WASM: Minerals, Energy and Chemical Engineering

Risk Assessment as a Tool for Mobile Plant Operators for Sustainable Development: Lessons from the Western Australian Mining Industry

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DECLARATION

To the best of my knowledge and belief this thesis contains no material previously published by any other person except where due acknowledgment has been made.

This thesis contains no material which has been accepted for the award of any other degree or diploma in any university.

The research presented and reported in this thesis was conducted in accordance with the National Health and Medical Research Council National Statement on Ethical Conduct in Human Research (2007) – updated March 2014. The proposed research study received human research ethics approval from the Curtin University Human Research Ethics Committee (EC00262), Approval Number 13969.

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ABSTRACT

Mobile plant is used extensively not only in the Western Australian (WA) Mining Industry but internationally as well. The use of mobile plant has inherently high risk and every year is associated with a significant number of workplace fatalities and injuries. Prior to this research being conducted there was no specific data published related to mobile plants incidents and fatalities for the Western Australian mining industries. The aim of this research was to improve the safety performance of mobile plant operators in the Western Australia (WA) mining industry by identifying the causes of mobile plant incidents reported to Resources Safety between 1/1/2007 and 31/3/2020.

A literature review was conducted: to identify the causes of mobile plant incidents internationally and in Australia, to determine the different types of risk assessment techniques being used for accident prevention particularly related to mobile plant. Interview questions were developed based on the findings of this comprehensive literature review.

The study explored causes of mobile plant incidents in the Western Australian mining industries using a concurrent embedded mixed methods approach. Research data was collected through conducting observations at mine sites, document reviews, through critically analysing the Department of Mines, Industry Regulation and Safety, Resources Safety Division Significant Reportable Incident Database and through conducting onsite interviews with management and other mine site mobile plant workers. Mine sites were selected to provide a range of types of mobile plant equipment currently in use in the WA mining industry and included companies with open cut iron ore mining, open cut and underground gold mining, and underground nickel and copper mining. This enabled a variety of workplaces to assess and identify best practices, where there are differences and where there are opportunities for improvements related to the use and maintenance of mobile plant equipment. Mine sites data collected through on-site observations, documents review and interviews was analysed using NVivo 12.

Research data analysis identified that the total number of incidents reported to Resources Safety for the time between 1 January 2007 and 31 March 2020 was 27,311; total number of mobile plant incidents were 5,767. Out of these mobile plant incidents there were 5,100 surface mining incidents with 13 fatal incidents and 667 underground mining incidents with three fatal incidents. Results identified that the major causes of fatal incident related to mobile plant incidents in Western Australian Mining industry for above ground mining were vehicle collisions, vehicle over-edge, vehicle rollover, vehicle runaway, maintenance procedure deficiency and machinery movement that crushed a person. Underground (UG) causes were rock falls, tyres and suspended loads.

Based on the research findings a framework "Triage Hazard Identification and Prevention Model" (THIP) was developed to improve hazard awareness and risk control selection for the prevention of workplace injuries due to mobile plant. Recommendations are made in relation to having a focus on refresher training for mobile plant operators and maintenance workers, improving in shift rosters, having more interactions between top, lower management and workers, the employer and management staff welcoming feedback from employees, introduction of mandatory breaks during 12 hours work shift and having a balanced work-load distribution.

Recommendations for further research are to extend this study and to use and test the THP model by the mining companies. It is anticipated that implementation of the research findings, model and recommendations would be of significant benefit for the Regulator, the mining industry generally, and that relevant companies could obtain maximum benefit by implementing the Triage Hazard Identification and Prevention Model to reduce the occurrence of low frequency high consequences injuries, improve mining industry workers' productivity and industry profits. This model and the research findings will provide investigators and risk assessment leads research-based information concerning known incidents and injuries related to mobile plant in the mining industry.

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ABBREVIATIONS

AIHS	Australian Institute of Health and Safety
AMA	Active Mining Area
AS	Australian Standard published by Standards Australia
CCC	Critical Control Coaching
DIDO	Drive in and Drive out
DMIRS	Department of Mines, Industry Regulation and Safety
EWP	Elevated work platform
FIFO	Fly In and Fly Out
ISO	International Organization for Standardization
JSA	Job safety analysis
JSEA	Job safety and environment analysis
JHA	Job hazard analysis
LDH	Load Haul Dump
LTI	Lost Time Injury
LV	Light Vehicle
MFL	Maximum Foreseeable Loss
MPU	Mobile processing unit
NOC	Not otherwise classified
OEM	Original Equipment Manufacturer
OHSMS	Occupational Health and Safety Management Systems
PM	Preventive Maintenance
PHMP	Principal hazard management plan
PTW	Permit to work
RCA	Root Cause Analysis
RMS	Risk Management System
RRR	Residual Risk Rating
SOP	Safe Operating Procedure
SJA	Safe job analysis
SME	Surface Mining Equipment
STAR	Situation or Task Action and Result
SWA	Safe Work Australia
SWI	Safe work instructions
SWP	Safe work procedures
THA	Task hazard analysis
THIP	Triage Hazard Identification and Prevention Model
UME	Underground Mining Equipment
WA	Western Australia
WSA	Work Safe Australia

RISK ASSESSMENT AS A TOOL FOR MOBILE PLANT OPERATORS FOR SUSTAINABLE DEVELOPMENT: LESSONS FROM THE WESTERN AUSTRALIAN MINING INDUSTRY

1. INTRODUCTION

"The costs of not building safety into the way a company does business are counted not just in dollars and cents, but in lives lost and changed forever."
(Andrew Chaplyn State Mining Engineer and Director Mines Safety. 2017, p.4).

1. Background

On the 11th of September 2019 "Ricky Hanson, a 57 year old truck driver was fatally injured when the mechanism used to open and close a tarpaulin cover on a road train trailer failed while he was in the process of closing the cover" (Department of Mines, Industry Regulation and Safety, 2021, p.4). Following this on the 27th of January 2020 "Howard Prosser, a 64-year-old contractor received fatal crush injuries in an incident involving the tele handler he was operating at a mine." (Department of Mines, Industry Regulation and Safety, 2021, p.4). This is similar to in the previous financial year when on the 15th of August 2018 "Daniel Patterson, a 29-year-old haul truck driver was fatally injured when he lost control of a Komatsu 830E A/C haul truck and crashed into a windrow" (Department of Mines, Industry Regulation and Safety, 2020a, p.4). Also, when on the 20th of June 2019 "Andrew Herd, a 44 year old truck driver was fatally injured when the Caterpillar 775G dump truck he was driving out of the pit crossed a windrow and fell down the pit wall to the bench below" (Department of Mines, Industry Regulation and Safety, 2020a, p.4). The only cause of fatal injuries in the Western Australian mining industry in the 2019 – 2020; 2019-2018 financial years was related to mobile plant. Over the last 5 years, the most common cause of fatalities in the Western Australian mining industry has been mobile plant (Department of Mines, Industry Regulation and Safety,

2021) which helps to highlight the need for this research to be conducted to develop a risk assessment tool for mobile plant operators to use.

Mobile plant is used extensively in the Western Australian Mining Industry (Safe Work Australia, 2014). The number of workplace fatalities and injuries related to the use of mobile plant is significantly high compared to other work-related causes (Safe Work Australia, 2014). Australia has profited greatly from mining, however the number of lives lost to the industry over the years have been both staggering and tragic (Safe Work Australia, 2014). In 2016, the Department of Mines, Industry Regulation and Safety released an analysis of serious injuries, which was followed by a similar analysis of fatalities in 2016 (Resources Safety, 2016). A risk identified in both reports (Resources Safety, 2015; 2016) involved low-frequency high-consequence events associated with mobile plant that typically result in near-miss situations, serious injuries or fatalities. Three of the top ten critical activities listed in the fatalities report by Department of Mines and Petroleum (2016e, p. 7) involved run-away vehicles, vehicles over edges and vehicle collisions.

An analysis of the Western Australian mining industry's fatalities identified that the main causes were unsafe acts or workplaces, hours of work, employee non-compliance with procedures, and other causes (Department of Mines, Industry Regulation and Safety, 2014). One of the recommendations made in this accident analysis report was to take measures to reduce incidents related to mobile plants in the Western Australian mining industry; promote the involvement of more workers in hazard identification and risk assessment and promote more employee involvement in the development of principal hazard management plans and safe work procedures.

