisational factors* are most commonly responsible for causing the specific *workplace factors.* Table 5.3 provides the parameters of the study of *organisational factors* as the respective *workplace factors* with which relationships are developed. The link between the *organisational factors* which caused the specific *workplace factors* provides further insight into the energy flow which led to the *human error* and eventually the incident occurring.

Table 5.3: Organisational factors analysis

Workplace factors	1. CP (*Competent People*)
	2. CWE (*Controlled Work Environment*) • Physical work environment • Behavioural work environment
	3. FFPE (*Fit for Purpose Equipment*)
	4. SWP (*Safe Work Practice*)

Understanding the leading incident causation factors and relationships between incident causation factors, builds a greater level of understanding of the energy flow pathway. This flow of energy is the cause of incidents when controls have failed, or when controls become inadequate to contain an increased magnitude of energy. Greater understanding of energy flow means that incident causation can be dealt with at the source, resulting in the prevention of future incidents. Section 5.3 provides insight into all factors involved in incident causation for the assessed incident reports.

5.3. Causation trends

5.3.1. Human error causation trends

Section 5.3.1.1 gives the proportional analysis of the 191 *human errors* across the 66 incident reports provided by the three companies. The proportional analysis of *human error* is shown for each company individually, after which an analysis is given working with a weighted average of all three companies. The weighted average ensures that data from each company counts equally when combining all the data. Section 5.3.1.2 gives the analysis of *human error* based on when the incident occurred, firstly in terms of the time of day and then in terms of the day of the week.

5.3.1.1. Human error proportions

Figures 5.1, 5.2 and 5.3 display the proportional analysis of the *human errors* for each individual company, whilst Figure 5.4 displays the proportional analysis of the *human errors* as a weighted average across all three companies. The weighted average of *human errors* is calculated using *Equation 5.1*:

$$HE\ Weighted\ Average\ (\%)$$

$$= \left(\frac{(\sum HE_{x,C1} \times I_{C1}) + (\sum HE_{x,C2} \times I_{C2}) + (\sum HE_{x,C3} \times I_{C3})}{I_{C1} + I_{C2} + I_{C3}}\right) \times 100 \qquad (5.1)$$

Where:

$x \in \{Mistake, Slip\ \&\ Lapse, Routine\ Violation, Latent\}$

HE – Proportion of Specific *human error*

I – Count of incidents

C1 – Company 1

C2 – Company 2

C3 – Company 3

The data associated with Figures 5.1 to 5.4 is given in Appendix H1. The following values are used for the weighted average in the analysis:

I_{C1} - 8

I_{C2} – 25

I_{C3} – 33

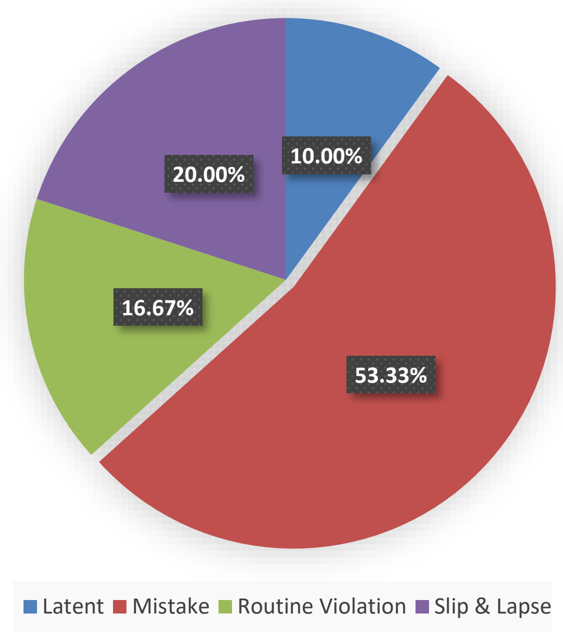


Figure 5.1: Human errors proportional contribution company 1

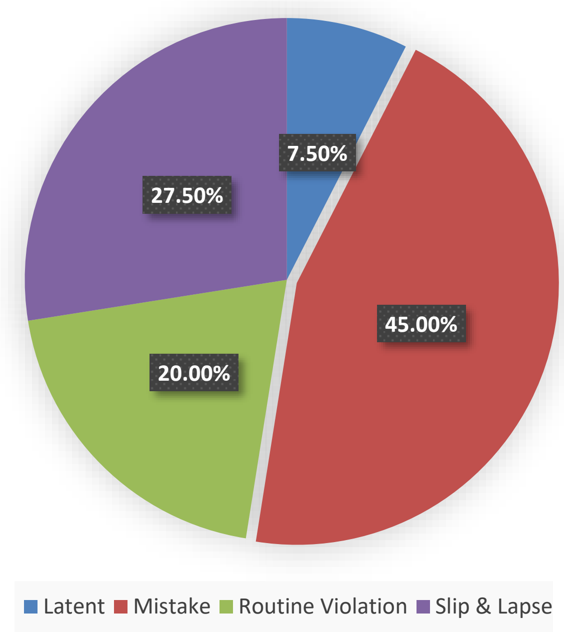


Figure 5.2: Human errors proportional contribution company 2

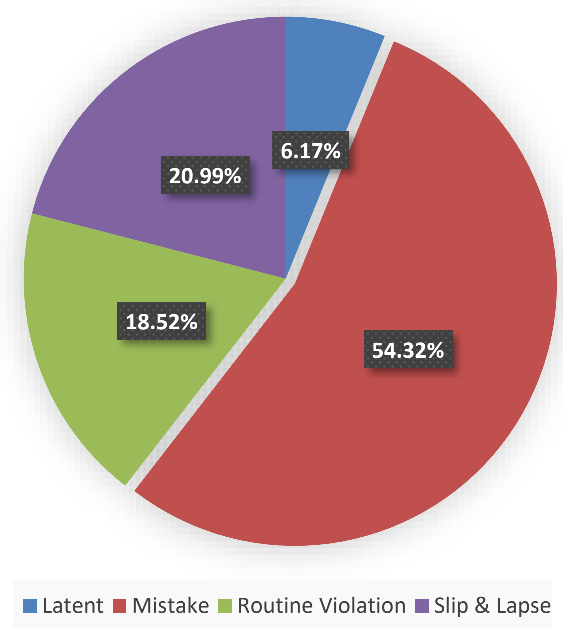


Figure 5.3: Human errors proportional contribution company 3

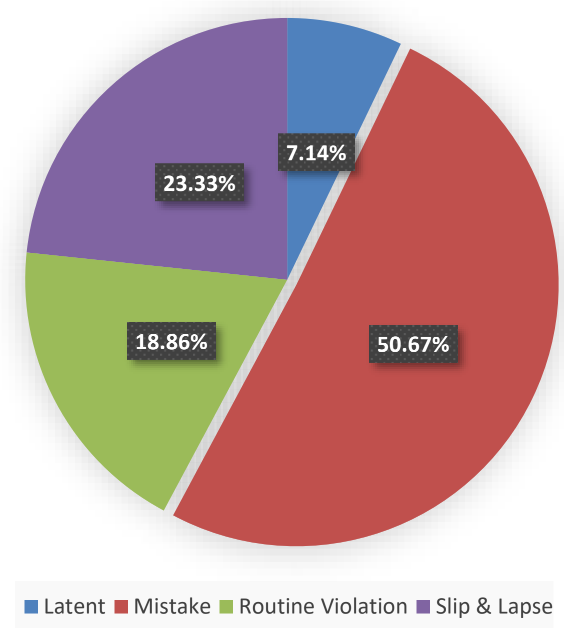


Figure 5.4: Human errors proportional contribution weighted average

As evidenced through the data of all three companies and the weighted average of this data, the leading *human error* is the factor '*mistakes'*. For each company demonstrated in Figures 5.1 to 5.3 *mistakes* contribute a range of 45.00% to 54.32% of the total *human error* and carry a weighted average across the three companies of 50.67%. For all three companies the *human error* rankings remain constant, as each company's next leading contributor to *human error* is *slip and lapse*, then *routine violation* and lastly *latent error*. Thus the same rankings occur for the weighted average of each *human error'*s proportional contribution to the total number of *human error*s.

As the leading contribution to *human error*, *mistakes* occur due to the lack of adequate knowledge for the completion of a task which when applied, results in an incident occurring (Bonsu *et al.*, 2016). Individuals who have the correct knowledge for the completion of a task should be able to perform the task without direct supervision, and provided that these individuals perform tasks in the correct manner, no violations occur. This means that with the correct management systems in place, all individuals performing tasks are ensured to have the required skill and execute tasks accordingly.

Figure 5.4 shows that *slips and lapses* contribute less than *mistakes* to the total *human error*, with a weighted average contribution of 23.33%. *Slip and lapse* are not related to a flaw in the individual committing the *human error* or to any sort of deliberate violations but rather a flaw in management systems. This is due to *slips and lapses* occurring from design flaws or from a change in the design that the individual performing the task was unaware of. The individual involved in a *slip and lapse* has the required knowledge to perform a task, but an incident occurs due to operational decision-making (discussed in Section 2.6). Operational decision-making often occurs when individuals are performing repetitive tasks and there is a variation in the task or the equipment deviates from what the individual is used to (Joy, 2000). If the individual does not account for this, the *human error* occurs. A possible means to overcome *slips and lapses* is the introduction of controls which activate an individual's cognitive thought process. Such controls are things such as systems that require a manual override before a process can continue. Alternatively, the designs of tasks and equipment must be standardised.

The third largest contributor to *human error* is *routine violations*, with a proportional contribution of 18.86% to the weighted average. A *routine violation* implies that procedures were purposely not followed by the individual in the completion of a task and others are doing it as well. Many of the incident reports assessed found a link between a lack of supervision and the occurrence of *routine violations*. Lack of supervision creates a work environment where employees perform tasks in a manner they see fit. Supervision is not an ideal means to reduce the occurrence of *routine violations* as increased supervision does not account for a resilient system. The source of the *routine violation* needs to be identified in order to create a system which is free of *routine* violation when supervision is not present. It may be noted that the incidents assessed are free of any *deviant violations*. R*outine violations* begin with a singular *deviant violation* which is then repeated by fellow employees.

Latent failure is an incident where there was an absence of *human error* by the individual involved. For data display purposes, the proportional contribution was given as if *latent error* is a form of *human error*. The lowest contribution to the total number of *human errors* was made by *latent error*, with a weighted average of 7.14%. *Latent errors* involve incidents where the *organisational* and *workplace factors* make up the entirety of the failure pathway. In order to deal with *latent errors*, flaws within the system need to be dealt with at a *workplace* and *organisational factor* level.

The proportional contribution of the types of *human errors* across the three companies remained remarkably consistent in terms of the relative contribution. The study found that across the three companies *mistakes* are the leading cause of incidents in the South African civil construction industry (CCI), which could indicate a general trend for the South African civil construction industry.

For a deeper insight into an individual's mindset when specific *human errors* occur, research was done into the time of day as well as the day of week the incidents occur.

5.3.1.2. Time and day of human error

In Section 5.3.1.2 analyses are given on the relationship between when (time of day and day of week) the incident occurred and the associated *human errors*. The time of day (Figure 5.5) and day of week (Figure 5.6) analyses provide information regarding the occurrence of specific *human errors* and are not considered for the relationship between *human errors*, *workplace factor*s and *organisational factor*s.

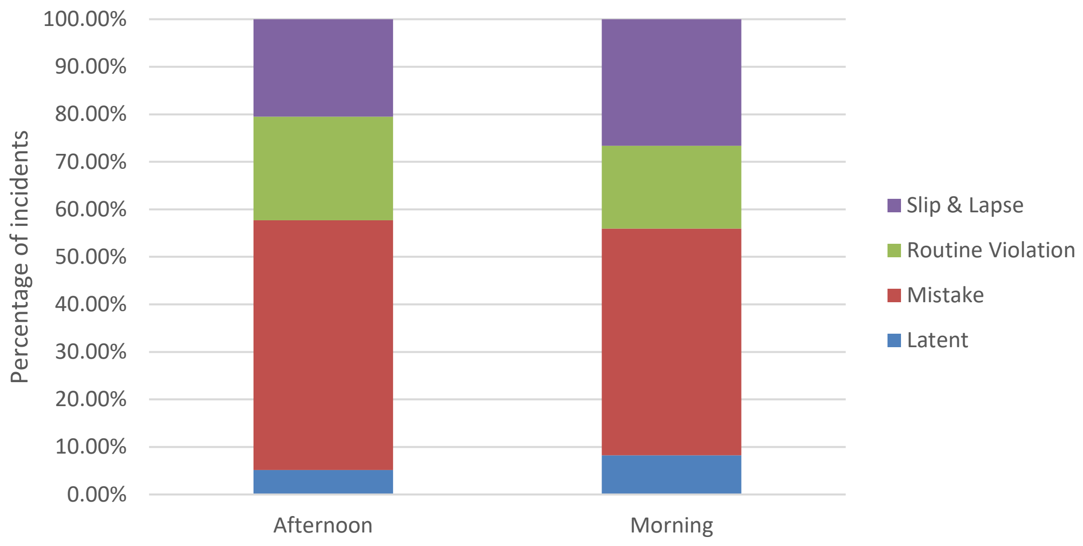


Figure 5.5: Time of day and associated human error

Appendix H2 provides the data points regarding the time of day the specific *human error* occurred. The day is split into morning and afternoon as 64 of the incidents (96.97%) occurred between 06:00 and 18:00, thus the data outside these times is statistically insignificant. As shown in Figure 5.5, the proportional contribution of *human errors* occurring in the morning and afternoon are very similar. There is, however, a difference with *routine violations* occurring more commonly in the afternoon, whilst *slips and lapses* occur more commonly in the mornings. As time progresses within the day individuals may be more prone to complete tasks in the quickest means possible, indicating the occurrence of high *routine violations*. Morning work routines association with *slips and lapses* show individuals are in operational decision-making mode in the mornings. Being tired could lead to operational decision-making and resulting in a *slip and lapse* occurring. The number of each human error according to the time of day is presented in Appendix H2.

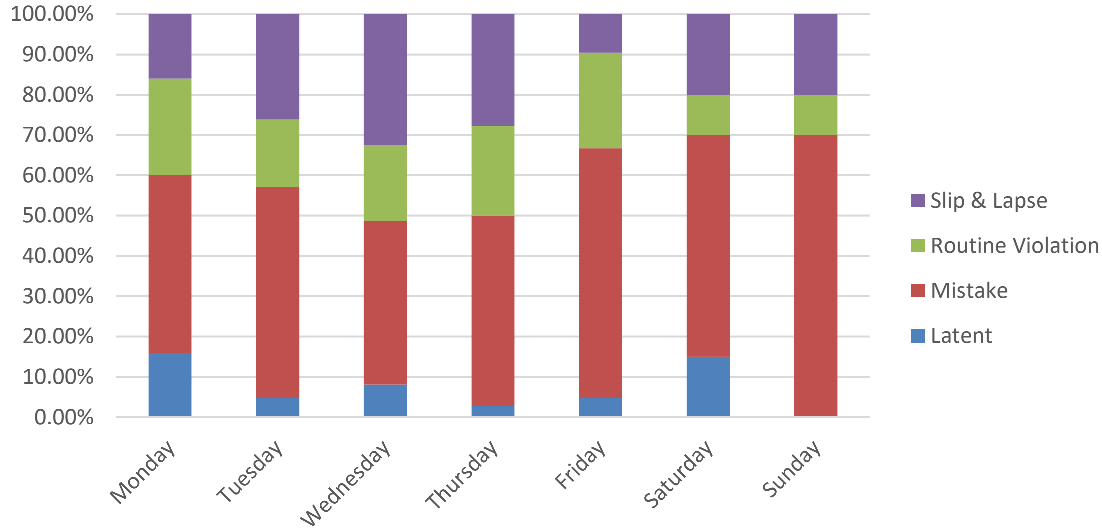


Figure 5.6: Day of the week and associated human error

According to the South African labour guide individuals work a maximum of 45 hours per week (9 hours per day), therefore, for this analysis it is assumed that individuals working on a Sunday are working overtime (Erasmus and Toit, 2018). Appendix H3 demonstrates the data points used in Figure 5.6 for the days on which specific *human errors* occurred. Appendix H4 provides the number of each *human error* per day of the week, associated with the total proportions.