A fatality occurred in 2015 (DMIRS, Safety incident 2017d), in which a MPU (mobile processing unit) operator was attempting to reach the final ring of drilled holes from inside the EWP's (elevated work platform) charge-up basket. The EWP's basket was accidentally activated, moving upwards resulting in the MPU operator being crushed between the backs and the basket when he leaned on the controls. This incident would have been prevented if a proper risk assessment for use of EWPs underground was conducted earlier and actions related to hazard control were taken in light of a previous similar incident. Therefore, prior risk assessment is a powerful tool for mobile plant operators to promote workplace safety and implement effective hazard control measures.

According to Dubinski (2013), the concept of "sustainable development" applied to the mining sector has been gaining particular importance. Thus, one of the main challenges to sustainable development in the mining sector is how to reduce injuries and fatalities, particularly related to light and heavy vehicle management, by taking pro-active risk assessment measures and contributing positively to promoting a positive safety culture. This is a major reason for the need to conduct research related to risk assessment and risk management for the mobile plant used in the Western Australian mining industries. This research had a focus on the analysis of incidents related to mobile plant in the Western Australian mining industry and developed a Triage Hazard Identification and Prevention Model as an outcome of this research as both risk assessment and risk management make important contributions in reducing risk and eliminating hazards that will ultimately benefit mining companies.

1.2 What is Mobile Plant?

Mobile plant is plant that is provided with some form of self-propulsion that is ordinarily under the direct control of an operator and includes earth moving machinery (rollers, graders, scrapers, and bobcats), excavators, cranes, hoists, elevated work platforms, concrete placement booms, reach stackers and forklifts. Mobile plant is used extensively in Western Australian Mining Industry (Resources Safety, 2015). The use of mobile plant every year is associated with a significant number of workplace fatalities and injuries (Cedergren, 2013; Latimer, 2015). The essential characteristics of mobile plant is its mobility. Safe use of mobile plant is affected by the level of operator skill and experience, the particulars of the workplace environment, the presence of people in the workplace, design and manufacture limitations and maintenance requirements (Safe Work Australia, 2013, Cedergren, 2013; Latimer, 2015). Types of injuries associated with use of mobile plant depend on the type of mobile plant and working environment. Table 1 gives some examples of the mechanism of injuries commonly caused by various types of mobile plant.

Table 1

Common Types of Injuries associated with use of Mobile Plant

Mobile Plant	Common Types of Injuries Caused by Use
Mobile Crane	Crushing, caught between or entrapment, electrocution, sprains and strains, falls, striking, hearing loss, hitting
Forklift	Crushing, caught between or entrapment, electrocution, sprains and strains, striking
Tractor	Crushing, caught between or entrapment, sprains and strains, falls, striking, hitting
Elevating work platform	Crushing, caught between or entrapment, electrocution, sprains and strains, falls, striking, hearing loss, hitting
Excavator	Crushing, caught between or entrapment, electrocution, sprains and strains, falls, striking, hearing loss
Bobcat	Crushing, caught between or entrapment, electrocution, sprains and strains, falls, striking, hitting

Note: From *Identify, assess and control hazards* by Safe Work Australia, 2018a, Australian Government. (https://www.safeworkaustralia.gov.au/risk), Copyright 2018 Safe Work Australia

Vehicles and mobile plant moving in and around workplaces are a cause of occupational injuries and deaths in Western Australia (Department of Commerce, 2015)

Harris, et al. (2012) identified that fires on mobile plant caused 30% of incidents in the Western Australian and Queensland mining industry between 1994 and 2005. Donoghue et al., (2014) reported that vehicle roll overs and mobile equipment collisions with other machinery or with people were physical hazards in the Bauxite mining industry. Other causes of mobile plant use incidents and fatalities include failure of machine component parts, falls from elevated mobile plant while repairing or servicing plant, explosions, operator fatigue, and cognitive, physical, organisational and environmental ergonomic factors (Durga & Swetha, 2015).

1.3 Risk factors and injuries associated with use of mobile plant

Risk is defined as the chance of something happening that will have an impact upon objectives (Standards Australia, 2018). Workplace Risk Assessment and Control is a proactive or pre-event approach to examining any or all parts of the work site to ensure that risks are understood and controlled to a reasonable level. It is 'a participative approach for identifying potential production or maintenance operational losses' (Mine Safety Operations Branch, 2011).

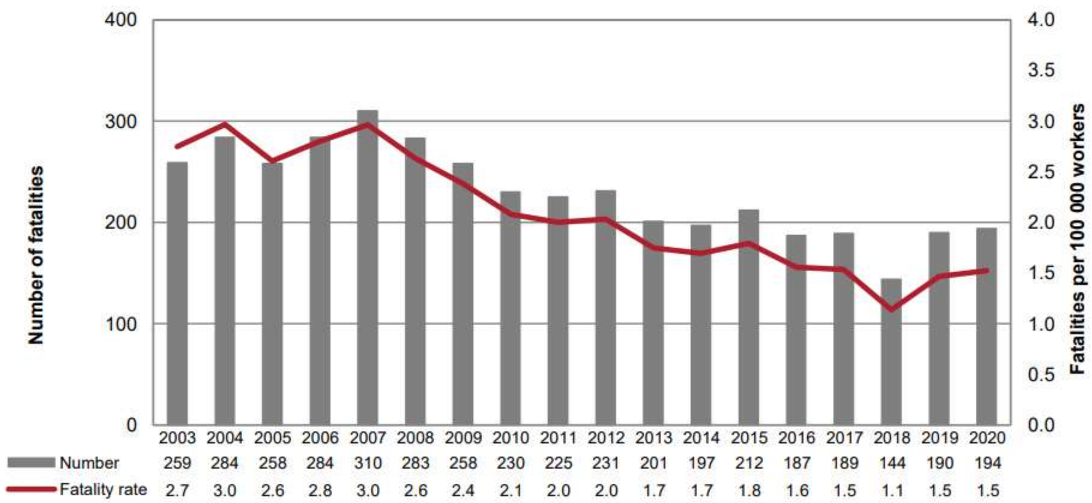
People who work with or near vehicles and mobile plant are most at risk. Serious and fatal incidents can occur during pedestrian movement near vehicles or plant, reversing and manoeuvring, arrivals or departures, loading or unloading, hitching or unhitching trailers, lowering ramps, mounting or dismounting from vehicles, securing of loads, movement of materials and maintenance work (Department of Mines and Petroleum, 2015a).

Common causes of mobile-plant-related incidents can be grouped into four categories (Toft et al., 2012). The first is the organisation of work and includes lack of, or inadequate, supervision; failure to communicate; time pressures; poor planning and design of the workplace, the task or the plant. The second is equipment, which includes poor selection of plant; lack of, or inadequate, maintenance; lack of or inadequate or faulty, control measures; manufacturing faults; design faults and environmental factors such as terrain. The third is procedures. Problems include lack of, or inadequate, procedures or failure to adhere to procedures; over-use or inappropriate use and maintenance or operation by unauthorised persons. The last is people. For people, causes can include lack of, or inadequate, training in plant use, operation or maintenance; lack of, or inadequate, knowledge of and/or experience with the plant and its operation, maintenance and limitations; lapses of concentration by the operator or people in proximity to the plant. Unauthorised access (Toft et al., 2012).

Over the past decade there has been a progressive downtrend in the number of fatalities across the Australian mining industry (Hagemann, 2014 and Safe Work Australia, 2014). This research commenced in 2017 and according to Industry Statistical Information (Safe Work Australia, 2020), the number of fatalities and fatality rate have been trending downward since 2007. In Australia, injuries at work resulted in the deaths of 190 workers in 2017, three more than in 2016. The highest number of work-related injury fatalities was recorded in 2007 when there were 310 deaths. Similarly, the fatality rate was 1.5 fatalities per 100,000 workers in 2017, which is 6 per cent less than the rate in 2016. The fatality rate in 2018 is the lowest since the series began and is around half the rate recorded at the peak in 2007 when there were 3.0 fatalities per 100,000 workers. See figure 1.

Figure 1

Worker fatalities: number of fatalities and fatality rate, 2003 to 2020



Note: From *"Work related Traumatic Injury Fatalities, Report 2020"* by Safe Work Australia, 2018, Australian Government. (https:// https://www.safeworkaustralia.gov.au). Copyright 2020 The Commonwealth of Australia.

In 2019 - 2020 mining fatalities comprising the 7th highest total number fatalities (7 fatalities in 2019 and 5 fatalities in 2020) of all industries in Australia. (Safe Work Australia, 2021). According to statistics released by the Department of Mines, Industry Regulation and Safety, Resource Safety Division (2020), from 2015-2016 to 2019-2020 in Western Australia there were 13 fatalities in the mining industry (including exploration) over the past five years, with one underground, eleven in surface mine operations and one in exploration.

1. The cause of the underground fatal accident which occurred during the five years from 2016 to 2020 was exposure to environmental heat.
2. The cause of the accident resulting in an exploration fatality was struck by object.
3. Of the seven types of surface fatal accidents occurring in the past five years the most common were:

1. vehicle or mobile plant rollover (3 fatalities)
2. caught by machine and fall from height (2 fatalities each).
3. This was followed by caught by or between objects, fall getting on or off vehicle, sting from insect and also struck by object (one fatality each). (Resources Safety Division, 2020)

1.4 Gaps in knowledge

The main gap in knowledge identified during the literature review was that there was no compilation of data in tabular form that directly specified the injuries and fatalities related to mobile plant, the type of mobile plant involved in the accidents or common mobile plant accident causes in the Western Australian mining industry. Another gap identified was the lack of published literature available, particularly for risk management, related to mobile plant in mining industries. These gaps in knowledge led to the following research aim and objectives as a need to conduct research to fill these knowledge gaps was identified to improve workplace and employee safety in the Western Australian mining industry.

1.5 Research Aim and Objectives

The aim of this research was to improve the safety performance of mobile plant operators in the Western Australia (WA) mining industry.

The objectives of the research were to:

1. Analyse the Resources Safety notifiable incident database to determine the causes of mobile plant accidents in the Western Australian mining industry between 2007 and 2016.

2. Observe mobile plant in use in mining workplaces to identify what strategies are in place to promote mobile plant safety and any safety barriers.
3. Conduct focus group interviews with mobile plant operators to identify their opinions on safety and risk control factors related to the use of mobile plant in their workplace.
4. Develop a "Triage Hazard Identification and Prevention Model" (THIP) to improve hazard awareness and control selection for prevention of workplace incidents associated with mobile plants to contribute to preventing low frequency severe consequence injuries related to mobile plants.

This research was primarily focused on lessons from Western Australian mining industry and learning from failures is an effective way to analyse and prevent the incidents as it has been researched as an outcome rather than the process itself. It has been argued by Madsen and Desai (2017) that learning from failures is basically related to improved performance. Moreover, Barach and Small (2000) also debate and then justify that learning from near misses helps in re-designing and improvement in overall processes.

1.6 What Was Known About This Topic

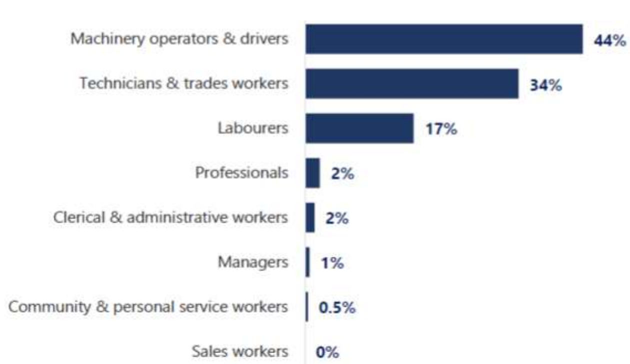
Historically, due to the associated high risk, plant (including mobile plant) safety has been highly regulated in all Australian jurisdictions under the principal health and safety Acts and Regulations (Toft et al., 2012). Most Australian jurisdictions developed detailed codes, guidance material and industry standards to compliment the regulations, and address particular types of plant and plant-related activities in specific industries (Toft et al., 2012). A *National Standard for Plant* (National Occupational Health and Safety Commission, 1994) was developed and incorporated to varying degrees into legislation in all jurisdictions. This guidance has been updated by Safe Work Australia (2018c) to the "Managing the risks of plant in the workplace Code of Practice". The practical nature of the plant-safety-management guidance material developed in the jurisdictions generally has been well received by Australian industries.

Safety and accident investigation professionals have been investigating accidents and recording results since the 19th century, with Du Pont leading the field in accident prevention (Toft et al.2012). A number of other studies, including those by Drupsteen and Hasle (2014), Labib and Read (2013) and Drupsteen and Wybo (2014), have identified failed industry learnings regarding the prevention of workplace injuries. However, these studies do not specifically identify the causes of injuries and risk assessment within the Australian general and mining industries. Further to this, the recommendations concluded from these studies are not focused on preventing one particular category of injury over another.

Data related to workers compensation lost time injuries in the Western Australian mining industry published by WorkCover WA (the government agency responsible for overseeing the WA workers compensation and injury management system) identified that there was no consolidation of mobile plant injuries and fatalities in the Western Australia mining industry that was published. According to Industry Statistical Information 2012/13 to 2015/16 (WorkCover WA, 2017) in all industries in Western Australia machinery operators and drivers were the employees who most likely to make a workers' compensation claim over the last five years with 554 lost time injuries amongst machine operators and drivers in 2015/16. See figure 2.

Figure 2

Lost-time claims proportion by Occupation



Note: From WorkCover WA Industry Statistical Report 2012/13 -2015/16, (p. 15), by WorkCover WA., 2016, Government of Western Australia.

(https://www.workcover.wa.gov.au/wp-content/uploads/2014/Documents/Resources/Annual%20reports/WorkCoverWA_AR2013_FINAL-version_interactive.pdf), Copyright 2016 WorkCover Western Australia.

According to the Accident and Injury Reports 2015-16 released by Department of Mines and Petroleum (Resources Safety, 2016, p.15), in the five years from 2011-12 to 2015-16 the most common fatal injuries were

1. struck by object (3 fatalities)
2. caught by or between objects, fall from height (2 fatalities)
3. vehicle or mobile plant rollover (1 fatality) (Resources Safety, 2016, p.15).

However, there was no compilation of fatal incident, serious injuries and lost time cases related to mobile plants that had been published. From the information that has been found on mining industries fatalities that have occurred due to the use of mobile plant it was evident that there was a need for this industry to have a specific tool to be able to identify mobile plant hazards and to know risk control measures to use to minimise the occurrence of mobile plant related incidents.

The following was known concerning Root Cause Analysis (RCA) techniques used in industry and their limitations in relation to mobile plant.

Table 2

Commonly used RCA Techniques and Limitations for Mobile Plant Risk Assessment.

Technique	Description	Limitations for mobile plant risk assessment & risk control
Event and causal factors (ECF) charting	An ECF chart is a flowchart that depicts the time sequence of a series of events and surrounding conditions leading up to the event causing the injury (Carhart & Yearworth, 2010). Events are displayed in cause-effects diagram (Standards Australia, 2016b).	Identifies some causal factors but does not necessarily determine the root causes (Energy Institute, 2008; Mahto & Kumar, 2008). This technique is too complicated for solving simple problems (Gravois, 2007).
Multilinear events sequencing (MES) and sequentially timed events plotting (STEP)	MCF and STEP are methods of data collection and tracking for the analysis of complex focus events (Benner, 1985). The results of this technique are displayed as a time-actor matrix of events (Morrison, 2004).	This technique is over-complicated for simple problems and injuries analysis. It needs explicit notation for recording the state of an on-going inquiry (Johnson, 2003; Johnson & Holloway 2003).
The 'why' method	The 'why' method is a technique of RCA analysis which guides through a causal chain by asking the question of why a number of times (usually 5) (Standards Australia, 2016a).	Is heavily dependent on the knowledge and expertise of the people answering the questions, with expertise in both technical failure modes and human error often required to reach the root cause (Phimister, et al., 2003).
Causes tree method (CTM)	CTM is a systematic technique for analysing and graphically depicting the events and conditions that contributed to a focus event (Bahr, 1997).	It is difficult to apply a CTM when an event occurs as a result in a change of quality in several areas (Pranger, 2009), where no single causal factor is a necessary causal factor (Katsakiori et al., 2009).
Why-because analysis (WBA)	WBA is a method of establishing the network of causal factors responsible for a focus event using a two-factor comparison test. The *why because* graph is a	In this technique, as the facts are not structured, WBA provides limited guidance on corrective action in the case where recurrence

	depiction of a network of factors (Ayeko, 2002).	needs to be prevented (Wisdom et al., 2006).
Fault tree method	Fault tree, or success tree, is a method to determine critical paths to success or failure with the help of a logic tree diagram (Attwood, Khan & Veitch, 2006).	Has no underlying model of causation. Provides no guidance on how to seek causal factors (Harms-Ringdahl, 2004). Requires an experienced practitioner (Wang et al, 2010).

1.7 New Knowledge Generated

This research has generated new knowledge that has identified the number, type and causes of mobile plant related incidents in the Western Australian mining industry for the period 1 /1/2007 to 31/3/2020 as described in chapter 4.