Figure 5.6 demonstrates that each day of the week there are slight fluctuations with the *human errors'* proportional contributions. On Tuesdays (26.19%), Wednesdays (32.43%) and Thursdays (27.78%) there are relatively large proportions of *slip and lapse* compared to the rest of the days of the week. Viewing Appendix H4 supports this, as a large number of *slips and lapses* occur on these three days. It may be possible that individuals have re-entered the operational decision-making process for the week, as cognitive thinking is performed on the first day of the week due to a break from the task. The operational decision-making is possibly caused by mid-week exhaustion which led to the individual possibly not taking note of deviations in the system which could lead to incidents.

Fridays (61.90%) and Sundays (70.00%) hold a large proportion of *mistakes* compared to the rest of the week. As Friday is the last day of a normal workweek and Sunday is considered overtime, individuals aim to finish work as quickly as possible. Individuals then perform tasks in a manner they think is effective and do tasks that they are not meant to be doing in order to complete them quicker, while thinking that is safe to do so. The executed plan fails, leading to an incident as the result of the individual's *mistake*.

The time of day and day of week analyses combined provide insight into psychological factors which contribute to *human errors* occurring. The time of day analysis showed the variations in time of day and the occurrence of *routine violations* and *slips and lapses*. The day of the week did provide a possible link between *slips and lapses* and mid-week exhaustion, as well as *mistakes* with a rushed process by individuals involved in the task.

The establishment of proportional contributions of *human error* gives a better understanding of the *human errors* involved in an incident. This understanding of *human errors* helps to better understand the relationships between *human errors* and *workplace factors* which are developed in Section 5.3.2.2. Through the establishment of relationships between *workplace factors* and *human errors* a better understanding is gained of the control failures that lead to the flow of energy in the failure pathway.

5.3.2. Workplace factors causation trends

*Workplace factor*s' causation trends are discussed in this section where 284 *workplace factors* are analysed. Section 5.3.2.1 provides the proportional contribution made by each *workplace factor* to the total number of *workplace factors*. Once the proportion of *workplace factor*s is established, a relationship is found between the *workplace factor*s and *human errors* discussed in Section 5.3.2.2.

5.3.2.1. Workplace factors proportions

Figures 5.7 to 5.9 display the proportion each *workplace factor* contributes to the total number of *workplace factors* for the three companies, whilst the weighted average proportional contribution across all three companies is provided in Figure 5.10. The *workplace factor*s used are those discussed in Section 4.3.1.4.

The weighted average for *workplace factors* is calculated using *Equation 5.2*:

$$WF_x\ Weighted\ Average\ (\%) = \left(\frac{(\sum WF_{x,C1} \times HE_{x,C1}) + (\sum WF_{x,C2} \times HE_{C2}) + (\sum WF_{x,C3} \times HE_{C3})}{HE_{C1} + HE_{C2} + HE_{C3}}\right) \times 100 \tag{5.2}$$

Where:

$x \in \{FFPE, CP, CWE, SWP\}$

Workplace factor – Count of Specific *workplace factor*

HE – Count of *human error*

C1 – Company 1

C2 – Company 2

C3 – Company 3

For *Equation 5.2* the proportional *workplace factor*s were taken from Appendix I1 and the following values were used for the *human error* count:

HE_{C1} – 30

HE_{C2} – 80

HE_{C3} – 81

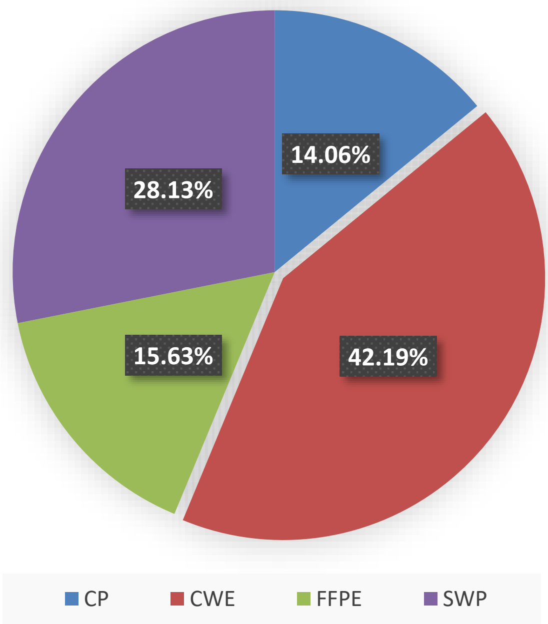


Figure 5.7: Workplace factors proportional contribution company 1

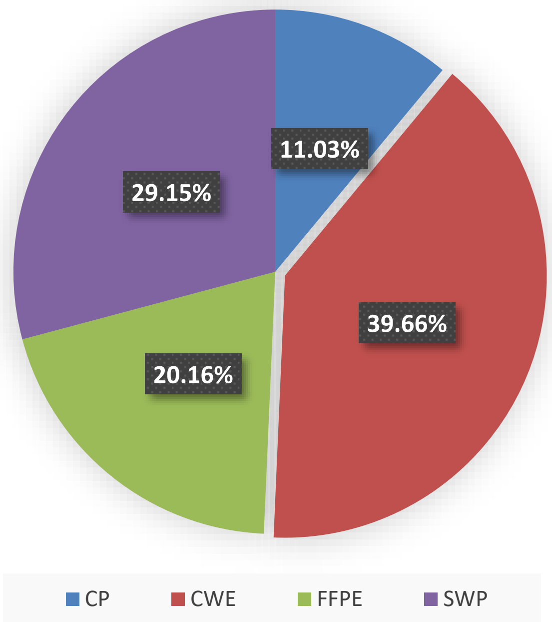


Figure 5.8: Workplace factors proportional contribution company 2

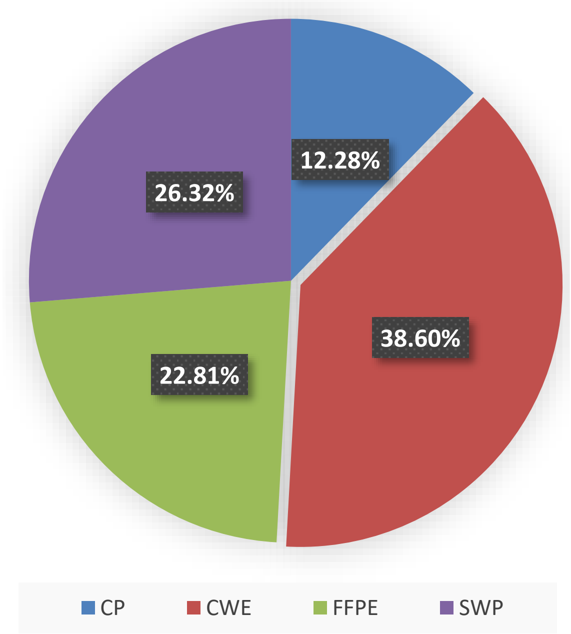


Figure 5.9: Workplace factors proportional contribution company 3

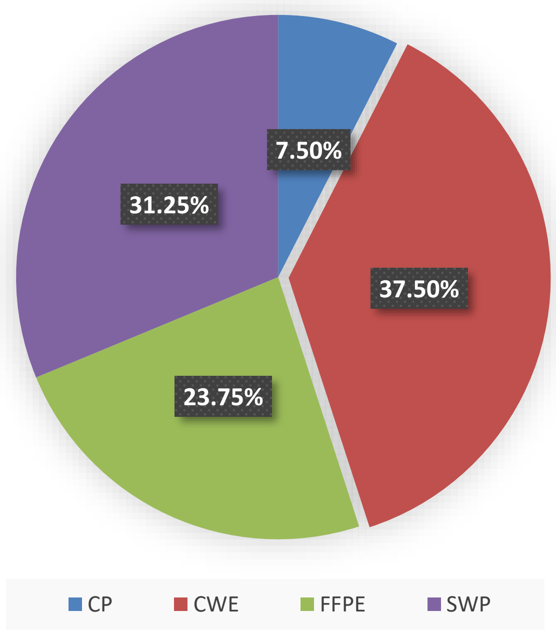


Figure 5.10: Workplace factors proportional contribution weighted average

Figures 5.7, 5.8 and 5.9 show that the largest proportional contribution of *workplace factors* for all three companies is CWE, contributing between 37.50% (Figure 5.8) and 42.19% (Figure 5.9) of the total number of *workplace factor*s. CWE was also found to occur in 56 of the 66 incident reports assessed. Each of the three companies assessed has their own safety systems set in place, however, these findings demonstrate that all three safety systems are most vulnerable to these specific *workplace factors*. When viewing the data from a South African civil construction industry wide perspective (see Figure 5.10), the weighted average demonstrates CWE is again the largest contributing *workplace factor* (39.66%). The two aspects which contribute to CWE-related incidents are the physical (48.67%) and behavioural (51.33%) working environment, as shown in Appendix I2. CWE in terms of the physical environment in many of the assessed incidents consisted of restricted workspaces and inefficient control of hazards present. The behavioural aspects involved scenarios where individuals were not following the correct safety procedure, and this was not identified and/or corrected by the relevant supervisors.

Figure 5.10 indicates that the second largest proportional contribution of *workplace factors* is SWP (29.15%). The high proportion of SWP suggests that work was completed either without procedures or with procedures that did not adequately account for the control of energy and thereby the safety of employees. The procedure dictates the way in which individuals handle the energy present within the system. Inefficient controls along with procedures which do not effectively account for these controls allows the uncontrolled release of energy, resulting in an incident. Work procedures need to be designed and implemented with employee safety as the leading consideration, above that of production, as commonly practiced in the civil construction industry (Kines *et al.*, 2010).

The third-largest proportional contribution to *workplace factors* is FFPE. The weighted average across all three companies (Figure 5.10) indicates that 20.16% of all *workplace factor*s are due to FFPE. In many of the incident reports analysed inadequate equipment or equipment not fit for the intended purpose was used. If correct and efficient equipment were used the likelihood of an incident would decrease. When taking into consideration the design of a task, the correct equipment of an adequate standard to complete the task should be specified. Equipment should be regularly maintained ensuring that no sub-standard equipment is used. Substandard equipment increases the possibility of a mechanical failure resulting in the uncontrolled release of energy.

CP makes the smallest proportional contribution to *workplace factors* with between 7.50% (Figure 5.8) and 14.06% (Figure 5.9) across the three companies and a weighted average contribution of 11.03% (Figure 5.10). CP focuses on whether correctly skilled individuals were allocated a task they were competent in completing. Competent individuals can still perform tasks which result in *mistakes*; this involves competent individuals completing a task with a gap in judgement over the method to complete the task. For example, in many of the assessed incident reports individuals stood behind operating machinery which resulted in a *mistake,* this is a gap in judgement and has no reflection on an individual's competence in completing the task they were performing.

By implication of CP being the lowest contributing *workplace factor*, it is demonstrated that training will not result in the reduction of *workplace factors*, however, many incident reports assessed requested training and discipline as the required corrective action. Training will only be effective in reducing CP, therefore, in reducing 11.03% of incidents. This demonstrates that according to the incident reports assessed, the three companies' methods to prevent or reduce future incidents focus on a method that is only effective on

11.03% of the *workplace factors* occurring. The *workplace factor* which in fact requires the most attention is that of CWE not CP.

When *workplace factor*s are understood, relationships can be developed with *human errors*. Establishing relationships between *workplace factor*s which caused specific *human errors* creates the possibility of reducing specific *human errors* through the reduction of a specific *workplace factor*.

5.3.2.2. Relationships between human errors and workplace factors

Multiple *workplace factor*s often lead to the occurrence of a single *human error* (Bonsu *et al.*, 2016). Figures 5.11 to 5.14 show which *workplace factors* contributed to the specific *human errors* occurring. The contributions of *workplace factors* are given for each of the three companies (Figures 5.11, 5.12 and 5.13) and as a weighted average (Figure 5.14). The data associated with Figures 5.11 to 5.14 is given in Appendix I3.

As demonstrated in Figure 5.4, 50.67% of all *human errors* are *mistakes*. Figure 5.11 provides insight as to the contribution of *workplace factors* to *mistakes*.

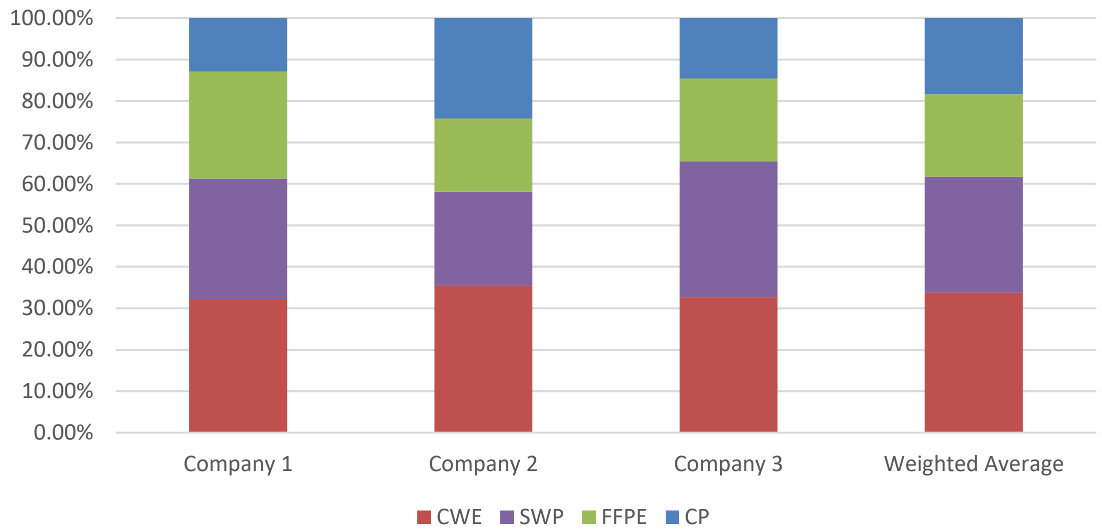


Figure 5.11: Mistakes and associated workplace factors

The largest contributing *workplace factor* to *mistakes* is CWE, contributing between 32.26% and 35.48% across the three companies, with a weighted average of 33.81%. The CWE-related incidents assessed were categorised as either due to the physical or behavioural work environment.

For many of the assessed incidents occurring due to the physical work environment it is found that effective controls were not in place to prevent the release of uncontrolled energy, and this was not picked up by the supervisory layer responsible to control the work environment. The behavioural aspect found that workers were possibly unaware that they were not following the correct work procedure and they were not restricted in proceeding with unsafe behaviour. Appendix I2 demonstrates that physical environment and behavioural environment for *mistakes* make up 57.69% and 42.31% of CWE respectively.

SWP contributes between 22.58% and 32.73% to *mistakes* across the three companies, with a weighted average contribution of 27.90%. SWP requires that there were procedures in place for the completion of a task and that these procedures adequately identify the hazards present during the task, well as the controls that should be in place to prevent the uncontrolled release of the underlying energy. In these instances, *mistakes* occur because work procedures are absent or do not offer the individual a safe method of performing the task (i.e. The procedure is incorrect). In addition, changes in the environment could result in a normally adequate procedure to become inadequate due to a change in the magnitude of the underlying energy.

FFPE contributes between 17.74% and 25.81% to *mistakes*, with a weighted average of 19.97%. FFPE relates to the use of equipment which is not fit for purpose either by being the wrong tool for the job or by being of substandard quality to perform the job safely. Individuals will use equipment that they think is correct; however, this equipment is not always correct for the completion of the specific task.

The lowest *workplace factor* contributing to *mistakes* is CP, at a weighted average of 18.33%. CP describes the competency of individuals being inadequate for the task that they are required to perform. Of the incidents assessed where CP led to *mistakes* occurring, a large number occurred due to individuals not being verified as competent in carrying out the task.