Further new knowledge generated was the importance of having positive communication between line managers and workers. This study identified that trust level was low between top management and workers down the line regarding that any concerns raised by employees of lower status in line management would be acknowledged and acted on. This factor was one of the contributing factors in raising the stress level and anxiety among the workers that ultimately affected the quality of their work. Research recommendations emphasize that more opportunities must be provided to mobile plant operators and maintenance workers to speak about and raise concerns, which are acknowledged and acted upon to reduce hazard risks of causing harm.

Other new knowledge generated was that there was a need to reduce the workload of Site Safety Officers by attaching a trainee to assist them with their site work as the Safety Supervisors at workplaces were mostly occupied with administrative responsibilities and paper work. This included responding to and conducting follow up actions on 20-30 emails a day, maintaining and updating safety registers, making and delivering presentations, all of which resulted in less time in workplace areas with the workers at the mine site. Recommendation have been made to improve the mine site Safety Supervisors excessive workload.

Additional new knowledge generated was that the biggest challenge for the mining companies was to train new mobile plant operators at mining sites to avoid operator injuries while working. Most of the operators recruited for the driving of dump trucks had no previous experience and they were inducted on the basis of having a driving license. This research has identified that more focus on site safety education, understanding of heavy vehicles and workplace safety procedures must be achieved by mining companies to contribute to preventing low frequency severe consequence injuries related to mobile plant and for the prevention of work place incidents associated with mobile plants in the Western Australian mining industries.

1.8 Research Significance

An outcome of this research was the development of a model named "Triage Hazard Identification and Prevention Model" (THIP). It was developed based on the findings of a review of published literature, the Resources Safety notifiable incident data base analysis and NVivo analysis of data collected from mining sites with the intent of pro-actively identifying hazards and preventing workplace injuries and fatalities.

It is anticipated that implementation of the research findings, model and recommendations would be of significant benefit for the Regulator, the mining industry generally, and that relevant companies could obtain maximum benefit by implementing the THIP model to reduce the occurrence of low frequency high consequences injuries, improve mining industry workers' productivity and industry profits. This model will provide investigators and risk assessment leads research-based information concerning known incidents and injuries related to mobile plant in the Western Australian mining industry.

The research findings and recommendations will help Department of Mines, Industry Regulation and Safety, mining companies and managers and safety professionals to tailor policies and work procedures that prevent injuries and improve the employment, lifestyle as well as health of mobile plant operators and other workers.

As this research is the first reported study to identify the causes of mobile plant incidents in the Western Australian mining industry the recommendations made from the research will be significantly beneficial in reduction in the occurrence of both low and high-level incident and injuries. This will have far reaching positive impacts for mining industries in Australia and other countries and ultimately lead the entire mining industry towards a "pro-active -generative" safety culture by creating a safe work environment for everyone.

1.9 Research Limitations

The principal limitation was the lack and quality of the available data related to mobile plant. It was identified during the literature review that there was no compilation of data in tabular form found which directly specified the injuries and fatalities related to mobile plant, or the type of mobile plant involved in the accidents, in the Western Australian mining industry. Therefore, this research will significantly assist in identifying and compiling data related to mobile plant accidents in the Western Australian Mining Industry.

The second limitation was found during the analysis of regulations and jurisdictions in all Australian States and Territories. It was identified that there were no specific regulations or acts or a code of practice for mining industry mobile plant, with the exception of autonomous mobile plant equipment.

A further limitation that occurred during data collection was the unavailability of mobile plant operators, workers and supervisors for conducting focus group interviews at mining sites. Although the mining companies co-operated well to arrange and organize meetings during site visits it was found to be too difficult to take four to six operators away from their work at the same time at most of the visited companies. Therefore, the researcher had to conduct one to one interviews with the participants to achieve research objective three.

Although a comprehensive analysis of mobile plant notifiable incidents was conducted it only covered mobile plant significant incidents in the Western Australian mining industry which may limit the application of the research findings to other countries where mobile equipment is not as technically advanced.

1.10 Outline of the Research Report

This research has been supported by the Department of Mines, Industry Regulation and Safety (DMIRS) and is comprised of seven chapters.

Chapter 1

The first chapter is an introduction to the research report. It describes the general background of the study and the information about the different types of mobile plants being used along with the hazard associated with their use. This is followed by research aim, research objectives, what was known about the topic, new knowledge generated through this study, research significance and research limitations. It provides an outline of the research report.

Chapter 2

The literature review chapter includes a description of the literature review methodology. This section highlights the important research published previously on mobile plant incidents particularly in Western Australian mining industry. It also describes the gaps in knowledge in this field. The literature review chapter is divided into three sections. Section one explores Risk Assessment techniques being used for analysing incidents related to vehicle collision at mining sites internationally and particularly in Australia. Section two primarily focuses on the causes of mobile plant /vehicle collisions at mining sites. Section three reviews published literature related to the methods and techniques being used in Western Australian mining industry for the prevention of mobile plants incidents.

Chapter 3

This chapter provides information on the research methodology and includes a description of the study design, setting and participants, data collection method and the methods of data analysis.

Chapter 4

This chapter includes the analysis of notifiable incidents related to mobile plant accidents in Western Australian mining industry between 2007 and 2020 from Resources Safety data base. It includes tabulation of cause-specific period prevalence of fatal and non-fatal accidents in the Western Australian mining industry. The chapter provides the answer to the first research objective and determines the causes of mobile plant accidents in the Western Australian mining industry.

Chapter 5

Chapter 5 includes a discussion on the different types of mobile plant being used in Western Australian industries and primarily focuses on the types that were identified as being used when the researcher visited mine sites. Strategies that are in place to promote mobile plant safety and the safety barriers which were present at mining sites which were visited are described.

Chapter 6

Chapter 6 presents the results of the individual and focus group interviews conducted with mobile plant operators, mobile plant workers in workshops and the plant managers at four mining sites. The chapter identifies the overall opinion of the workers on safety and risk control factors related to the use of mobile plant in their workplace.

Chapter 7

The final section explains the research conclusions. It highlights the main findings of the research and draws recommendations for the future studies.

1.11 Introduction Summary

This chapter has documented the research background, research aim and objectives, what was known about the topic, new knowledge generated, research significance and limitations. The next chapter reviews historical and currently published literature concerning mobile plant incidents, hazards, risk assessment and risk control methods.

2. LITERATURE REVIEW

2.1 Introduction

The purpose of this literature review was to provide a theoretical foundation for the research by reviewing previously published literature about mobile plant accidents particularly in the Western Australian mining industry. The review focused on the different types of risk assessment techniques used in international and in Australian published information for the analysis of incidents related to mobile plant, causes of vehicle collision and the published literature related to the prevention of mobile plant accidents. The chapter begins with an introduction to the literature review methodology.