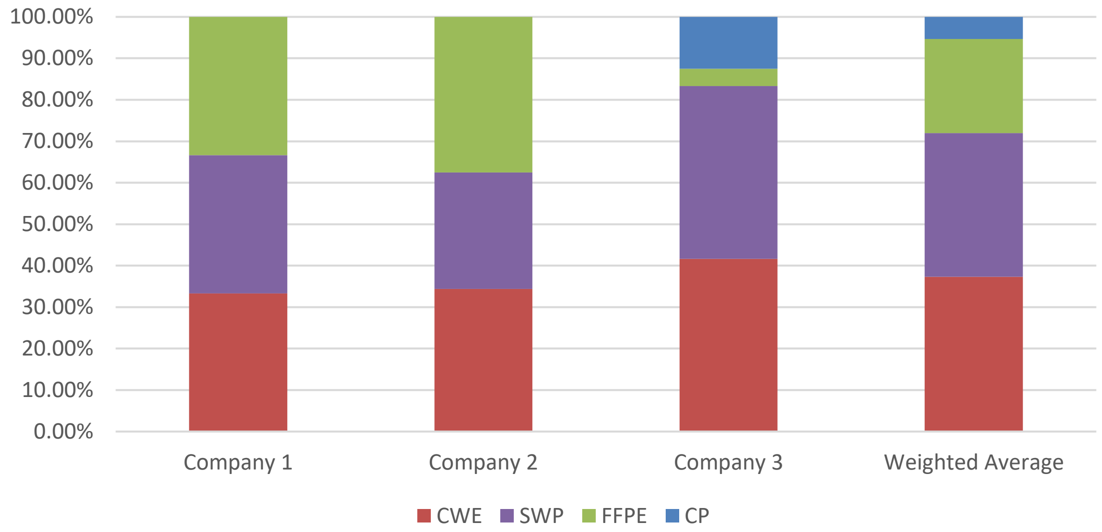


Figure 5.12: Slip and lapse and associated workplace factors

Slip and lapse describes a situation where there is a design flaw or change in the task design which the worker is unaware of. The result of this is the worker performing a task as normal, however, a *human error* results due to the design flaw or change in the task design.

As shown in Figure 5.12, CWE and SWP are the leading contributors to this form of *human error*, with weighted averages of 37.30% and 34.69% respectively. As seen in Appendix I2, the CWE-related *slips and lapses* are broken up into 40% behavioural and 60% physical working environment. The behavioural aspects primarily occurred due to operational decision making, in which individuals often attempt to complete a task in ''autopilot' and thereby not accounting for additional factors and/or changes around them. The physical environment in many cases revolved around ineffective controls in the form of warning systems. A common error in the physical work environment was controls such as warning signals that could not effectively control individual's actions around hazards.

SWP accounts for *slip and lapse* incidents where there was no procedure or the procedure did not account for changes in the task design which led to a *slip and lapse*-related incident. When a task design changes, SWP should ensure that the workers are aware of the deviations which they must account for and provide guidance on what to do if it is not safe to continue with the task.

FFPE contributes 22.71% to *slips and lapse*-related *human errors. Slips and lapses* association with *human error* involved many incidents where individuals were performing the same task; however, small variations in equipment led to incidents. Small variations include equipment which individuals were not used to using. The variation in equipment often resulted in the equipment not being fit for purpose. The individual performs the task in operational decision-making mode, not realising the change in the equipment, resulting in an incident.

Only 5.30% of all *slip and lapse*-type errors were contributed by CP. This contribution occurred when individuals were placed on tasks where they were not made aware of design changes and did not have the required skill set to perform the task safely with the slight variations.

Routine violations result in an individual performing a task in a manner which is commonly practised but directly disobeys procedures or rules set out. It is evident in Figure 5.13 that CWE makes a contribution of 55.50% to *routine violations*. According to the incident reports this is primarily made up of behavioural environment (83.33%), as seen in Appendix I2. The behavioural work environment makes a very large contribution to *routine violations*, as the violation is not identified and/or corrected by supervisory or management individuals. Individuals performing the task continue to do so in a manner of their own choosing, often not according to safety procedures, resulting in an incident. Pete Kinas (2010), found that an increase in verbal safety communication by supervisors resulted in a significantly increased level of safety on the construction site (Kines *et al.*, 2010). Improvement of the behavioural work environment can be effected through verbal correction of violations to reduce incidents and increase safety.

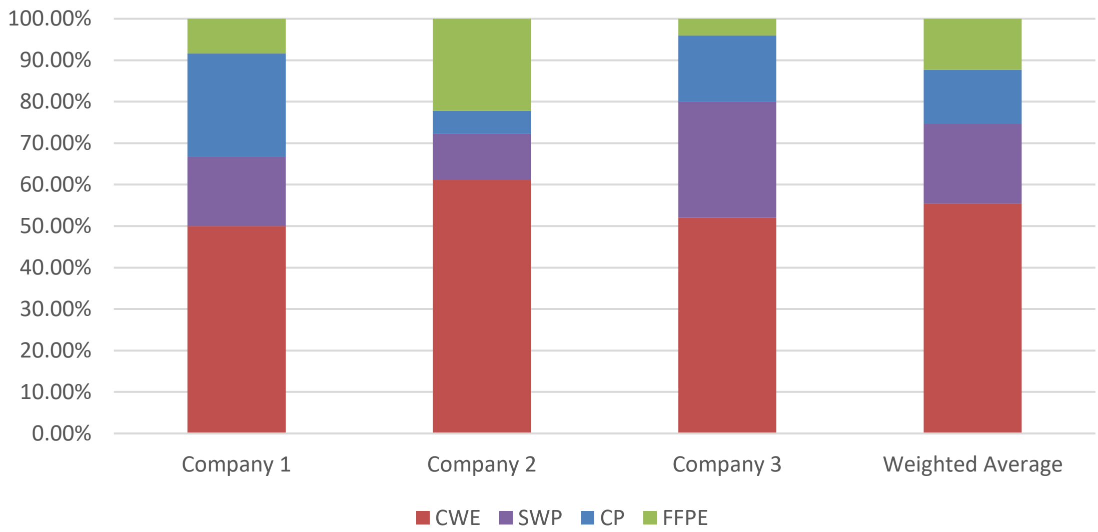


Figure 5.13: Routine violations and associated workplace factors

The second-largest *workplace factor* is SWP, which contributes 19.15%. The connection between SWP and *routine violations* is related to instances where the work procedure did not effectively cover all aspects of the task. Individuals potentially disobeyed the procedure to perform a task in a manner they thought was more effective. SWP should ensure that workers do not purposely stray from procedures due to the procedure not being detailed sufficiently.

CP and FFPE make up the remaining 25.35% of *routine violations*, with a weighted average of 13.04% and 12.31% respectively. The connection between CP and *routine violations* is when individuals purposely disobey procedures because they are incompetent in performing the task. FFPE involves instances where individuals are using equipment that was not prescribed but they think is more efficient for the task. This proves to be incorrect as in many incidents the equipment chosen is not fit for purpose.

Figure 5.14 displays the proportional contribution of *workplace factors* involved in *latent error*. As it has been established in the definition of a *latent error*, these *workplace factors* have no associated *human error*. Figure 5.14 demonstrates FFPE has a strong relationship with *latent error* with a 58.50% contribution to the weighted average. The high association with FFPE in the case of *latent error* involved more incidents of equipment which failed than equipment not suited to the purpose of the task. This is clear as *latent errors* involve no *human error*, therefore, the individual working with the equipment was not aware that it was substandard.

Figure 5.14: Latent error and associated workplace factors

CWE is the second-largest contributing factor to *latent errors*, with a proportional contribution of 32.37%. *Latent errors'* high association with CWE is primarily due to the physical work environment (83.33%) as seen in Appendix I2. Control systems set out are unable to effectively control the energy associated with the hazards, therefore, management systems have failed in their task. There is no *human error* as the physical environment as set out was incorrectly controlled by the management systems.

Figure 5.15 compares the weighted average for each relationship between the *workplace factors* and the *human errors* they cause. This figure indicates the high occurrence of CWE in *routine violations* in comparison to the other *human errors*. Shown in Figure 5.15 is the contribution of SWP to both *mistakes* and *slips and lapses* is relatively large compared to the other *human errors*. *Latent errors* high contribution due to SWP is made very evident in this comparison.

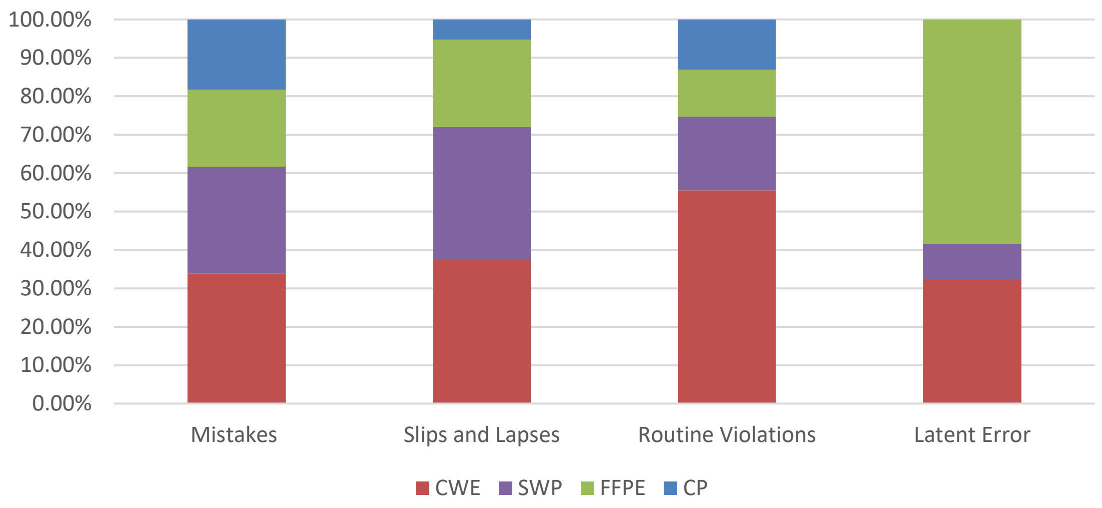


Figure 5.15: Human errors and weighted average of associated workplace factors

The data presented in this section aims to build relationships between the type of *human error* and the *workplace factors* which caused the *human error*. Figures 5.11 to 5.14 define the relationships between the *human errors* and the associated *workplace factors*. For each of the *human errors* across the three companies there were similar contributions seen by the respective *workplace factors*. The consistency does indicate that there is possibly an industry-wide trend in terms of *workplace factors* which cause the *human errors*. Figure 5.15 provided a comparison of the *workplace factors* weighted averages proportional contribution to each *human error*.

Relationships are now found between the *organisational factors* and the specific *workplace factors* that are caused by the *organisational factors*. *Organisational factor*s provide understanding into the ways in which management level individuals can improve safety systems in the workspace.

5.3.3. Organisational factor causation trends

*Organisational factor*s revolve around management level systems and demonstrates how the management layer of the civil construction company contributed to the failure pathway (Kines *et al.*, 2010). Management systems which prove inefficient in correctly managing safety within the organisation contribute as *organisational factors*. *Organisational factors* cause *workplace factors* which in return cause *human errors*. Section 4.3.1.5 discussed the concept of *organisational factors* in more detail.

Organisational factors are initially analysed using a proportional analysis which identifies the leading *organisational factors* which contributed to incidents. In total, 485 *organisational factors* are analysed. After the proportional analysis, relationships are found between the *organisational factors* which cause the specific *workplace factor*s. These relationships build understanding of how the improvement in specific *organisational factor*s can contribute to reducing or eliminating specific *workplace factor*s.

5.3.3.1. Organisational factor proportions

Organisational factors demonstrate the relationships to incidents caused by failure in management systems. The proportional contributions of each *organisational factor* to the total number of *organisational factors* is given for each of the three companies (Figures 5.16, 5.17 and 5.18) and as a weighted average (Figure 5.19). The weighted average calculation for *organisational factors* is given in *Equation 5.3* which demonstrates how the data in the table in Appendix J1 was obtained*:*

$$OF\ Weighted\ Average\ (\%)$$
$$= \left(\frac{(\sum OF_{C1} \times WF_{C1}) + (\sum OF_{C2} \times WF_{C2}) + (\sum OF_{C3} \times WF_{C3})}{WF_{C1} + WF_{C2} + WF_{C3}}\right) \times 100 \qquad (5.3)$$

Where:

$x \in \{auditing\ and\ monitoring, communication, design, hazard\ identification,$

$leadership, learning\ from\ incidents, procurement, risk\ management,$
$Strategic\ Planning, Task\ Design, Training\ and\ Competence\}$

OF	–	Proportion of Specific *organisational factor* for the relevant company.
WF	–	Count of total *workplace factor*s for the relevant company.
C1	–	Company 1
C2	–	Company 2
C3	–	Company 3

For *Equation 5.3* the proportional *organisational factor*s are shown in Appendix J1 and the following values were used for the count of *workplace factors*:

WF_{C1} – 57
WF_{C2} – 118
WF_{C3} – 109

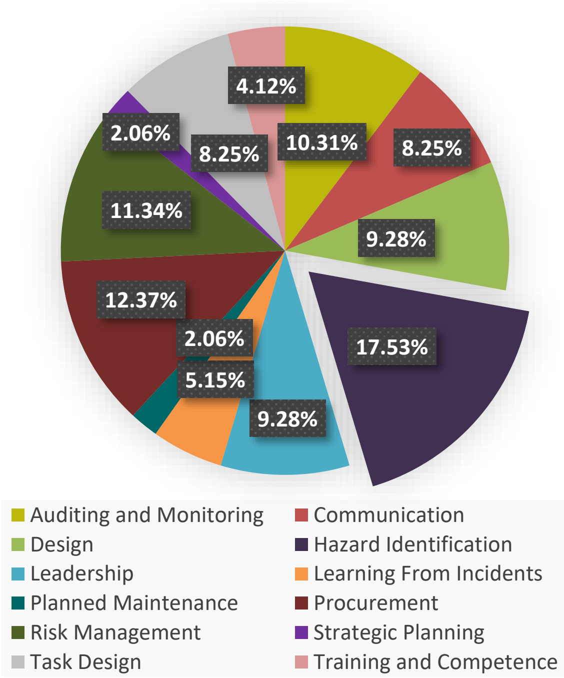


Figure 5.16: Organisational factors proportional contribution company 1

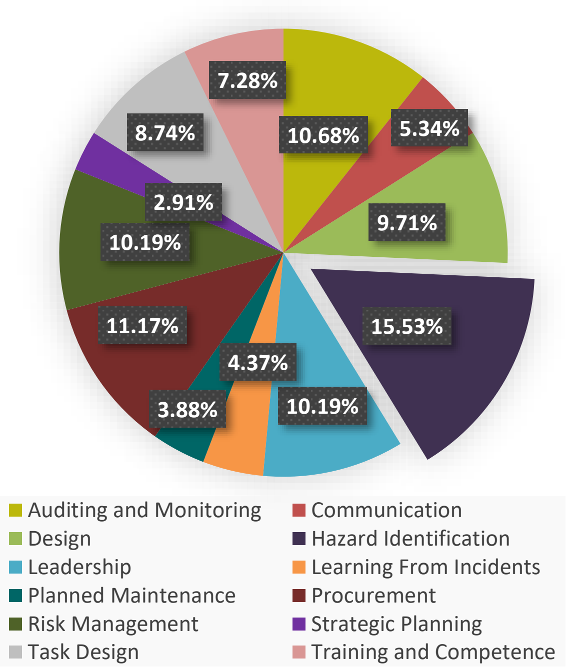


Figure 5.17: Organisational factors proportional contribution company 2

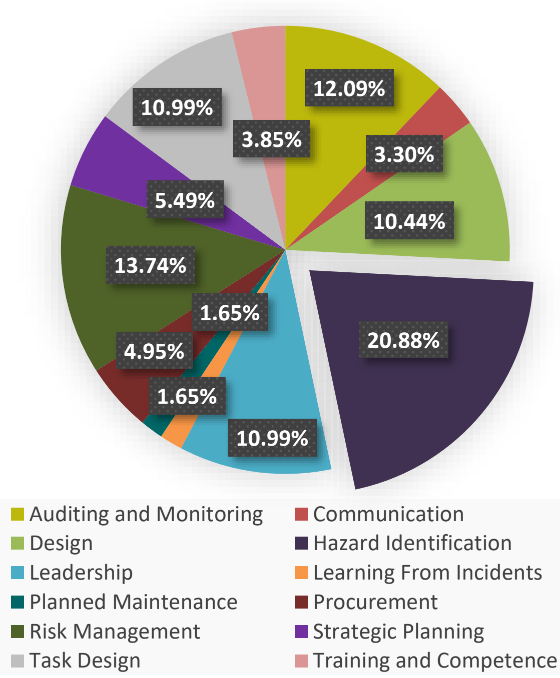


Figure 5.18: Organisational factors proportional contribution company 3

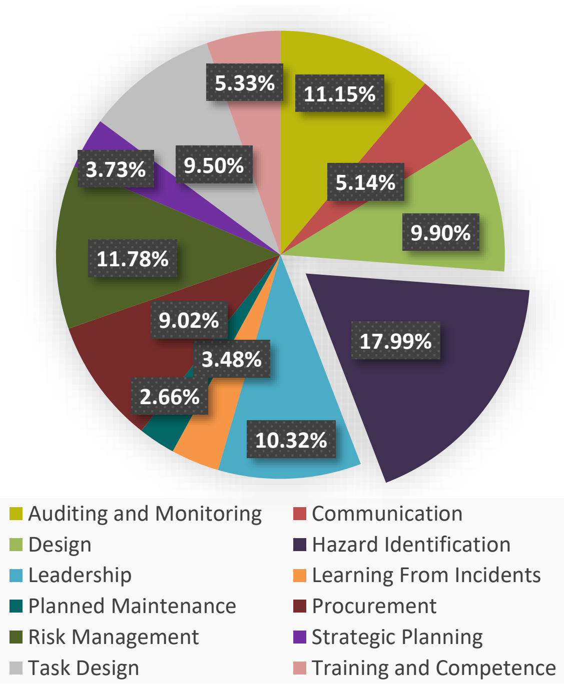


Figure 5.19: Organisational factors proportional contribution weighted average

Figures 5.15 to 5.18 demonstrate that the leading *organisational factor* for each of the three companies is *hazard identification*, with a proportional contribution ranging from 15.53% (Figure 5.17) to 20.88% (Figure 5.18) and a weighted average of 17.99% (Figure 5.19). *Hazard identification* revolves around the organisation's development of systems which both identifies all hazards present as well as prescribes suitable controls required for the magnitude of the hazard's energy. The application of effective *hazard identification* allows for individuals to know what hazards are present in the current workspace.

The second- and third-largest contributing *organisational factor*s according to the weighted averages are *risk management* (11.78%) and *auditing and monitoring* (11.15%). *Risk management* is in relation to situations where there is a known risk which the organisation has chosen to not use effective risk control methods in dealing with it. In many of the assessed *risk management*-related incidents, the individuals involved did not deal with the risk as they underestimated its ability to cause harm. *Auditing and monitoring* involved situations whereby the organisation failed to properly monitor whether the controls are in place and whether the controls could effectively control the energy. In many of the incident reports assessed supervisory and management level individuals failed to regularly monitor the control effectiveness. Failure to assess these controls led to them being proven to be inefficient in controlling the energy source.

Companies 1 and 2 demonstrate much higher proportions in *procurement* contributing to *organisational factors* compared to company 3, with contributions of 12.37% (Figure 5.16) and 11.17% (Figure 5.17) compared to the 4.95% (Figure 5.18) contribution by company 3. In the assessed incident reports *procurement* often occurred due to the organisation using equipment purchased which only had the basics in terms of safety features or was unreliable. Availability and cost seemed to have been prioritised over safety features when purchasing the equipment.

When viewing the data across the three companies, it is found that the *organisational factors'* proportional contributions remain fairly consistent. Consistency was prescribed as instances where there was a proportional contribution deviation of 5% or less when comparing the minimum and maximum contribution for each *organisational factor*. According to the prescribed allowable deviation for consistency it is found that the *hazard identification* (company 2 compared to company 3) and *procurement* (companies 1 and 2 compared to 3) were the only factors that were inconsistent across the three companies. This analysis aimed to prove that three separate companies have similar weaknesses in *organisational factors* which resulted in incidents occurring.

Rankings are given for the *organisational factor* proportional contributions of each of the companies in Appendix J2. The ranking system is to provide information regarding comparison of the leading contributors of *organisational factors* for each company. Where *organisational factors* are highlighted in grey they are equal in ranking and percentage.

Section 5.3.3.1 describes which *organisational factor*s contribute the most to the incidents assessed. In the next section the failure pathway builds on this to show relationships as to which *organisational factors* cause specific *workplace factors*.

5.3.3.2. Relationships between workplace factors and organisational factors

Finding the relationship between *organisational factor*s and *workplace factor*s deepens our understanding of the causation pathway which lead to an incident occurring. The relationships between *human errors* and *workplace factor*s were established in Section

5.3.2.2. Therefore, to link *organisational factors* and *human errors*, the relationship between *organisational factors* and *workplace factors* must be understood. Figures 5.19 to 5.24 show the proportional contribution of *organisational factors* which caused the specific *workplace factor*. The data points for Figures 5.19 to 5.24 are given in Appendix J3.

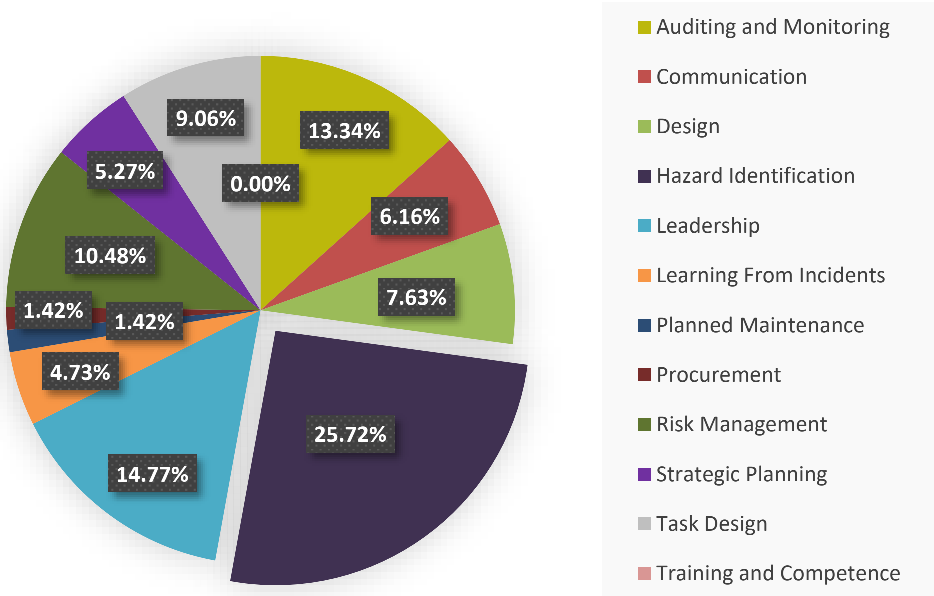
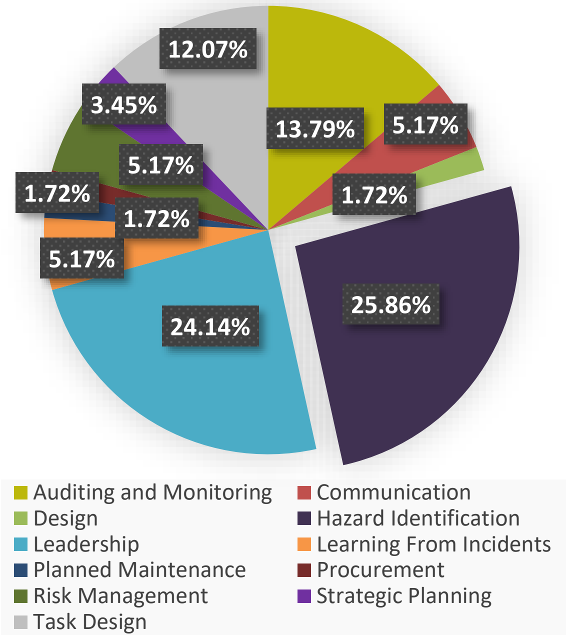


Figure 5.20: Organisational failures causing CWE failures

As shown in Figure 5.10, CWE is the largest contributing *workplace factor* to incidents, demonstrating the need for an improvement in the control of work environment. Figure 5.20 displays the proportional contribution of the *organisational factors* which resulted in CWE-related incidents occurring. Figure 5.20 demonstrates that *hazard identification* is the leading *organisational factor* associated with CWE, contributing 25.72%. As shown in Appendix J4, 51.72% of *hazard identification*-related CWE incidents were behavioural whilst 48.28% were related to the physical work environment. Many incident reports assessed demonstrated a lack of correct identification of on-site hazards present within the working environment. In addition, where hazards were identified, they were ineffectively controlled for this type of working environment. CWE aims to control the work environment. In order to control the work environment *hazard identification* is a vital aspect.

Following *hazard identification*, *leadership* (14.77%) and *auditing and monitoring* (13.34%), were the largest contributors to CWE-related incidents. As shown in Appendix J4, 93.33% of CWE incidents resulting from *leadership* failure, were due to the behavioural working environment. Many *leadership*-related CWE incidents resulted from the incorrect behaviour of individuals not being corrected by supervisory or management-level individuals. *Auditing and monitoring* shown in Appendix J4 has a small variation between behavioural (44.44%) and physical (55.56%) working environment. The incidents reported suggested situations where management-level individuals failed to check the condition of the construction workspace. The workspace requires the correct and effective controls to be in place, ensured by supervisory and management-level individuals.



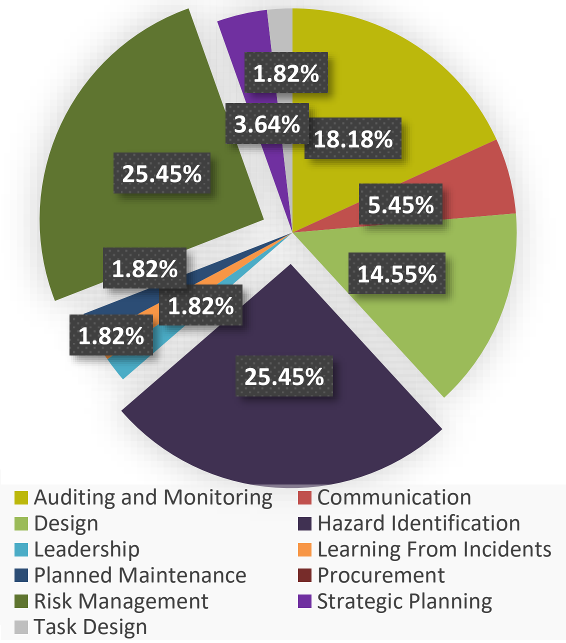


Figure 5.21: Organisational factors linked to behavioural work environment

Figure 5.22: Organisational factors linked to physical work environment

Figures 5.20 and 5.21 show the proportional contribution of the *organisational factors* which caused each of the two types of CWE, behavioural and physical work environment (Appendix J5). The behavioural work environment seen in Figure 5.21 shows large contributions from *hazard identification* (25.86%) and *leadership* (24.14%). *Hazard identification* is the largest contributor to both the behavioural and physical work environments. This is consistent with the contribution *hazard identification* made to the total CWE. *Leadership*, however, contributes 24.14% (Figure 5.21) to the behavioural work environment compared to the 14.77% (Figure 5.20) contribution to the total CWE. *Leadership* makes a minimal contribution of 1.82% (Figure 5.22) to the physical work environment. The large contribution of *leadership* to the behavioural work environment describes a situation in which safety leadership in civil construction is inadequate. Safety leadership is where leadership makes a conscious effort to improve safety in highly hazardous and complex working environments (Wu *et al.*, 2016). It has been found by researchers that ineffective safety leadership has resulted directly in the increase of incidents and injuries in the workplace (Mullen and Kevin Kelloway, 2009). Safety leadership revolves around management level individuals practising safety principles that they instruct others to follow, providing an approach which focuses on following the correct safety procedures is promoted.

For the physical work environment, it is found that *hazard identification* (25.45%) and *risk management* (25.45%) have the largest proportional contribution. *Hazard identification* is once again proportional with its total CWE contribution, which has been discussed relating to Figure 5.20. *Risk management* involves using effective risk control methods, which assess the risk and apply the relevant controls using knowledge gained through previous risk management practices (Bonsu *et al.*, 2016). The physical work environment requires more effective means to control risk, for example the use of a flag to slow down traffic. This method attempts to deal with the risk in a means which if not adhered to, will not effectively control the risk. The physical work environment needs to be maintained with effective controls that can effectively contain the unwanted release of energy. This ensures that the means chosen in dealing with *risk management* is capable of effectively controlling the magnitude of the hazards energy.

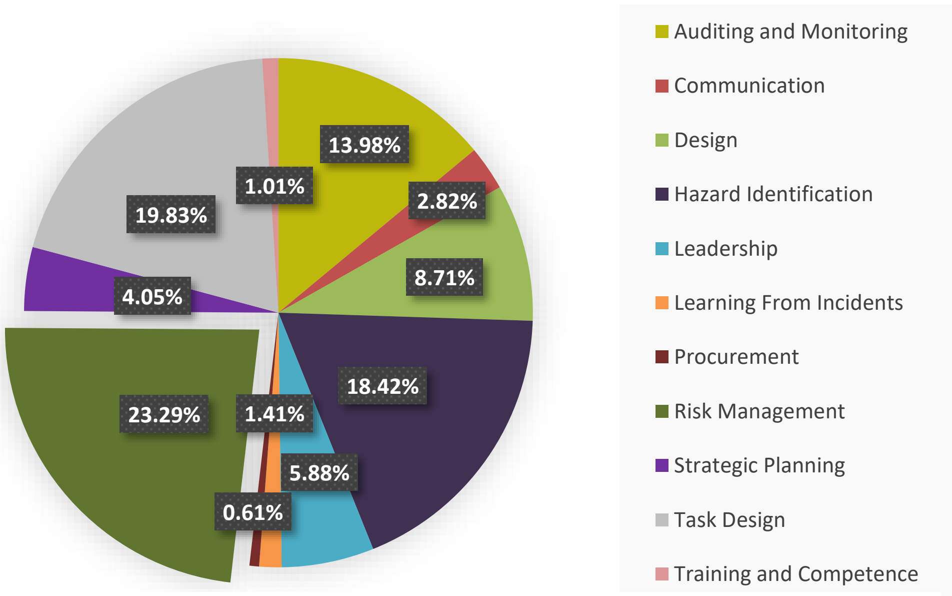


Figure 5.23: Organisational failures causing SWP failures

Figure 5.23 shows the proportional contribution of *organisational factors* to SWP-related incidents. At 29.35%, SWP makes the second-largest proportional contribution to *workplace factors*. For SWP the largest contributor to incidents is *risk management*, contributing 23.29%. *Risk management* is the use of effective risk management methods in order to deal with a risk known to the organisation. The relationship between SWP and *risk management* is due to the use of substandard safety procedures, or to non-existent safety procedures, in order to deal with risk that the organisation is aware of.

Task design and *hazard identification* make up the second- and third-largest contributors with 19.83% and 18.42% respectively. *Task design* ensures that all risks have been identified, and the risk has then been dealt with through correct risk control methods. SWP's relation to task design is found where procedures did not identify risk and therefore suitable methods of risk control were not implemented. *Hazard identification* and SWP build the relationship based on procedures being created before correctly identifying the hazards present. Work procedures should be developed which can effectively control the magnitude of the identified hazard's energy. In doing so the procedure acts as a very necessary control. If work practices fail to account for risk and the correct control of hazards, incidents are likely to occur due to work procedures being substandard.

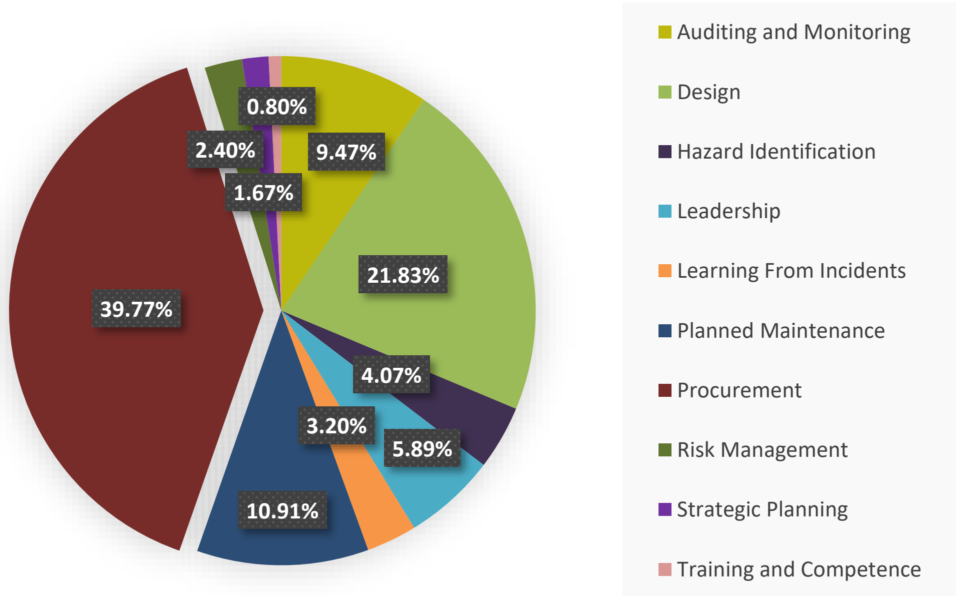


Figure 5.24: Organisational failures causing FFPE failures

Figure 5.24 shows the proportional contribution of *organisational factors* to FFPE-related incidents. The largest contributing *organisational factor* to FFPE is *procurement* at 39.77%. *Procurement* ensures that the equipment bought is of a suitable standard and is the correct equipment for the desired task. The relationship between FFPE and *procurement* in the incident reports assessed often contained cases where the equipment bought for the task was not fit for purpose or lacked essential safety features.

Design (21.83%) is the second-largest *organisational factor* leading to FFPE-related incidents. The use of equipment which lacks clear safety standards in order to complete the task is categorised as *design*. FFPE and *design* are then related through the use of equipment that does not fit the purpose in terms of required safety features. *Planned maintenance* contributed 10.91% to the occurrence of FFPE-related incidents. *Planned maintenance* ensured equipment was in correct working order through regular inspections and/or maintenance. The incident reports involving *planned maintenance* which caused FFPE-related incidents frequently involved the use of equipment which was not in correct working order. Individuals maintaining the equipment should have realised this through regular inspection. If this equipment was maintained correctly the probability of an incident occurring would have been greatly reduced.

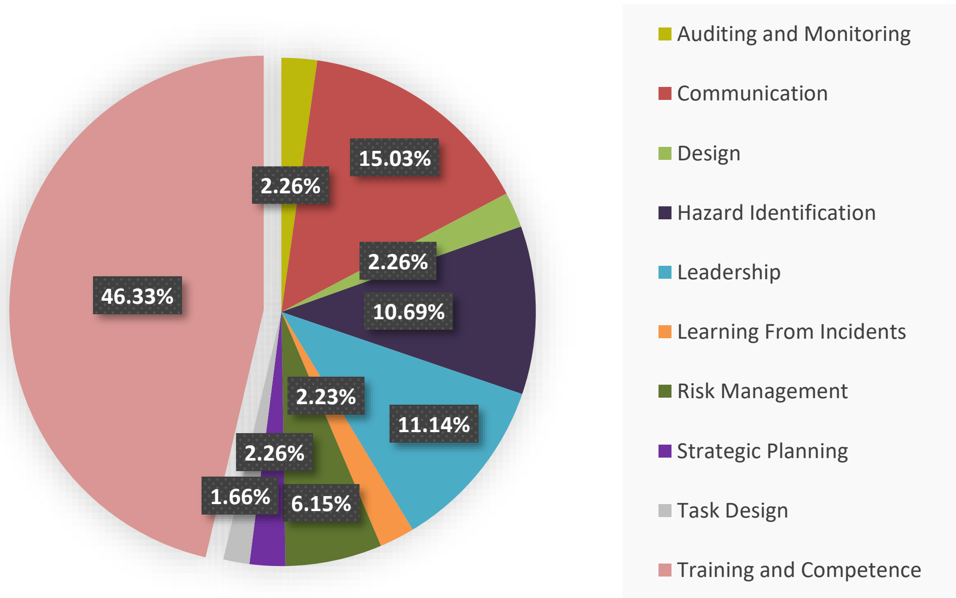


Figure 5.25: Organisational failures causing CP failures

Figure 5.25 depicts the relationship between CP and the associated *organisational factors*. The leading *organisational factor* which resulted in CP is *training and* *competence* which contributes 46.33% to the total. In many of the incident reports *training and competence*-related CP incidents occurred due to workers not understanding the correct method to complete a certain task. *Training and competence* ensures that individuals are trained in the correct method to perform a task with safety considerations taken into account. *Training and competence* has a relationship with CP as it ensures that individuals receive the correct training in the completion of the task and are competent in this task.

Communication (15.03%) and *leadership* (11.14%) are responsible for resulting in the next-largest contribution to CP. The incident reports found that a large number of CP incidents occurred due to individuals not understanding the correct safety protocol. The inability to understand the correct safety protocol leads to the root cause of the incident, being the *organisational factor communication.* In the case of *leadership* it is found that violations in the completion of task is not being corrected by supervision or management. In the incident reports, a large number of CP-related incidents occurred due to incorrect safety practices. These practices were not corrected and thus occurred due to *leadership* being ineffective. As found for the behavioural work environment, CP is also affected due to safety leadership being ineffective.

This section has shown relationships between *organisational factors* and the specific *workplace factors* that they cause. In this section, the relationships have been explained, providing the reason that strong relationships exist between specific factors. The relationships support the idea that management systems can be improved to reduce specific *organisational factors*, in the process reducing specific *workplace factors*.

5.4. Major incident causation failure pathways

The failure pathway involved in incident causation is developed from *organisational factors* which cause *workplace factors*, which then cause *human errors* and incidents to occur. Focusing on the South African civil construction industry, more specifically the three companies assessed, a definitive failure pathway is established in Figure 5.26. The failure pathway depicts the leading incident causations for each incident causation factor.

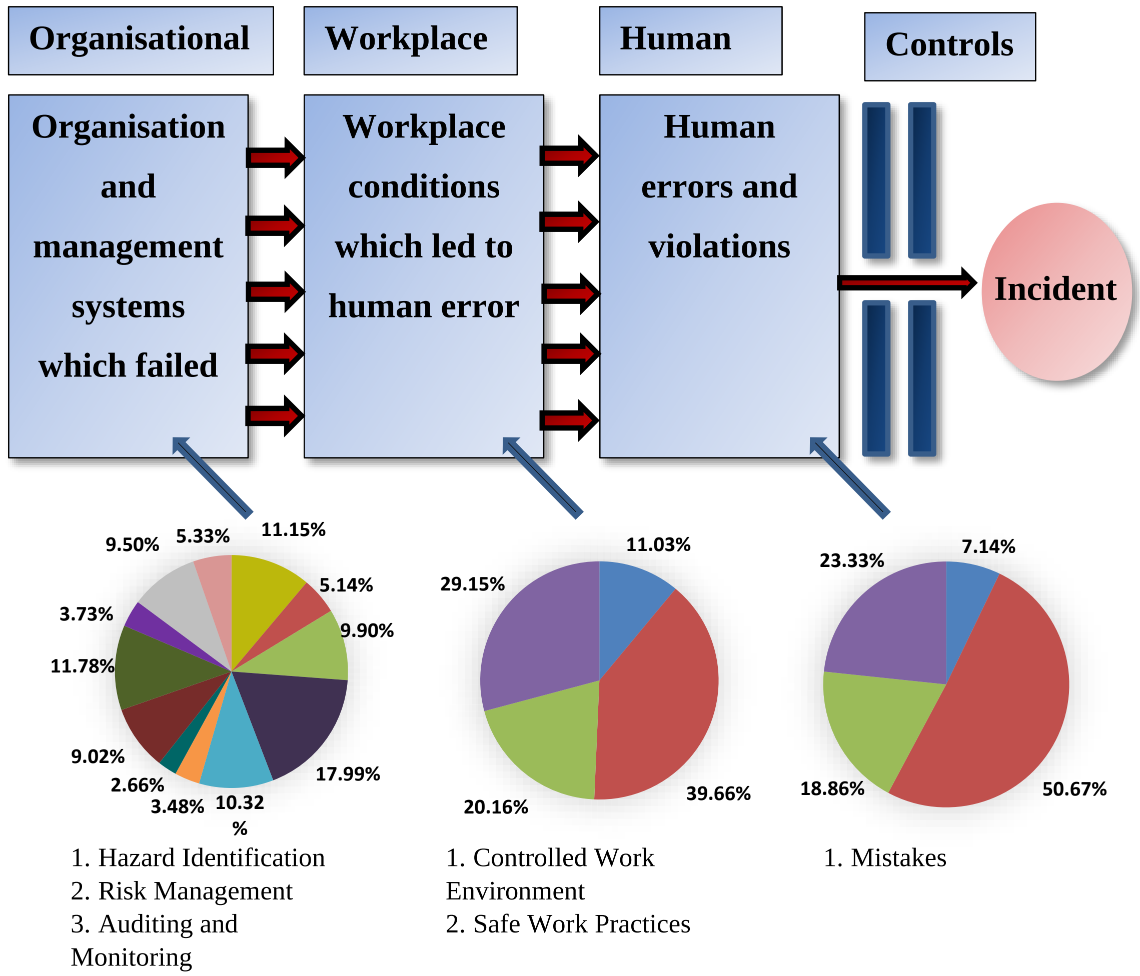


Figure 5.26: Major incident causation failure pathway

When reviewing the incident reports assessed it was found that a majority of these recommended the use of either disciplinary action or training as the chosen method to deal with the individuals involved. Viewing the incident failure pathway in Figure 5.26 it becomes evident that training and discipline is not effective in reducing incidents in the South African civil construction industry.

As seen in Figure 5.26, 50.67% of *human errors* involved in incidents are *mistakes*. In order to reduce the occurrence of *mistakes*, management systems should implement effective controls which prevent uncontrolled energy release. Training teaches the way to perform specific tasks but is not effective if individuals are placed on the wrong task, whilst disciplinary action does not solve the gap in knowledge of the individual. This provides the evidence that training and disciplinary actions will not effectively control *mistakes*. In order to understand why individuals are performing tasks without the correct knowledge in this task, the *workplace factors* are analysed.

CWE (39.66%) and SWP (29.15%) are the leading *workplace factors* across the assessed incidents. CWE describes a work environment within which both the physical and behavioural work environments are under control. For the work environment to be under control, on-site leadership should ensure a safe working environment whereby hazards are effectively controlled. To ensure that the individuals performing the tasks have a procedure which prioritises safety, effective SWP is vital. CWE and SWP cannot be effectively reduced through training and discipline as they are not the fault of the individual who performs the *human error*. The management systems should effectively account for on-site leadership and procedures which control the hazards at their source.

The leading *organisational factor* is *hazard identification*, contributing 17.99%. Hazards should be clearly identified to all workers and accounted for in the development of resilient controls which prohibit uncontrolled energy release. These controls are to be of an adequate standard to account for the magnitude of the hazard's energy. Management systems are to set out these controls. As this is the leading *organisational factor* it demonstrates management has failed to do this. This once again indicates that discipline and training are not a correct response, as management needs to improve their own systems in order to prevent harm to individuals performing the tasks. *Auditing and monitoring* as the third-highest contributing *organisational factor* also indicates that management has not been proactive in continually assessing that current controls are up to standard. *Risk management* also indicates that management has been unresponsive in correctly assessing the level of risk individuals are exposed to along with the means to deal with this risk.

The method of training and disciplinary action in dealing with incidents is ineffective and will not result in the reduction or prevention of future incidents. The incidents need to be dealt with at an organisational level, turning focus away from a 'culture of blame' directed at the individuals involved. In order to deal with these incidents, management systems need to be reassessed ensuring that they apply effective controls to on-site hazards. The use of effective controls and the identification of hazards potentially have a direct effect on reducing incidents and removing the potential of *human error* occurring.

5.5. Chapter 5 summary

Chapter 5 explained the data analysis process and showed the key findings for the study. Section 5.3.1 started with the discussion of the *human errors* involved in the incident reports analysed. Across the 66 incidents, it was found that 191 *human errors* had occurred that led to these incidents. The proportional contribution of *human errors* developed the conclusion that *mistakes* contributed 50.67% of *human errors* across the three companies. Section 5.3.2.1 provided the proportional contribution of *workplace factors*, where 284 *workplace factors* were found and analysed. The leading *workplace factor* was found to be CWE which contributed a weighted average of 39.66% of all *workplace factors*. Section 5.3.2.2 found relationships between the *human errors* and the *workplace factors* which caused them. Analysing each *human error*, it was found that for *mistakes*, *slips and lapses*, and *routine violations* CWE made the largest contribution. Section 5.3.3.1 analysed the proportional contribution of each *organisational factor*, where 485 *organisational factors* were analysed. The proportional analysis found that *hazard identification* was the leading *organisational factor*, with a contribution of 17.99% to the weighted average. Section 5.3.3.2 found relationships between the *organisational factors* and the *workplace factors* they caused. The findings of Section 5.3.3.2 found the following largest contributors for each *workplace factor*; CWE and *hazard identification* (25.72%), SWP and *risk management* (23.29%), FFPE and *procurement* (39.77%), CP and *training and competence* (46.33%). Strong relationships have been found between the *workplace factors* and the *organisational factors* which cause them. The relationships found provide links between the three incident causation factors, creating an understanding of the failure pathway that leads to an incident occurring.

Chapter 6.

Conclusions and recommendations

6.1. Introduction

In Chapter 5 the data analysis and results have been summarised and presented to the reader. The analysed data provided information regarding the leading incident causation factors for the three South African civil construction companies. A South African civil construction industry-wide perspective is gained through the weighted average across the three companies.

Chapter 6 aims to summarise this study and the insight gained into incident causation within the South African civil construction industry. Section 6.2 summarises the findings of the study by providing key conclusions drawn. Chapter 6 ends by demonstrating the possible benefits this study has made to the South African civil construction industry (Section 6.4) and the recommendation of future work (Section 6.5) that could be developed from this studies key findings. Concluding that this study has made significant findings that could possibly benefit the industry in future understanding of incident causation.

6.2. Conclusion

This section summarises the major findings of the study drawing out the key conclusions developed. Key conclusions are those which are most relevant to the objectives and aims set out in Sections 1.4 and 1.6. There are five key conclusions which are discussed below.

Relationships are proven to exist between the incident causation factors, namely between *human errors* and *workplace factors,* and between *workplace factors* and *organisational factors*. Shown and explained in Sections 5.3.2.2 and 5.3.3.2, strong relationships do exist between particular incident causation factors. The primary relationship is found between the leading incident causation factors, where it is found that *mistakes* primarily occur due to CWE failures and CWE failures are primarily occurring due to *hazard identification.*

These relationships show that if a work environment is not being controlled in both the physical and behavioural aspects, *mistakes* are likely to occur on a more common basis. These relationships also show that in order for the working environment to remain under control, the identification and correct control of all hazards present is essential. The relationships develop an understanding of how the majority of incidents are occurring within the South African civil construction industry. Understanding of these relationships is essential in preventing the future occurrence of incidents.

The leading incident causation factors were found in Section 5.3.1.1, 5.3.2.1 and 5.3.3.1. The leading incident causation factors were *mistakes*, CWE and *hazard identification*, showing similarity to the leading relationship between the incident causation factors. *Mistakes* as the leading *human error* were found to result in 50.67% of *human error*, therefore, accounting for more than half of the *human error* which occurred. CWE as the leading *workplace factor* accounted for 39.66% of *workplace factors*. CWE was also found to have occurred in 56 of the 66 incident reports assessed. This indicates that CWE can be considered as playing a role in the majority of incidents occurring. *Hazard identification* occurred in 17.99% of *organisational factors*. The leading source of the development of the failure pathway is the leading *organisational factor* which is *hazard identification*.