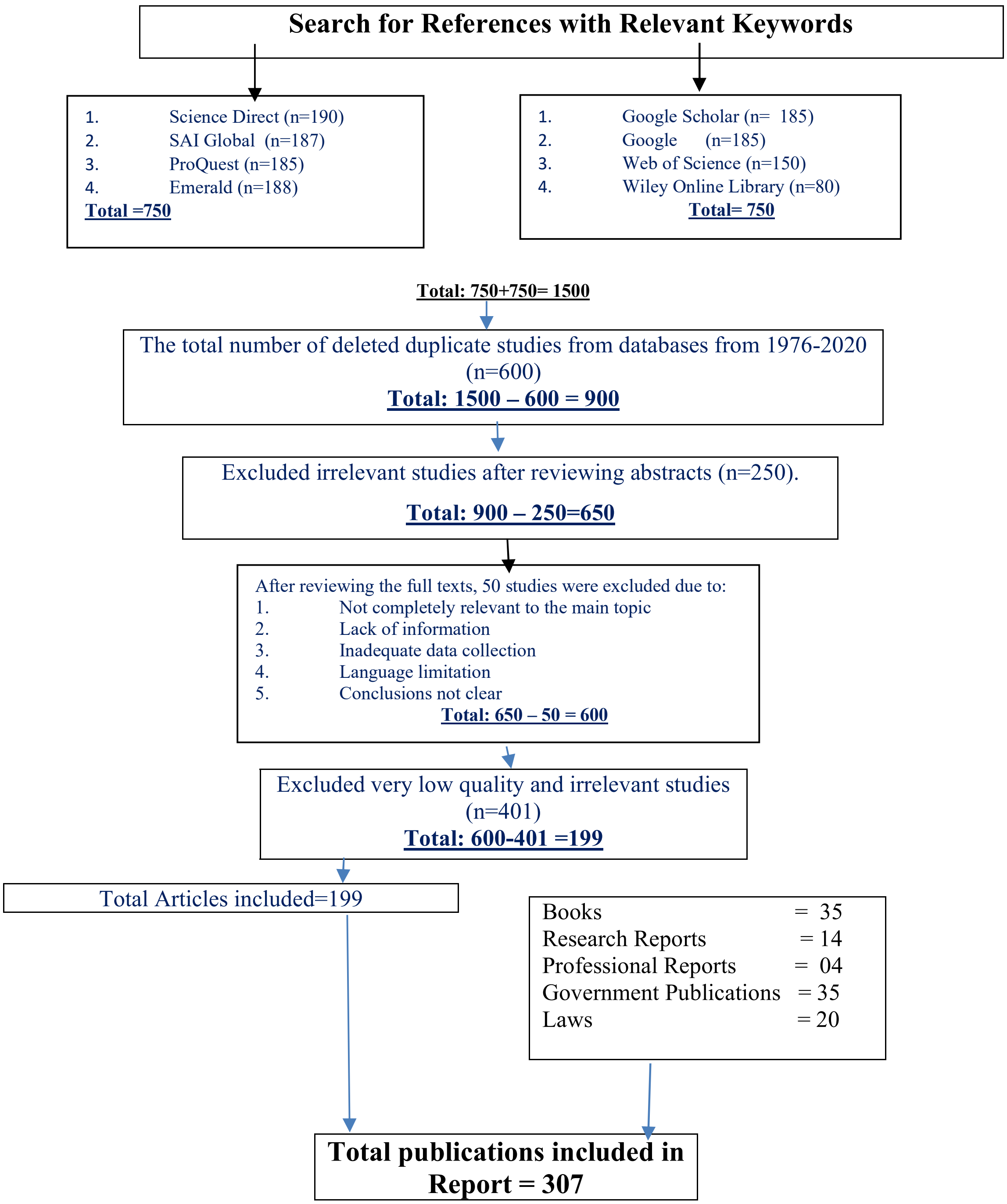
2.2 Literature Review Methodology

The literature review was conducted using an initial search of the databases Science Direct, PubMed, ProQuest, Emerald, EBSCO, SAGE, Wiley Online Library and Web of Science. Other searches were conducted through Google Scholar, a Curtin University library catalogue search and through exploring the Western Australian Department of Mines, Industry Regulation and Safety websites. The literature search was limited to the English language and included published literature from 1971 to 2021. In graphs and figures relevant statistics published by the Department of Mines, Industry Regulation and Safety and by Safe Work Australia are included.

A total of 1500 relevant references were identified using the relevant keywords. Relevant key words used in the literature search were *mobile plant*, *causes of mobile plant accidents*, *legislation for prevention of mobile plant accidents*, *risk assessment methods*, *mobile plants accidents from 2006 to 2020 in Western Australia*, *causes of fatalities in Western Australian mining industry*, *risk assessment in mining industry*, *what is sustainable development*, *prevention of mobile plant accidents*. The method used for the literature search and screen process is summarised with the figure 3 flow chart.

Figure 3

Method of Literature Review Process.



The first section of the literature review describes risk management in detail along with risk assessment techniques and methodology used internationally and in the Australian mining industry.

SECTION ONE

Risk and Risk Assessment in the Australian Mining Industry

2.3 Introduction

A systemic literature review was conducted to understand the concept of occupational health and safety management systems (OHSMS) over the last 10 years. A variety of OHSMS based standards, risk assessment guidelines and audits were reviewed (Standards Australia, 2018; Frick et al., 2000; Gallagher et al., 2003; Grayham & del Rosario, 1997) along with statistics published at Department of Mines, Industry Regulation and Safety website.

As documented in “Managing the risks of plant in the workplace” published by Safe Work Australia (2018a), hazards generally arise from four aspects of work and their interaction. These work aspects are the physical work environment, equipment, materials, and substances used, work tasks and how they are performed, work design and management. Hazards may be identified by looking at the workplace and how work is carried out. It is also useful to talk to workers, manufacturers, suppliers and health and safety specialists and review relevant information, records and incident reports (Safe Work Australia, 2018a, p. 13)

A hazard is a source with the potential to cause harm while risk is how likely the hazard will give rise to unacceptable consequences (Verma & Chaudhri, 2014). The evaluation of levels of risk associated with identified hazards provides information as to what extent, and with what priority, the mitigation plan for the hazards identified are to be prepared and implemented. This allows the timely treatment of the most hazards, which ultimately should prevent some mishaps from happening (Verma & Chaudhri, 2014).

Risk is a complex concept difficult to define in a single sentence. According to Shorter Oxford English Dictionary (1973) the word 'risk' was first used in the English language in the 17th century and probably evolved from the Italian or French word meaning to run into danger. Early usage of the word as a noun is in the sense of exposure to mischance or peril, or the chance of loss. This dictionary also records early usage of the verb 'to risk' as to venture upon, or to take the chance of. Today the word risk is used in multiple ways in the English language (Hamilton et al., 2007). Often in common usage the words risk, danger and hazard are used synonymously. In technical and safety publications, more precision is required.

Hansson (2004) identified five common uses of the word in technical publications:

1. Risk as an unwanted event that may or may not occur.
2. Risk as the cause of an unwanted event that may or may not occur. (This is also a definition of a hazard.)
3. Risk as the probability of an unwanted event that may or may not occur.
4. Risk as the statistical expectation value of unwanted events that may or may not occur. [A statistical expectation value is the sum of the values of each possible outcomes multiplied by its probability]. Risk as the fact that a decision is made under conditions of known probabilities (*decision under risk*) (Hansson, 2004, p. 1).

Risk assessment and accident investigations have evolved with the development of complex socio-technical systems and associated complexities of their related accidents; the rise of industrialised manufacturing being a clear example (Coury et al., 2010). The Australian Standard for Risk Management, AS ISO 31000:2018 Risk Management – Guidelines, is the current Standard guideline used in Australian workplaces for risk management. This Standard provides a generic guide for managing risks and is a common starting reference for all forms and areas of risk management. Risk is defined as "effect of uncertainty on objectives. An effect is a deviation from the expected. It can be positive, negative, or both, and can address, create or result in opportunities and threats. Risk is usually expressed in terms of risk sources, potential events, their consequences and their likelihood" (Standards Australia, 2018, p. 1).

As described in "WHAT IS RISK" published by the Department of Mines, Industry Regulation and Safety (DMIRS) (2017), a risk is the chance of something happening that will have a negative effect. The level of risk reflects the likelihood of the unwanted event and the potential consequences of the unwanted event (Department of Mines and Petroleum, 2017). A hazard is a source or a situation with the potential for harm in terms of human injury or ill health, damage to property, damage to the environment, or a combination of these. Hazards at work may include noisy machinery, a moving vehicle, chemicals, electricity, working at heights, a repetitive job or inappropriate behavior that adversely affects a worker's safety and health. (Department of Mines and Petroleum, 2017).

In 1995 the Western Australian Mine Safety and Inspection Act 1994 (MSIA) replaced the previous Mines Regulations and Acts and introduced Safety and Health Representatives into the Western Australian mining industry (Gilroy & Jansz, 2014). The Western Australian *Mine & Safety Inspection Regulations 1995* requires mines to conduct occupational safety and health risk assessments in relation to certain high risk, prescribed hazards associated with ground instability, inrush, atmospheric contamination, mine shafts, conveyors, earth moving machinery, fire, explosives, electrical work and mine roads. *Mine Health & Safety Inspection Regulations 1995 of Western Australia* section 6.2 documents that during the design of a mine, the designer must consider whether the risk of exposure may be reduced by ensuring the plant is designed according to the relevant Australian Standard. Also by ensuring that any powered mobile plant is designed to reduce, as far as is practicable, the risk of overturning, or of a falling object coming into contact with the operator and ensuring that where, despite reduction measures, there is a risk of exposure to a situation where:
(i) a powered mobile plant may overturn; or
(ii) a falling object may come into contact with the operator of a powered mobile plant; or

(iii) the operator of a powered mobile plant may be ejected from the seat, the risk of exposure to a hazard in that type of situation is limited by the provision of an appropriate combination of operator protective devices.

Further these regulations require that a system is implemented to identify any hazards associated with the plant and assess the risks of an employee being exposed to those hazards; and all practical measures are taken to reduce those risks. [Part 2, Div 1, (Sub division 1)].