The findings from the comparison of the South African civil construction and mining industries incident statistics, Section 4.2.1, showed that the South African civil construction industry requires improvements in their methods of incident control. This comparison identifies that in terms of fatality frequency rate, the civil construction industry has a lack of control over the occurrence of fatalities. The mining industry has managed to successfully reduce their fatality frequency rates. In terms of injury frequency rates, both industries have been successful in making steady reductions. The key difference is that civil construction has an injury frequency rate substantially greater than that of mining. Civil constructions high injury frequency rate and uncontrolled fatality frequency rate shows an industry which is struggling to control or reduce the occurrence of incidents.

Methods used in dealing with incidents are often found to centre around training and discipline of the individuals involved. Training and discipline would essentially only be effective in reducing CP related incidents, which account for 11% of all *workplace factors*. Having knowledge of the leading incident causation factors and the relationships between incident causation factors shows that other methods are required for effective control of incidents. Dealing with incidents should take a more proactive approach, not focusing on the reactive approach of disciplining the individuals performing the task.

The final key conclusion drawn from this study is that incidents are not occurring as the fault of *human error*. Incidents are occurring due to a failure in management systems and controls at an organisational level. The failure is in reference to both *workplace factors* and *organisational factors* which develop the source of the failure pathway. This source of the failure pathway develops the failures in controls and eventually the resultant incident through the uncontrolled energy release. In order to deal with incidents, the understanding of these factors and the relationships between the incident causation factors is essential.

The key conclusions show why this study can benefit the South African civil construction industry. Providing an insight into incident causation within the South African civil construction industry. The civil construction industry can apply this study to understand what is leading to the occurrence of incidents.

6.3. Industry benefits

The three main contributions that this study could make to the South African civil construction industry are the following:

- Taking focus away from analysing singular incidents in isolation and benefit from analysing multiple incidents.
- Understanding leading incident causations for the South African civil construction industry.
- Understanding the relationships between incident causation factors and the failure pathway that leads to incidents occurring.

Viewing incidents as singular isolated events does not help develop an understanding of common incident causations. A cross-sectional view through analysis of multiple incidents builds understanding of leading incident causations. The understanding of incident causation gained through the cross-sectional view can be utilised for the benefit of the South African civil construction industries. Multiple incidents provide incident causation trends and relationships between incident causation. Solving singular incidents in isolation does not allow for understanding of causation to be developed. This singular view of incidents then often allows for the event to reoccur due to the fundamental problem not being solved. The cross-sectional view of incidents prevents this. Through the understanding so gained, incidents can be targeted and resolved at the source, preventing similar incidents from reoccurring.

Analysing the data collected for this study identifies the leading incident causation factors for the South African civil construction industry. The leading *organisational factors*, *workplace factors* and *human errors* are identified. Identification of the leading incident causation factors allows for the development of resilient management systems which better control the hazard's energy. Understanding of what causes an incident is a crucial step in developing these management systems and setting effective controls in place. Through the findings in Sections 5.3.1.1, 5.3.2.1 and 5.3.3.1 the leading incident causation factors are explained. The explanations given in these Sections describe each incident causation factor. Through understanding these, incidents can be greatly reduced.

Incident causation factors cause incidents through what is known as the failure pathway. The failure pathway forms through *organisational factors* causing *workplace factors* which in turn cause *human errors*. Many *organisational factors* may contribute to a single *workplace factor*, after which many *workplace factors* may contribute to a single *human error*. The relationships developed in Sections 5.3.2.2 and 5.3.3.2 explain the failure pathway. Section 5.3.2.2 provides relationships between the *workplace factors* and the *human errors* which they cause. Understanding these relationships demonstrates that the reduction of certain *workplace factors* may have a direct effect on the reduction of certain *human errors*. Furthermore, Section 5.3.3.2 shows relationships between *organisational factors* and the *workplace factors* which they cause. This demonstrates how the reduction of specific *organisational factors* may have a direct effect on the reduction of specific *workplace factors*. The relationships given in Sections 5.3.2.2 and 5.3.3.2 are analysed to provide insight as to how incident causation factors affect one another, forming the failure pathway. Essentially, by applying the knowledge gained in this study, better controls can be put in place through resilient management systems which prevent the failure pathway from forming.

The incident causation failure pathway is described in further detail in Section 5.4. This reveals that the South African civil construction industry has a current focus on the use of training and discipline to reduce or prevent the occurrence of incidents. Viewing the incident causation failure pathway, it is made clear in Section 5.4 that these methods are not effective. Incidents need to be dealt with at the core problem, focusing on management systems to be more resilient with the correct controls. The use of the correct controls and resilient systems would potentially have a direct effect in reducing or preventing the occurrence of incidents.

This study has provided the basic information for understanding incident causation. Implementation of better controls from this information could potentially have a direct positive effect on safety in the South African civil construction industry.

6.4. Recommendations for future work

In order to expand on the findings of this study, recommendations have been developed from the conclusions. The recommendations are given whereby the South African civil construction industry can implement these.

The first conclusion revolved around the understanding of the relationships between the incident causation factors for the South African civil construction industry. This conclusion promotes that from this understanding the industry can develop improved management systems and controls. The improvement of these management systems focuses on reducing incidents from a perspective of understanding incident causation relationships. In order to prevent the occurrence of *mistakes*, the reduction of CWE failures is essential, which in turn is gained through improved *hazard identification.* This leads to an organisation which focus on the correct controls being implemented and the identification of all hazards. This principle can be applied in order to reduce the occurrence of incidents occurring due to all incident causation factors.

Identification of the leading incident causation factors shows the specific areas the industry can improve on in order to reduce the occurrence of incidents. Improvements in the areas of *mistakes*, CWE and *hazard identification* is the key focus of the industry. Reducing these forms of incident causation factors can have a large impact on reducing the number of incidents which are occurring within the South African civil construction industry.

The comparison drawn between the South African civil construction and mining industries developed the argument for improved incident control in the civil construction industry. The adopting of principles similar to those used in the mining industry can help improve safety in the civil construction industry. The mining industries implementation of the culture transformation framework (CTF) described in Section 4.2.3 is an example of such principles. The CTF involves prioritising safety as the leading concern for the mining industry. Focus is on the reduction and management of risk. If civil construction could place safety as the key industry concern, they could potentially receive a similar reduction in the occurrence of incidents.

Methods of training and discipline are ineffective in dealing with the occurrence of incidents. This means that the civil construction industry needs to move away from a culture of ‘blame’, whereby individuals involved in the incident are seen as being the cause. Efforts must rather be applied to developing improved methods of incident control, moving away from focusing on the *human error*.

Improved methods of incident control can be used to reduce incidents at the source of the failure pathway. Focusing on effective controls being designated for the *organisational factors* is essential in the control of incidents. This method aims to prevent the failure pathway from forming, in the process removing the potential for incidents to occur.

The recommendations made from the study should ideally be implemented by the South African civil construction industry. This implementation can lead to an industry that has effective means to control the occurrence of incidents and boost safety for employees.

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Appendix A:

Appendix A1: Certificate of editing

Anne Erikson
Copy Editor, Technical Writer and Indexer

CERTIFICATE OF EDITING

To whom this may concern

This is to certify that I have copy edited the full thesis of

SHANE GEOFFREY ALLSOPP
Student Number: 18373453

"CROSS-SECTIONAL ANALYSIS OF INCIDENT CAUSATIONS WITHIN THE SOUTH AFRICAN CIVIL CONSTRUCTION INDUSTRY"

submitted in fulfilment of the requirements for the degree

Master in Industrial Engineering

in the Faculty of Engineering

at

Stellenbosch University

for spelling and grammatical errors.

Any changes made following my submission
of the edited document to the student are not attributable to me.

Date: 16 October 2019

MA Erikson

M A Erikson
BA (UKZN), BEd (Wits)
Full Member of Professional Editors' Guild
Member of ASAIB (Association of Southern African Indexers and Bibliographers)

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Appendix B:

Appendix B1: Civil construction number of injuries

		Number of Injuries		
Year	**No. Workers**	**Civil construction**	**Other Sectors**	**Total building industry**
2007	95138	3829	6602	10431
2008	109173	4173	6700	10873
2009	119900	4449	5887	10336
2010	116072	3925	5192	9117
2011	117548	3323	4671	7994
2012	129034	3422	4959	8381
2013	138593	3614	5029	8643
2014	141752	3703	4973	8676
2015	133549	3356	5132	8488
2016	140569	3389	5125	8514

Appendix B2: Civil construction number of fatalities

		Number of Fatalities		
Year	**No. Workers**	**Civil Construction**	**Other Sectors**	**Total building industry**
2007	95138	33	39	72
2008	109173	32	35	67
2009	119900	36	37	73
2010	116072	61	38	99
2011	117548	28	23	51
2012	129034	40	36	76
2013	138593	52	42	94
2014	141752	30	36	66
2015	133549	37	30	67
2016	140569	35	42	77

Appendix B3: Incident frequency rates

Year	Injury incident frequency rate	Fatalities incident frequency rate
2007	4.020	0.035
2008	3.820	0.029
2009	3.710	0.030
2010	3.380	0.053
2011	2.830	0.024
2012	2.650	0.031
2013	2.610	0.038
2014	2.610	0.021
2015	2.510	0.028
2016	2.410	0.025

Appendix C:

Appendix C1: Ethical clearance certificate

NOTICE OF APPROVAL

REC Humanities New Application Form

8 November 2018

Project number: 6512

Project Title: Fundamental study of incident causation within the South African civil construction industry

Dear Mr Shane Allsopp

Your REC Humanities New Application Form submitted on 5 November 2018 was reviewed and approved by the REC: Humanities.

Please note the following for your approved submission:

Ethics approval period:

Protocol approval date (Humanities)	Protocol expiration date (Humanities)
8 November 2018	7 November 2021

GENERAL COMMENTS:

Please take note of the General Investigator Responsibilities attached to this letter. You may commence with your research after complying fully with these guidelines.

If the researcher deviates in any way from the proposal approved by the REC: Humanities, the researcher must notify the REC of these changes.

Please use your SU project number (6512) on any documents or correspondence with the REC concerning your project.

Please note that the REC has the prerogative and authority to ask further questions, seek additional information, require further modifications, or monitor the conduct of your research and the consent process.

FOR CONTINUATION OF PROJECTS AFTER REC APPROVAL PERIOD

Please note that a progress report should be submitted to the Research Ethics Committee: Humanities before the approval period has expired if a continuation of ethics approval is required. The Committee will then consider the continuation of the project for a further year (if necessary)

Included Documents:

Document Type	File Name	Date	Version
Proof of permission	Consent Forms	16/10/2018	1.0
Research Protocol/Proposal	Shane Allsopp Research Proposal 2.0	22/10/2018	2

If you have any questions or need further help, please contact the REC office at cgraham@sun.ac.za.

Sincerely,

Clarissa Graham

REC Coordinator: Research Ethics Committee: Human Research (Humanities)

National Health Research Ethics Committee (NHREC) registration number: REC-050411-032.
The Research Ethics Committee: Humanities complies with the SA National Health Act No.61 2003 as it pertains to health research. In addition, this committee abides by the ethical norms and principles for research established by the Declaration of Helsinki (2013) and the Department of Health Guidelines for Ethical Research: Principles Structures and Processes (2nd Ed.) 2015. Annually a number of projects may be selected randomly for an external audit.

Page 1 of 2

Investigator Responsibilities

Protection of Human Research Participants

Some of the general responsibilities investigators have when conducting research involving human participants are listed below:

1.Conducting the Research. You are responsible for making sure that the research is conducted according to the REC approved research protocol. You are also responsible for the actions of all your co-investigators and research staff involved with this research. You must also ensure that the research is conducted within the standards of your field of research.

2.Participant Enrollment. You may not recruit or enroll participants prior to the REC approval date or after the expiration date of REC approval. All recruitment materials for any form of media must be approved by the REC prior to their use.

3.Informed Consent. You are responsible for obtaining and documenting effective informed consent using **only** the REC-approved consent documents/process, and for ensuring that no human participants are involved in research prior to obtaining their informed consent. Please give all participants copies of the signed informed consent documents. Keep the originals in your secured research files for at least five (5) years.

4.Continuing Review. The REC must review and approve all REC-approved research proposals at intervals appropriate to the degree of risk but not less than once per year. There is **no grace period.** Prior to the date on which the REC approval of the research expires, **it is your responsibility to submit the progress report in a timely fashion to ensure a lapse in REC approval does not occur.** If REC approval of your research lapses, you must stop new participant enrollment, and contact the REC office immediately.

5.Amendments and Changes. If you wish to amend or change any aspect of your research (such as research design, interventions or procedures, participant population, informed consent document, instruments, surveys or recruiting material), you must submit the amendment to the REC for review using the current Amendment Form. You **may not initiate** any amendments or changes to your research without first obtaining written REC review and approval. The **only exception** is when it is necessary to eliminate apparent immediate hazards to participants and the REC should be immediately informed of this necessity.

6.Adverse or Unanticipated Events. Any serious adverse events, participant complaints, and all unanticipated problems that involve risks to participants or others, as well as any research related injuries, occurring at this institution or at other performance sites must be reported to Malene Fouche within **five (5) days** of discovery of the incident. You must also report any instances of serious or continuing problems, or non-compliance with the RECs requirements for protecting human research participants. The only exception to this policy is that the death of a research participant must be reported in accordance with the Stellenbosch University Research Ethics Committee Standard Operating Procedures. All reportable events should be submitted to the REC using the Serious Adverse Event Report Form.

7.Research Record Keeping. You must keep the following research related records, at a minimum, in a secure location for a minimum of five years: the REC approved research proposal and all amendments; all informed consent documents; recruiting materials; continuing review reports; adverse or unanticipated events; and all correspondence from the REC

8.Provision of Counselling or emergency support. When a dedicated counsellor or psychologist provides support to a participant without prior REC review and approval, to the extent permitted by law, such activities will not be recognised as research nor the data used in support of research. Such cases should be indicated in the progress report or final report.

9.Final reports. When you have completed (no further participant enrollment, interactions or interventions) or stopped work on your research, you must submit a Final Report to the REC.

10.On-Site Evaluations, Inspections, or Audits. If you are notified that your research will be reviewed or audited by the sponsor or any other external agency or any internal group, you must inform the REC immediately of the impending audit/evaluation.

Appendix D:

Appendix D1: Company 1 incident report

[redacted]

INTERNAL INCIDENT INVESTIGATION (HSE)

DATE OF INCIDENT: 02-12-2017	**TIME OF INCIDENT:** 00:20
NAME OF PERSON INVOLVED: [redacted]	**ID. NO:** [redacted] **AGE:** [redacted]
DEPARTMENT: Centremark	**REGULAR OCCUPATION:** Paint Machine Operator
YEARS OF COMPANY SERVICE: 3 Years	**PERIOD IN PRESENT JOB:** 3 Years
NAME OF SUPERVISOR: [redacted]	**NAME OF DEPARTMENT HEAD:** [redacted]

1 SAFETY INCIDENT	CLASSIFICATION: F ☐	MI ☐	LTI ☐	RI ■	NEAR MISS ☐
PART OF BODY EFFECTED	HEAD	NECK	EYE	TRUNK	FINGER	HAND
	ARM	TOE	FOOT	LEG	INTERNAL	MULTIPLE
EFFECT ON PERSON	SPRAINS	STRAINS	CONTUSION	WOUNDS	FRACTURES	BURNS
	AMPUTATION	ELEC.SHOCK	ASPHYXIATION	UNCONSCIOUS	POISONING	MULTIPLE
NATURE OF INJURY	*Fractured Left Tibia – Fibula and Fractured Right Distal Fibula.*					
	Tentatively booked off to 01 June 2018					

2 DAMAGE INCIDENT	CLASSIFICATION: MAJOR ☐	SERIOUS ☐	MODERATE ☐	MINOR ☐	NEAR MISS ☐
MAN CAUSED	MVA	THEFT	VANDALISM	WEAR & TEAR	CIVIL	STRIKE
	FIRE	OTHER – SPECIFY :				
NATURAL CAUSES	FLOOD	CYCLONE	EARTHQUAKE	TORNADO	HAIL/RAIN	LIGHTNING
	OTHER – SPECIFY : N/A					

3 HEALTH INCIDENT (INCLUDING OVER-EXPOSURE)	CLASSIFICATION: SKIN ☐	DUST ☐	NOISE ☐		
OCCUPATIONAL STRESSOR	PHYSICAL	BIOLOGICAL	CHEMICAL	ERGONOMICAL	PSYCHOLOGICAL
NATURE OF DISEASE (DESCRIBE)					

RESULT	FIT – RETURN TO	TRANSFER – TEMP.	TRANSFER -	PERMANENTLY DISABLED	FATAL

4 ENVIRONMENTAL INCIDENT	CLASSIFICATION: MAJOR ☐ MEDIUM ☐ MINOR ☐ NEAR MISS ☐
INCIDENT TYPE	**INCIDENT CONSEQUENCE**
CONTAINED EMISSIONS/DISCHARGE	POLLUTION
UNCONTAINED EMISSIONS/DISCHARGE	LEGAL NON COMPLIANCE
CONTROLLED EMISSIONS/DISCHARGE	PERMIT REQUIREMENTS EXCEEDED
UNCONTROLLED EMISSIONS/DISCHARGE	NON-CONFORMANCE WITH CORPORATE STANDARD OR POLICY
EXCESSIVE RESOURCE USE	FINANCIAL CONSEQUENCE
INAPROPRIATE MANIPULATION OF THE ENVIRONMENT	COMMON LAW CLAIM
EXCESSIVE WASTE GENERATION AND/OR DISPOSAL	NUISANCE TO PUBLIC OR COMMUNITY
COMPLAINT/UNDESIRED PUBLIC OR MEDIA ATTENTION	DAMAGE TO PUBLIC OR COMMUNITY
ENVIRONMENTAL DAMAGE – **NATURAL**	SOCIO-ECONOMIC DISRUBTION
ENVIRONMENTAL DAMAGE – **HUMAN**	ECOLOGICAL STRESS OR DAMAGE
OTHER:	RESOURCE DEPLETION
	CLIMATIC CHANGE
	NEGATIVE PUBLICITY
	ALTERATION OF PHYSICAL ENVIRONMENT
	OTHER:

SEVERITY OF ENVIRONMENTAL INCIDENT:

STATE OF POLLUTANT*(e. g. Solids, liquid, etc.)*	
QUANTITY OF POLLUTANT*(e. g. 12g/m² or less than 25 ppm, etc.)*	

DURATION OF POLLUTION	LESS	1 DAY	1 MONTH	1 YEAR	5 YEARS	MORE THAN	5 YEARS

ON SITE - CONTAINED	ON SITE – NOT CONTAINED	LOCAL	REGIONAL
NATIONAL	GLOBAL	OFF-SITE AFFECTING ON SITE	OTHER:

DESIGNATED INVESTIGATOR (TEAM) APPROPRIATE TO INVESTIGATE THE INCIDENT (qualifications, experience,expertise, etc.)	YES	NO

INCIDENT INVESTIGATOR NAME:	**DATE OF INVESTIGATION:**

[redacted]

COST/CAUSE ANALYSIS

HSE INCIDENT COSTS:	
DESCRIPTION OF DAMAGE/MEDICAL/FEES/REPAIR/REPLACEMENT/ETC.	REPLACEMENT/REPAIR COST
Ist day in hospital	R 6 166.00
10 days in hospital @ R 3 530.00	R35 300.00
19 days at home @ R 1 860.00	R35 340.00
	R
	R
Total incident costs (Replacement of equipment and repair (labour) costs.)	R76 806.00

INCIDENT CAUSE ANALYSIS

GENERAL AGENT/S				OCCUPATIONAL HEALTH/ENVIRONMENTAL AGENT/S			
STRUCK BY	SLIP & FALL	CAUGHT BETWEEN	TRANSPORT	CHEMICAL	FUMES	FIRE	GAS
STRUCK AGAINST	FALLING OBJECT	MACHINE	ELECTRICITY	DUST	NOISE	VAPOUR	TEMPERATURE

WHAT WAS THE DIRECT OR IMMEDIATE AND THE BASIC OR ROOT CAUSE OF THE INCIDENT

DIRECT CAUSES/IMMEDIATE CAUSES

	SUBSTANDARD PRACTICES/UNSAFE ACTS		SUBSTANDARD CONDITIONS/UNSAFE CONDITIONS
	OPERATING EQUIPMENT WITHOUT AUTHORITY	X	INADEQUATE GUARDS OR BARRIERS
	FAILURE TO WARN		IMPROPER/INADEQUATE PROTECTIVE/CONTROL EQUIPMENT
	FAILURE TO SECURE OR CONTAIN		CO EXPOSURE
X	OPERATING IN IMPROPER MANNER e. g. SPEEDING		DEFECTIVE TOOLS/EQUIPMENT/MATERIALS
	MAKING SAFETY OR CONTROL DEVICES INOPERABLE		CONGESTION OR RESTRICTED MOVEMENT
	REMOVING SAFETY OR CONTROL DEVICES	X	INADEQUATE WARNING SYSTEMS
	USING DEFECTIVE EQUIPMENT		FIRE AND EXPLOSION HAZARDS
	USING EQUIPMENT IMPROPERLY OR INCORRECTLY		POOR HOUSEKEEPING/DISORDERLY WORKPLACE
	FAILURE TO USE PPE		HAZARDOUS ENVIRONMENT
	IMPROPER LOADING		NOISE EXPOSURES
	IMPROPER PLACEMENT		RADIATION EXPOSURES
	IMPROPER LIFTING		HIGH OR LOW TEMPERATURE EXPOSURES
	IMPROPER POSITION FOR TASK		HCS EXPOSURES (DUST, FUMES, VAPOUR ETC.)
	SERVICING EQUIPMENT IN OPERATION		INADEQUATE OR EXCESSIVE ILLUMINATION
	UNDER THE INFLUENCE OF ALCOHOL OR DRUGS		INADEQUATE OR INAPROPRIATE VENTILATION
	IMPROPER RESOURCE USE OR DISPOSAL	X	INAPROPRIATE /UNSAFE DESIGN OR CONSTUCTION
	OTHER:		OTHER:

BASIC CAUSES/ROOT CAUSES/INDIRECT CAUSES

	PERSONAL FACTORS		JOB FACTORS
	UNSUITABLE PHYSICAL/PHYSIOLOGICAL CAPABILITY		INADEQUATE LEADERSHIP AND/OR SUPERVISION
	UNSUITABLE MENTAL CAPABILITY		INADEQUATE PLANNING
	PHYSICAL STRESS		INADEQUATE PURCHASING
	LACK OF KNOWLEDGE		INADEQUATE MAINTENANCE
	LACK OF SKILL		INADEQUATE TOOLS AND EQUIPMENT
	IMPROPER MOTIVATION	X	INADEQUATE WORK STANDARDS/PROCEDURES
	FATIQUE		WEAR AND TEAR
			ABUSE OR MISUSE

PREVENTATIVE ACTION – RECOMMENDED

	ADDRESSING PERSONAL FACTORS		ADDRESSING JOB FACTORS
	ATTEND TRAINING COURSE		WRITE WORK STANDARDS (SPECIFICATIONS)
	INSTRUCT HOW TO FOLLOW REVISED WORK STANDARD		REVISE WORK STANDARDS (SPECIFICATIONS)
	HAVE MEDICALLY EXAMINED		REVISE RISK ASSESSMENT
	TRANSFER TO ANOTHER JOB		GUARD/PROVIDE PROTECTION
	ATTEND HSE COMMITTEE MEETING		REPAIR
	ENFORCE/WARN		MODIFY Site area Annexure 1
	ATTEND SPECIFIC TRAINING (ON THE JOB)		LOCK – OUT
	MENTOR		HOUSEKEEPING
	OTHER		OTHER

[redacted]

INCIDENT DETAILS AND REMEDIAL ACTION PLAN

INCIDENT DESCRIPTION (PROVIDE A BRIEF DESCRIPTION OF THE INCIDENT AS SEEN BY THE INVESTIGATING TEAM)
The sequence of events is from statements and the scene was not inspected by the investigation team.
On the night of the accident, Centremark were painting lines on the onramps from the N2 from the Airport (West) and Bellville (East) towards the R300 North Bound. Work commenced approximately 22:00 and the accident occurred approximately 00:20 when a public vehicle on one of the onramps road into the closure of cones and collided with the now injured [redacted] The driver did not stop and has not been identified.
The onramp from the airport had a closure of delineators up to the island intersection with the Bellville onramp. The TSO claims that it was unsafe to close any further as the traffic using the Bellville onramp needed to be diverted away from the crew doing the painting. In addition there were not sufficient delineators. There are sufficient delineators for two closure but this night three closures were needed. The plan was to use the delineators from the airport onramp once the paint had dried for the additional closure. This is disputed by the [redacted] who claim that they were assisted to close off the additional area using their cones.
The fact that cones were used for the closure could have been the direct cause of the accident as they are not sufficiently visible at night. The witnesses claim that the driver of the vehicle was speeding at the time.
One issue that is evident is that there is an animosity between the two crews concerning the closures. This seems to stem from a previous job in the PE area. Although this is probably not a direct cause it could be an underlying cause and needs to be addressed.
HSE REPRESENTATIVE SIGNATURE: [redacted] **DATE: 06 December 2017**
INCIDENT CAUSE 1. Unsafe Acts OR Unsafe Conditions 2. Personal Factors OR Job Factors
DIRECT CAUSE – Speeding Vehicle. Equipment not sufficiently visible at night.
BASIC CAUSE – Haste in trying to do more than is safe (possible starting late & not planned properly). No direct supervision from Roadmac at the job in the form of a Foreman.
Investigator Conclusion: [redacted] **DATE: 06 December 2017**
The job is nearing completion and towards closing for December. Time constraints on outstanding work before the December break.
Animosity between the two crews is evident and has not been dealt with, allowing it to escalate to an unhealthy situation. Problem area need to be dealt with as they arise and not left to escalate.
A direct supervisor from the primary contractor on site could assist in ensuring that safe and proper work standards are maintained.

SUGGESTED REMEDIAL/CORRECTIVE ACTION PLAN	ACCOUNTABILITY
Animosity between the two sub-contractors needs to be cleared.	**Site Management**
Daily issues that arise must be sorted out immediately	**Site Management**
Problems encountered during the shift need to be recorded and management can deal with shortcommings.	**Site Management**
Planning in terms of the work and closures needs to be well executed. Record to be kept.	**Site Management**
Site supervision must not be depleated prior to the end of the contract.	**Site Management**
No qualified safety officer on site. An alternative to be considered.	**Site Management**
Regular visits from safety personnel to be carried out and findings recorded.	**Safety**

REMEDIAL/CORRECTIVE ACTION TAKEN	Date Completed

The above action was implemented and is effective	YES	NO	Proof of action attached	YES	NO

RISK ASSESSMENT OF IMPLEMENTED CORRECTIVE ACTION – CLOSING THE LOOP
NOTES:

3

[redacted]

Is there any possible new/additional risk in terms of:	SAFETY	HEALTH	ENVIRONMENT	YES	NO	UNCERTAIN
Indicate the additional hazards/risks and specify the action to be taken				ACTION BY		DATE

PERSON INVOLVED IN INCIDENT:	PRINT NAME:	SIGNATURE:	DATE:

HSE DEPARTMENT:	**HSE COMMITTEE CHAIRPERSON:**	**MANAGEMENT:**
SIGNATURE:	SIGNATURE:	SIGNATURE:
PRINT NAME:	PRINT NAME:	PRINT NAME:
DATE:	DATE:	DATE:

INCIDENT ASSESSOR:	**PRINT NAME:**	**SIGNATURE:**	**DATE:**

4

Appendix E:

Appendix E1: Mining industry incident statistics

Year	No. Workers	Number of injuries	Number of fatalities
2007	469351	3867	220
2008	489791	3750	171
2009	466395	3650	168
2010	475298	3438	127
2011	487261	3299	123
2012	497607	3377	112
2013	510099	3126	93
2014	468030	2700	84
2015	479062	3138	77
2016	457290	2785	73

Appendix E2: Mining industry incident frequency rates

Year	Injury frequency rate	Fatality frequency rate
2007	0.820	0.047
2008	0.770	0.035
2009	0.780	0.036
2010	0.720	0.027
2011	0.680	0.025
2012	0.680	0.023
2013	0.610	0.018
2014	0.580	0.018
2015	0.660	0.016
2016	0.610	0.016

Appendix F:

Appendix F1: Fatal incident statistical significance

Civil Construction Fatal								
Regression Statistics								
Multiple R	0.014166239							
R Square	0.000200682							
Adjusted R Square	-0.12477423							
Standard Error	10.98980244							
Observations	10							
ANOVA								
	df	*SS*	*MS*	*F*	*Significance F*			
Regression	1	0.193939394	0.193939394	0.001605781	0.969017571			
Residual	8	966.2060606	120.7757576					
Total	9	966.4						
	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	-59.1272727	2433.791615	-0.0242943	0.981212912	-5671.460802	5553.206256	-5671.460802	5553.206256
X Variable 1	0.048484848	1.209937427	0.040072195	0.969017571	-2.741635861	2.838605558	-2.741635861	2.838605558

Mining Fatal								
Regression Statistics								
Multiple R	0.957739096							
R Square	0.917264176							
Adjusted R Square	0.906922198							
Standard Error	14.69477334							
Observations	10							
ANOVA								
	df	*SS*	*MS*	*F*	*Significance F*			
Regression	1	19152.10909	19152.11	88.6933	1.32598E-05			
Residual	8	1727.490909	215.9364					
Total	9	20879.6						
	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	30772.74545	3254.29109	9.456052	1.29E-05	23268.33674	38277.15417	23268.33674	38277.15417
X Variable 1	-15.23636364	1.617841299	-9.41771	1.33E-05	-18.96711236	-11.50561491	-18.96711236	-11.50561491

Appendix F2: Fatality frequency rates statistical significance

Civil Construction Fatality Frequency Rate

Regression Statistics	
Multiple R	0.372441824
R Square	0.138712912
Adjusted R Square	0.031052026
Standard Error	0.008805061
Observations	10

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	9.98904E-05	9.98904E-05	1.288424395	0.28920014
Residual	8	0.000620233	7.75291E-05		
Total	9	0.000720123			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	2.244642767	1.949960691	1.15112206	0.282922737	-2.25197465	6.741260184	-2.25197465	6.741260184
X Variable 1	-0.00110036	0.000969405	-1.135087836	0.28920014	-0.003335813	0.001135092	-0.003335813	0.001135092

Mining Fatality Frequency Rate

Regression Statistics	
Multiple R	0.942514415
R Square	0.888333422
Adjusted R Square	0.8743751
Standard Error	0.003647753
Observations	10

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	0.000846825	0.000846825	63.64184783	4.4559E-05
Residual	8	0.000106449	1.33061E-05		
Total	9	0.000953274			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	6.470559423	0.8078281	8.00982217	4.32842E-05	4.607704485	8.333414362	4.607704485	8.333414362
X Variable 1	-0.003203833	0.000401604	-7.977584085	4.4559E-05	-0.004129934	-0.002277732	-0.004129934	-0.002277732

Appendix F3: Injury frequency rate statistical significance

Civil Construction Injury Frequency Rate

Regression Statistics	
Multiple R	0.948395549
R Square	0.899454117
Adjusted R Square	0.886885882
Standard Error	0.20595123
Observations	10

ANOVA

	df	SS	MS	F	Significance F
Regression	1	3.035522727	3.035522727	71.56566468	2.91458E-05
Residual	8	0.339327273	0.042415909		
Total	9	3.37485			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
Intercept	388.8972727	45.60977136	8.526621842	2.75198E-05	283.7209514	494.0735941	283.7209514	494.0735941
X Variable 1	-0.191818182	0.022674484	-8.459649206	2.91458E-05	-0.244105636	-0.139530728	-0.244105636	-0.139530728