As defined by Verma and Gupta (2013) in "Risk Assessment in mining industry" a hazard is anything that has potential to cause harm and risk is how likely it is that a hazard will cause actual harm. Having defined the work to be undertaken a risk assessment will give a clearer picture of what could go wrong and how serious an accident could be; what could cause injury or harm; whether the hazards could be eliminated, if not and what preventive or protective measures are, or should be, in place to control the risks (Verma & Gupta, 2013). Risk management is therefore defined as "the coordinated activities to direct and control an organization with regard to risk." (Standards Australia, 2018, p. 1).

In the context of the sustainability challenge, the mining industry has to manage numerous risks throughout the mine life cycle by reducing risks to acceptable levels while pursuing business objectives and opportunities. A common approach is to define risk as the combination of the probability (or likelihood) and consequence of an event (or outcome or result of exposure).

Investigating accidents is thought to contribute to preventing recurrence of similar accidents (Benner, 1985; Dekker, 2011; Toft et al., 2012), specifically by finding out what happened, why it happened and identifying actions that can be implemented to prevent recurrence (United States Department of Energy [DOE], 1992; Sklet, 2004; Boraiko et al., 2008).

2.4 Risk Assessment Method and Process

Risk assessment is a technique that helps mine operators to identify low, medium, high levels of risk associated with hazards. This helps them to prioritize the hazards based upon the levels of risk associated with them, so that hazards with the highest potential to cause harm can be mitigated and a safe work environment can be developed. Risk assessment is a requirement of the Western Australian Mines Safety & Inspection Regulations 1995. Risk management is a proactive process that can be used for managing safety and health risks in the workplace. Although it is the responsibility of leadership to manage risks, developing and maintaining psychologically healthy and safe workplaces relies on everyone participating in the risk management process (Department of Mines, Industry Regulation and Safety, 2020d).

Risk management is essential for preventing injury and disease. It includes spotting the hazards, assessing the risks and making the changes necessary to eliminate the hazard or minimise the risk of injury or harm to health (Department of Mines, Industry Regulation and Safety, 2020d, p.4). Adopting a risk management approach helps organizations to prevent and reduce the number and severity of injuries and illnesses from exposure to psychosocial hazards and risk factors, promote worker health and wellbeing and identify and take opportunities for continuous improvement and innovation in their safety and health management systems (Department of Mines, Industry Regulation and Safety, 2020d, p.4)

Risk management is recognized as an integral component of good management and governance. It is an iterative process consisting of steps, which, when undertaken in sequence, enables continual improvement in decision-making (Department of Mines, Industry Regulation and Safety, 2020d). Risk management is the term applied to a logical and systematic method of establishing the context, identifying, analyzing, evaluating, treating, monitoring and communicating risks associated with any activity, function or process in a way that will enable organizations to minimize losses and maximize opportunities. (Department of Mines, Industry Regulation and Safety, 2020e). The first step in the risk management process for mobile plant is to identify all hazards associated with plant in the workplace. This involves finding things and situations that could potentially cause harm to people (Safe Work Australia, 2018a, p 13).

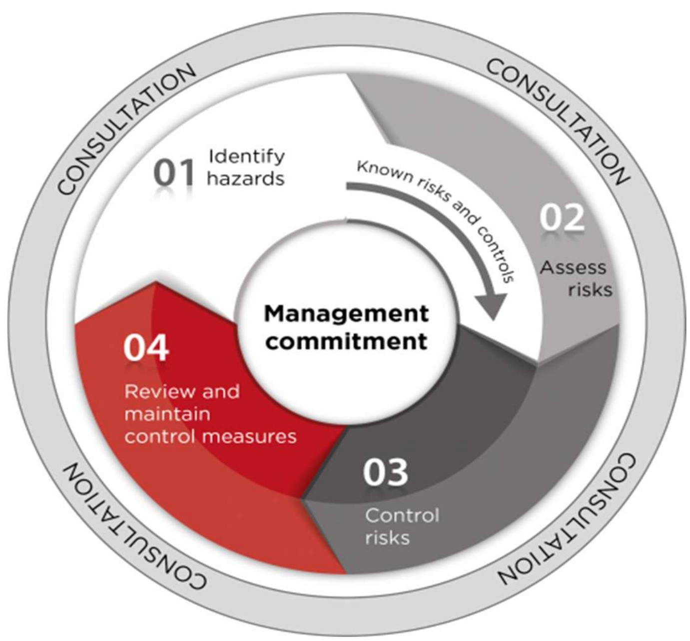
To assess the risks, the team must have an understanding of the context in which a hazard can be controlled. The objective is to eliminate the risk, however it is not always possible. Risk level criteria are agreed on at the commencement of the process. Risk criteria set the "acceptable" level of risk against which each risk is to be assessed. The criteria allow the team to determine what action needs to be taken to control the risk. Before identifying the hazards and assessing the risk, the team needs to agree on what is an "acceptable level of risk" for that workplace, and this becomes the "risk criteria" against which risks are assessed (Department of Mines, Industry Regulation and Safety, 2020). Risk management is as much about identifying opportunities as avoiding or mitigating losses (Department of Mines, Industry Regulation and Safety, 2018c).

The Department of Mines, Industry Regulation and Safety (2020d), reported that the main elements of the risk management process are to (1) establish the context which means establish the context in which the rest of the process will take place and the criteria against which risk will be evaluated should be established and the structure of the analysis defined. (2) Identify risks as to what, why and how things can arise as the basis for further analysis. (3) Analyse risks to determine the existing controls and analyse risks in terms of consequence and likelihood in the context of those controls. Analysis should consider the range of potential consequences and how likely those consequences are to occur. (4) Evaluate risks and compare estimated levels of risk against the pre-established criteria so risks can be ranked and management priorities identified. (5) Treat risks with low-priority risks monitored and reviewed and for higher consequence risks, develop and implement a specific management plan or procedure that includes consideration of all aspects required to mitigate the risk of harm to an acceptable level. (6) Monitor and review the performance of the risk management system and changes that might affect it. (7) Communicate and consult with internal and external stakeholders as appropriate at each stage of the risk management process as well as the process as a whole (Department of Mines, Industry Regulation and Safety, 2020d).

The following figure 4 is a depiction of Risk Management criteria as documented by Safe Work Australia (2018a). It shows the most important four steps in Risk Management. The fourth step is highlighted with RED because *review and maintain control measures* are important to check that what has been done has actually controlled the risks as much as reasonably practical and not created new risks. Maintain means that the risk control measures are continued.

Figure 4

Risk Management Criteria



Note: From *A step-by-step approach to managing WHS risks*, by Safe Work Australia, 2018, Australian Government.

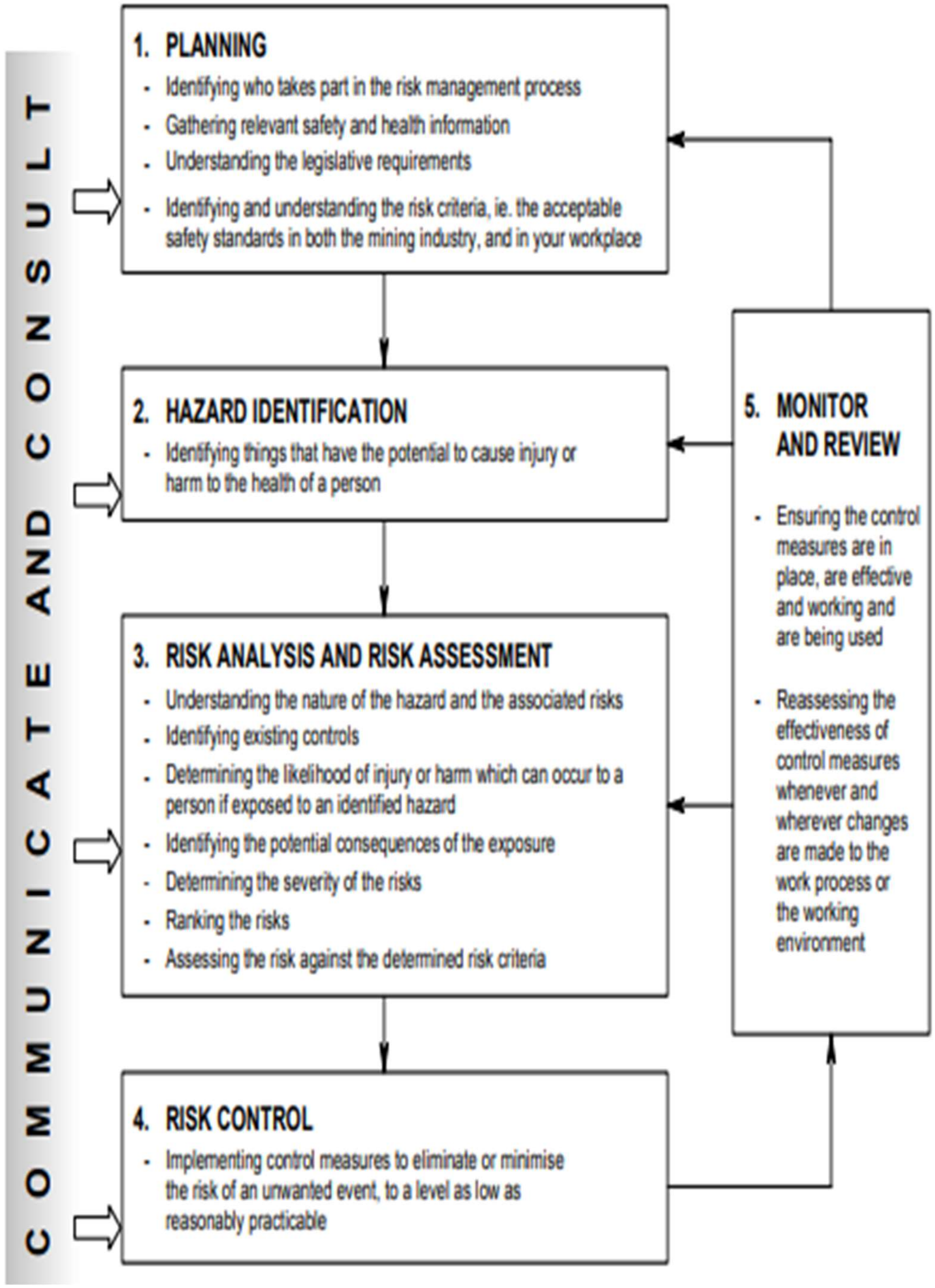
(https:// https://www.safeworkaustralia.gov.au/risk). Copyright 2018 The Commonwealth of Australia.

According to the Department of Mines, Industry Regulation and Safety (2020d), an important Risk Management step is consultation with workers and their health and safety representatives which is required for each step of the Risk Management process. By drawing on the experience, knowledge and ideas of the workers, there is more likelihood of identifying all hazards and to being able to choose effective risk control measures

Another step in Risk Assessment is deciding what is reasonably practicable to protect people from harm. This requires taking into account and considering all the relevant matters, including: the likelihood of the hazard or risks occurring, the degree of harm that might result from the hazard or risks, knowledge about the hazard or risks and ways of minimizing or eliminating the risks and the availability and suitability of ways to eliminate or minimize the risk. According to the act mentioned in Work Health and Safety Act 2020 (WA), s. 17, 18 and published by DMIRS (2020d) , after assessing the extent of the risk and the available ways of eliminating or minimizing the risks, the cost associated with available ways of eliminating or minimizing the risks, including whether the cost is grossly disproportionate to the risk must be determined (Department of Mines, Industry Regulation and Safety, 2020d).

Figure 5

The Risk Management Process.



Note. From *Safety and Risk Management Guidelines* (p. 4), by Department of Industry and Resources, 1999, The Government of Western Australia. (http://www.dmp.wa.gov.au/Documents/Safety/MSH_G_SafetyAndHealthRisk Management.pdf). Copyright 1999 The Government of Western Australia.

According to guidelines as mentioned in Standard Australia risk process can play a vital role in reducing fatalities and adverse incidents and recommends that the risk assessment team include management, supervisors, the employees who can be exposed to hazards and that further the team members be selected depending on their expertise, work area and activity being assessed. The purpose of risk identification is to find, recognize and describe risks that might help or prevent an organization achieving its objectives. Relevant, appropriate and up-to-date information is important in identifying risks. (Standards Australia, 2018, p. 11).

One of the first published models of risk assessment was the Nertney Wheel that was named after Bob Nertney (Nertney & Bullock, 1976). In 1976 Nertney was employed at EG&G in Idaho and was thinking about what aspects of the work process were involved in keeping people safe. The three requirements for people, equipment and work practices that he came up with made sense and were practical to use when managing work related risks. Nertney considered that the heart and goal of the work process is production, but it needs to be done safely. Nertney and Bullock, (1976) wrote that this Wheel demonstrates the 4 components contributing to the safe and effective management of workplace activities. The components are people, safe methods of work, right tools for the job and a controlled work environment – not just climatic or physical conditions but also the "culture" within the workplace (Nertney & Bullock, 1976). These factors need to be considered to ensure safe, effective management of the work activities (Nertney & Bullock, 1976).

Figure 6

The Nertney Wheel

Note. From *Human Factors in Design* (p.208*)* by Nertney & Bullock, 1976, *US Department of Energy.*

An organization can use a range of techniques for identifying uncertainties that may affect one or more objectives. The Australian Standard AS ISO 31000:2018 provides a guideline of risk management factors, and considers tangible and intangible sources of risk, causes and events, threats and opportunities, vulnerabilities and capabilities, changes in the external and internal context, indicators of emerging risks, the nature and value of assets and resources. Consequences and their impact on objectives, limitations of knowledge, reliability of information, time-related factors biases and assumptions and beliefs of those involved are considered (Standards Australia, 2018, p. 11):

In the report *Evaluation of Safety Assessment Methods for the Mining Industry* (Battelle Pacific Northwest Laboratories, 1983), it is stated that analyzing risks is necessary in order to identify the relative importance or priority of controlling the risk of harm from an unwanted event. In the analysis made in the publication *Safety and Health Risk Management* by Department of Minerals and Energy (1999), it is recommended that the possible events be discussed to obtain information about their extent and nature to include all who could be affected; such as contractors, or visitors, to highlight those groups or individuals particularly at risk, and take into account and objectively assess the effectiveness of existing control measures (Department of Minerals and Energy, 1999, p. 8).

The Department of Minerals and Energy (1999) documented that for analyzing risk the team needs to consider the chance of the hazardous situation occurring, the likelihood, the extent of the harm that would result and the consequence. It is recommended that for each hazard, the team needs to determine how people are exposed, likelihood of exposure happening, frequency of exposure (when and how often), e.g., intermittent (decanting a hazardous substance), or continuous (noise) and consequences of exposure, e.g., fatality, serious injury or permanent health impairment, machinery damage, minor injury or reversible health effect, lost production time (Department of Minerals and Energy,1999, p. 8).

In summary, it can be concluded that Risk Assessment involves a detailed and systematic examination of each activity, location, or operational system to identify hazards. Furthermore, every task, especially for mobile plant, needs to be rated on the likelihood of any incident that could occur during the risk analysis process. For the mining industry a risk severity table for every task can be used by the workers at site to categorize the severity of risk and the necessary precautions be taken to significantly reduce the possible injuries and lost time cases.

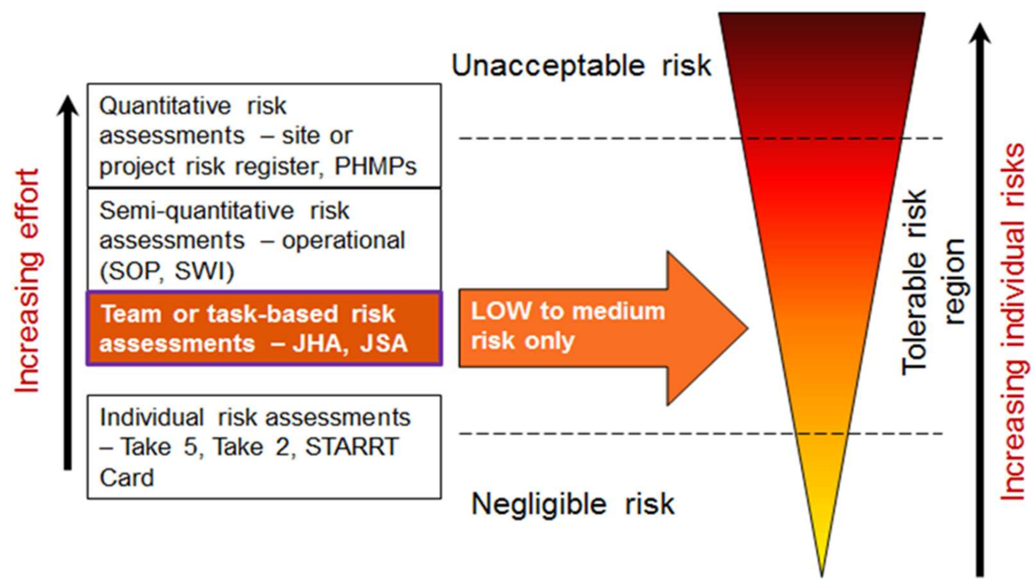
2.5. Types of Risk Assessment Used in Mining Industries

The main types of risk assessment used in mining industries are quantitative, semi-quantitative and task-based risk assessments which involve a detailed and systematic examination of any activity, location or operational system to identify potential hazards.