Mining Injury Frequency Rate

Regression Statistics	
Multiple R	0.909743368
R Square	0.827632995
Adjusted R Square	0.806087119
Standard Error	0.035438808
Observations	10

ANOVA

	df	SS	MS	F	Significance F
Regression	1	0.048242727	0.048242727	38.41259501	0.000260054
Residual	8	0.010047273	0.001255909		
Total	9	0.05829			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
Intercept	49.33272727	7.848246001	6.285828358	0.000236372	31.23463954	67.43081501	31.23463954	67.43081501
X Variable 1	-0.024181818	0.003901684	-6.197789526	0.000260054	-0.033179118	-0.015184518	-0.033179118	-0.015184518

Appendix G:

Appendix G1. Human errors evaluation flow chart

Appendix G2: Outline for workplace factors analysis

CP

- Were the correct individuals, with the correct skill levels completing the task?
- Were the individuals completing the task competent in doing so?
- If not, workplace factor: CP

SWP

- Were there procedures in place which individuals were following to complete the task?
- Were the work procedures in place adequate in ensuring employee safety?
- If not, workplace factor: SWP

FFPE

- Was fit for purpose equipment used for completion of this task?
- Was the equipment in good working order, with adequate safety features?
- If not, workplace factor: FFPE

CWE

- Does the physical work environment account for safety aspects?
- Are incorrect work practices being controlled and corrected?
- If not, workplace factor: CWE
- Stipulate whether CWE was due to physical or behavioural work environment

Appendix G3: Organisational factors checklist

Organisational Checklist	
Are individuals auditing and monitoring that safety controls within the system are able to deal with work environment?	YES.
	NO. Insert: **Auditing and Monitoring**
Are individuals auditing and monitoring that safety controls within the system are being adhered to?	YES.
	NO. Insert: **Auditing and Monitoring**
Do individuals completing the task seem to understand correct safety protocol?	YES.
	NO. Insert: **Communication**
Are individuals communicating safety complaints to individuals in charge?	YES.
	NO. Insert: **Communication**
Is the equipment and the workplace adequately designed to prioritise safety?	YES.
	NO. Insert: **Design**
Has the hazard been identified?	YES.
	NO. Insert: **Hazard Identification**
Are the controls in place efficient in dealing with the magnitude of the hazards energy?	YES.
	NO. Insert: **Hazard Identification**
Are individuals following safety protocol and if not is this being corrected by supervision?	YES.
	NO. Insert: **Leadership**
Has the incident which occurred, not occurred previously in multiple other incident reports.	YES.
	NO. Insert: **Learning from Incidents**
Has the equipment been maintained regularly and done so to an adequate standard?	YES.
	NO. Insert: **Planned Maintenance**

Organisational Checklist	
Has required equipment for the task been purchased?	YES.
	NO. Insert: **Procurement**
Does the equipment being purchased meet safety standards for the completion of the task?	YES.
	NO. Insert: **Procurement**
Are identified risks being dealt with?	YES.
	NO. Insert: **Risk Management**
Are effective risk control methods being used to deal with identified risk?	YES.
	NO. Insert: **Risk Management**
Is the company prioritising safety requirement over other goals?	YES.
	NO. Insert: **Strategic Management**
Have the task instructions identified all risks?	YES.
	NO. Insert: **Task Design**
Is there a correct use of controls for all identified risk?	YES.
	NO. Insert: **Task Design**
Did the individual performing the task have the correct level of knowledge and skill?	YES.
	NO. Insert: **Training and Competence**
Was the individual assessed to be competent before completing the task?	YES.
	NO. Insert: **Training and Competence**

Appendix H:

Appendix H1: Human error proportion table

Human Error	Proportion
Latent (Company 1)	10.00%
Latent (Company 2)	7.50%
Latent (Company 3)	6.17%
Latent (Weighted Average)	7.14%
Mistake (Company 1)	53.33%
Mistake (Company 2)	45.00%
Mistake (Company 3)	54.32%
Mistake (Weighted Average)	50.67%
Routine Violation (Company 1)	16.67%
Routine Violation (Company 2)	20.00%
Routine Violation (Company 3)	18.52%
Routine Violation (Weighted Average)	18.86%
Slip and Lapse (Company 1)	20.00%
Slip and Lapse (Company 2)	27.50%
Slip and Lapse (Company 3)	20.99%
Slip and Lapse (Weighted Average)	23.33%

Appendix H2: Time of day and associated human errors

No. of Human errors	Latent	Mistake	Routine Violation	Slip & Lapse	Accumulative
Afternoon	4	41	17	16	78
Morning	9	52	19	29	109
Percentage of Human errors	**Latent**	**Mistake**	**Routine Violation**	**Slip & Lapse**	**Accumulative**
Afternoon	5.13%	52.56%	21.79%	20.51%	100.00%
Morning	8.26%	47.71%	17.43%	26.61%	100.00%

Appendix H3: Day of week and associated human error proportions

	Latent	Mistake	Routine Violation	Slip & Lapse
Monday	16.00%	44.00%	24.00%	16.00%
Tuesday	4.76%	52.38%	16.67%	26.19%
Wednesday	8.11%	40.54%	18.92%	32.43%
Thursday	2.78%	47.22%	22.22%	27.78%
Friday	4.76%	61.90%	23.81%	9.52%
Saturday	15.00%	55.00%	10.00%	20.00%
Sunday	0.00%	70.00%	10.00%	20.00%

Appendix H4: Day of week and associated number of human errors

	Latent	Mistake	Routine Violation	Slip & Lapse	Grand Total
Monday	4	11	6	4	25
Tuesday	2	22	7	11	42
Wednesday	3	15	7	12	37
Thursday	1	17	8	10	36
Friday	1	13	5	2	21
Saturday	3	11	2	4	20
Sunday		7	1	2	10
Grand Total	**14**	**96**	**36**	**45**	**191**

Appendix I:

Appendix I1: Workplace factor proportion table

Workplace Factor	Proportion
CP (Company 1)	12.28%
CP (Company 2)	7.50%
CP (Company 3)	14.06%
CP (Weighted Average)	11.03%
CWE (Company 1)	38.60%
CWE (Company 2)	37.50%
CWE (Company 3)	42.19%
CWE (Weighted Average)	39.66%
FFPE (Company 1)	22.81%
FFPE (Company 2)	23.75%
FFPE (Company 3)	15.63%
FFPE (Weighted Average)	20.16%
SWP (Company 1)	26.32%
SWP (Company 2)	31.25%
SWP (Company 3)	28.13%
SWP (Weighted Average)	29.15%

Appendix I2: Human error and associated behavioural and physical work environment for CWE

	Behavioural	Physical
Latent	16.67%	83.33%
Mistake	42.31%	57.69%
Routine Violation	83.33%	16.67%
Slip & Lapse	40.00%	60.00%
Total CWE	**51.33%**	**48.67%**

Appendix I3: Human error and associated workplace factor proportions

	CP	CWE	FFPE	SWP
Latent (Company 1)	0.00%	60.00%	20.00%	20.00%
Latent (Company 2)	0.00%	14.29%	71.43%	14.29%
Latent (Company 3)	0.00%	40.00%	60.00%	0.00%
Latent (Weighted Average)	0.00%	32.37%	58.50%	9.12%
Mistake (Company 1)	12.90%	32.26%	25.81%	29.03%
Mistake (Company 2)	24.19%	35.48%	17.74%	22.58%
Mistake (Company 3)	14.55%	32.73%	20.00%	32.73%
Mistake (Weighted Average)	18.33%	33.81%	19.97%	27.90%
Routine Violation (Company 1)	25.00%	50.00%	8.33%	16.67%
Routine Violation (Company 2)	5.56%	61.11%	22.22%	11.11%
Routine Violation (Company 3)	16.00%	52.00%	4.00%	28.00%
Routine Violation (Weighted Average)	13.04%	55.50%	12.31%	19.15%
Slip and Lapse (Company 1)	0.00%	33.33%	33.33%	33.33%
Slip and Lapse (Company 2)	0.00%	34.38%	37.50%	28.13%
Slip and Lapse (Company 3)	12.50%	41.67%	4.17%	41.67%
Slip and Lapse (Weighted Average)	5.30%	37.30%	22.71%	34.69%

Appendix J:

Appendix J1: Organisational factor proportion table

Organisational factor	Proportion
Auditing and Monitoring (Company 1)	10.31%
Auditing and Monitoring (Company 2)	10.68%
Auditing and Monitoring (Company 3)	12.09%
Auditing and Monitoring (Weighted Average)	11.15%
Communication (Company 1)	8.25%
Communication (Company 2)	5.34%
Communication (Company 3)	3.30%
Communication (Weighted Average)	5.14%
Design (Company 1)	9.28%
Design (Company 2)	9.71%
Design (Company 3)	10.44%
Design (Weighted Average)	9.90%
Hazard Identification (Company 1)	17.53%
Hazard Identification (Company 2)	15.53%
Hazard Identification (Company 3)	20.88%
Hazard Identification (Weighted Average)	17.99%
Leadership (Company 1)	9.28%
Leadership (Company 2)	10.19%
Leadership (Company 3)	10.99%
Leadership (Weighted Average)	10.32%
Learning from Incidents (Company 1)	5.15%
Learning from Incidents (Company 2)	4.37%
Learning from Incidents (Company 3)	1.65%
Learning from Incidents (Weighted Average)	3.48%
Planned Maintenance (Company 1)	2.06%
Planned Maintenance (Company 2)	3.88%
Planned Maintenance (Company 3)	1.65%
Planned Maintenance (Weighted average)	2.66%
Procurement (Company 1)	12.37%
Procurement (Company 2)	11.17%
Procurement (Company 3)	4.95%
Procurement (Weighted Average)	9.02%
Risk Management (Company 1)	11.34%

Risk Management (Company 2)	10.19%
Risk Management (Company 3)	13.74%
Risk Management (Weighted Average)	11.78%
Strategic Planning (Company 1)	2.06%
Strategic Planning (Company 2)	2.91%
Strategic Planning (Company 3)	5.49%
Strategic Planning (Weighted Average)	3.73%
Task Design (Company 1)	8.25%
Task Design (Company 2)	8.74%
Task Design (Company 3)	10.99%
Task Design (Weighted Average)	9.50%
Training and Competence (Company 1)	4.12%
Training and Competence (Company 2)	7.28%
Training and Competence (Company 3)	3.85%
Training and Competence (Weighted Average)	5.33%

Appendix J2: Ranked organisational factors contribution to incidents

Ranking	Company 1	Company 2	Company 3	Weighted Average
1	Hazard Identification	Hazard Identification	Hazard Identification	Hazard Identification
2	Procurement	Procurement	Risk Management	Risk Management
3	Risk Management	Auditing and Monitoring	Auditing and Monitoring	Auditing & Monitoring
4	Auditing and Monitoring	Risk Management	Leadership	Leadership
5	Leadership	Leadership	Task Design	Design
6	Design	Design	Design	Task Design
7	Communication	Task Design	Strategic Planning	Procurement
8	Task Design	Training and Competence	Procurement	Training and Competence
9	Learning from Incidents	Communication	Training & Competence	Communication
10	Training and Competence	Learning from Incidents	Communication	Strategic Planning
11	Strategic Planning	Planned Maintenance	Learning from Incidents	Learning from Incidents
12	Planned Maintenance	Strategic Planning	Planned Maintenance	Planned Maintenance

Appendix J3: Workplace factors and associated organisational factors proportional contributions

	Auditing and Monitoring	Communication	Design	Hazard Identification	Leadership	Learning from Incidents
CP (Company 1)	0.00%	22.22%	0.00%	0.00%	11.11%	11.11%
CP (Company 2)	0.00%	20.00%	0.00%	4.00%	16.00%	0.00%
CP (Company 3)	5.9%	5.88%	5.88%	23.53%	5.88%	0.00%
CP (Weighted Average)	2.26%	15.03%	2.26%	10.69%	11.14%	2.23%
CWE (Company 1)	11.63%	9.30%	6.98%	27.91%	13.95%	6.98%
CWE (Company 2)	13.64%	6.82%	6.82%	23.86%	14.77%	5.68%
CWE (Company 3)	13.92%	3.80%	8.86%	26.58%	15.19%	2.53%
CWE (Weighted Average)	13.34%	6.16%	7.63%	25.72%	14.77%	4.73%
FFPE (Company 1)	14.29%	0.00%	19.05%	0.00%	4.76%	0.00%
FFPE (Company 2)	3.85%	0.00%	19.23%	5.77%	3.85%	7.69%
FFPE (Company 3)	13.04%	0.00%	26.09%	4.35%	8.70%	0.00%
FFPE (Weighted Average)	9.47%	0.00%	21.83%	4.07%	5.89%	3.20%
SWP (Company 1)	8.00%	8.00%	8.00%	20.00%	4.00%	4.00%
SWP (Company 2)	19.51%	0.00%	9.76%	17.07%	4.88%	0.00%
SWP (Company 3)	11.11%	3.17%	7.94%	19.05%	7.94%	1.59%
SWP (Weighted Average)	13.98%	2.82%	8.71%	18.42%	5.88%	1.41%

	Planned Maintenance	Procurement	Risk Management	Strategic Planning	Task Design	Training and Competence
CP (Company 1)	0.00%	0.00%	11.11%	0.00%	0.00%	44.44%
CP (Company 2)	0.00%	0.00%	4.00%	0.00%	4.00%	52.00%
CP (Company 3)	0.00%	0.00%	5.88%	5.88%	0.00%	41.18%
CP (Weighted Average)	0.00%	0.00%	6.15%	2.26%	1.66%	46.33%
CWE (Company 1)	0.00%	2.33%	13.95%	2.33%	4.65%	0.00%
CWE (Company 2)	3.41%	1.14%	7.95%	4.55%	11.36%	0.00%
CWE (Company 3)	0.00%	1.27%	11.39%	7.59%	8.86%	0.00%
CWE (Weighted Average)	1.42%	1.42%	10.48%	5.27%	9.06%	0.00%
FFPE (Company 1)	9.52%	52.38%	0.00%	0.00%	0.00%	0.00%
FFPE (Company 2)	9.62%	42.31%	5.77%	0.00%	0.00%	1.92%
FFPE (Company 3)	13.04%	30.43%	0.00%	4.35%	0.00%	0.00%
FFPE (Weighted Average)	10.91%	39.77%	2.40%	1.67%	0.00%	0.80%
SWP (Company 1)	0.00%	0.00%	20.00%	4.00%	24.00%	0.00%
SWP (Company 2)	0.00%	0.00%	24.39%	4.88%	17.07%	2.44%
SWP (Company 3)	0.00%	1.59%	23.81%	3.17%	20.63%	0.00%
SWP (Weighted Average)	0.00%	0.61%	23.29%	4.05%	19.83%	1.01%

Appendix J4: Physical and behavioural working environments proportional contributions to organisational factors

Organisational factor	Behavioural	Physical
Auditing and Monitoring	44.44%	55.56%
Communication	50.00%	50.00%
Design	11.11%	88.89%
Hazard Identification	51.72%	48.28%
Leadership	93.33%	6.67%
Learning from Incidents	75.00%	25.00%
Planned Maintenance	50.00%	50.00%
Procurement	100.00%	0.00%
Risk Management	17.65%	82.35%
Strategic Planning	50.00%	50.00%
Task Design	87.50%	12.50%
Training and Competence	0.00%	0.00%

Appendix J5: Organisational factors proportional contributions to behavioural and physical working environment

Organisational factor	Behavioural	Physical
Auditing and Monitoring	13.79%	18.18%
Communication	5.17%	5.45%
Design	1.72%	14.55%
Hazard Identification	25.86%	25.45%
Leadership	24.14%	1.82%
Learning from Incidents	5.17%	1.82%
Planned Maintenance	1.72%	1.82%
Procurement	1.72%	0.00%
Risk Management	5.17%	25.45%
Strategic Planning	3.45%	3.64%
Task Design	12.07%	1.82%
Training and Competence	0.00%	0.00%