Internationally ISO 1210:2010 is the reference standard for carrying out risk analyses of machinery for industrial fields. Aven and Renn, (2009), Aven (2012), and ISO 1210:1210, (2010) define risk as the combination of two attributes (acronyms are taken from; ISO/TR 14121-2 (2012): Severity (Se), which is a rough quantification of the effect of the analysed incident scenario and Likelihood (Cl), which is a coarse estimation of the uncertainty regarding the occurrence of the incident scenario. As defined by Department of Mines and Petroleum (2015e), following are the types of Risk Assessment.

Figure 7

Types of Risk Assessment



Note. From *Mines Safety Road Show* (p.12) by Department of Mines & Petroleum, 2015, Western Australian Government.

Copyright 2015 by Department of Mines & Petroleum.

2.5.1 Semi-quantitative risk assessment

Wijeratne et. al., (2014) wrote that there are two semi-quantitative risk assessment methods for occupational risk assessment which are commonly used in mining industries. Wijeratne et. al., (2014) documented that semi-quantitative analysis is the most preferred technique of stating the risk in this industry and the risk calculator and the Wijeratne et. al., (2014) stated that semi-quantitative approaches to risk assessment are currently widely used to overcome some of the shortcomings associated with qualitative approaches as semi-quantitative risk assessments provide a more detailed prioritized ranking of risks than the outcomes of qualitative risk assessments.

Semi-quantitative Risk Assessment is primarily a term used to describe a risk assessment that will generally be used to assess a wide range of high and medium level risks associated with a complex group of individual tasks, like in assessing all of the contributing risks associated with operating an excavator at the bottom of a pit or learning to maintain and water haul roads. An example is a risk assessment developed during the process of writing a standard operating procedure (SOP) or safe work instruction (SWI) (Department of Mines and Petroleum. 2014)

2.5.2 Qualitative or task (team) based risk assessment

A qualitative risk value can be created for each unwanted event by using pre-established tables to assist in identifying the likelihood and consequences, usually the maximum reasonable (Joy, 2004). Joy (2004) in his paper explained the qualitative risk ranking approach in a very simple way using a risk-ranking table. He explained that the three consequence ratings are often all considered, with the highest risk rank in any category (1 is the highest rank) selected as the level of consequence. The method of deriving a risk rank is illustrated in the following table. Numbers are used to rank the unwanted events in order to devise methods to reduce the risks. Methods are commonly called risk controls and discussions occur for all the ‘unacceptable’ risk ranking scenarios (possibly rank 1–4).

Table 3

Risk ranking

Consequences	Likelihood				
	A	B	C	D	E
1	1	1	2	3	4
2	1	2	3	4	5
3	2	3	4	5	6
4	3	4	5	6	7
5	4	5	6	7	7

Note. From Occupational safety risk management in Australian Mining (p. 311-315), by Joy, J. 2004, Occupational Medicine

Hassan et al. (2009) developed a Quantitative Risk Assessment (QRA) with basic steps that included system definition, hazard identification, frequency analysis, consequence modelling, risk calculations and assessment to determine the safest route for the transportation of hazardous materials.

Team or task-based risk assessment technique is used to list the major components of a job and therefore the major hazards associated with that job

1. Examples are job hazard analysis (JHS) and job safety analysis (JSA). These are task-based risk assessment and applicable for the following:
   1. When exposure to hazards or potential risks are predicted to be low to medium
   2. Non-routine jobs and task planning where there is no SOP or SWI
   3. Routine jobs where there has been a change in the complexity, detail or make-up of the job
   4. Developing, reviewing or modifying existing SOPs or SWIs (Department of Mines and Petroleum, 2014)

Quantitative risk assessment is generally linked to principal hazard management plans (PHMPs). Sites will generally develop a project risk register or operational risk register that breaks down each hazardous component at a site and lists all of the associated hazards within each section (Department of Mines, Industry Regulation and Safety, 2018b)

2.5.3 Individual risk assessments

Individual risk assessments are undertaken by individuals, usually prior to commencing a task, to identify any hazards that may affect the worker. Hazards can be unsafe employee behaviour, machinery design, chemicals used, methods of work and working environment (NIOSH, 2005). Usually, hazard identification, estimation of exposure, and acceptability of the risk can be identified by risk assessment because they serve as a basis for controlling the hazard (British Standards Institution, 2004).

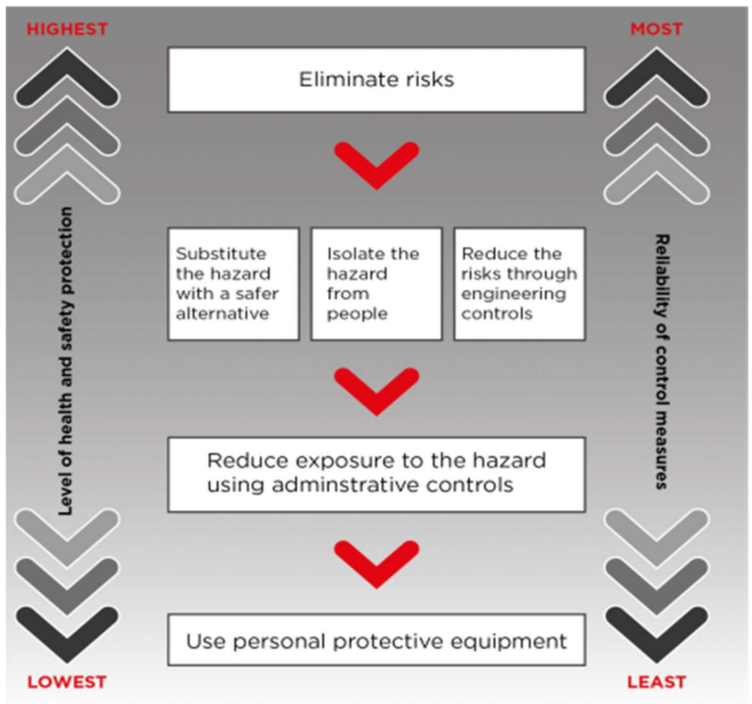
In the Department of Mines, Industry Regulation and Safety publication related to risk assessment tools, job safety analysis (JSA) is defined as one of several hazard identification and risk assessment tools used by the mining industry. There are many versions of this type of assessment tool being used in industry, including: job safety and environment analysis (JSEA), job hazard analysis (JHA), task hazard analysis (THA), safe job analysis (SJA), task safety analysis, pre-work safety check, and job task analysis (Department of Mines, Industry Regulations and Safety, 2020).

2.6. Hierarchy of Risk Control Measures

Ways of controlling risks are ranked from the highest level of protection and reliability to the lowest and this ranking is known as the hierarchy of risk control measures. The hierarchy of risk control measures can be applied in relation to any risk. (Safe Work Australia, 2017b). The hierarchy of risk control measures are explained by Butch de Castro (2003) who wrote that by understanding the hierarchy of risk control measures, the worker can prevent exposure to the hazard because the purpose of risk control is to prevent and eliminate, or minimize if the hazard cannot be eliminated, the exposure of the worker to the identified hazard. There are six steps in the hierarchy of risk control measures that commences with elimination of the hazard, followed by substitution with something less hazardous, isolation of the hazard, engineering control, administrative control and lastly the use of personal protective equipment (Butch de Castro, 2003). Risk of harm can be eliminated through using effective risk control measures. If elimination of the risk is not reasonably practicable, then the risk should be minimized by working through the other alternatives in the hierarchy (Safe Work Australia, 2017b). See figure 8

Figure 8

Hierarchy of Risk Control Measures



Note: From *Identify, assess and control hazards* by Safe Work Australia, 2017, Australian Government (https://www.safeworkaustralia.gov.au/risk). Copyright 2017 Safe Work Australia

Relatively new and less recognized types of risk associated with mining production are social and ecological in nature, that are associated with the concept of Sustainable Development (SD) and Corporate Social Responsibility (CSR) (Xu et al., 2018; Hąbek & Wolniak, 2016a, 2016b). Despite many successes in risk management implemented in mining production, mining enterprises are still highly vulnerable when it comes to risk, especially risks associated with external market conditions (Bluszcz, 2017). Risk control and risk reduction involves identifying and implementing a range of options to treat identified risks that fail to meet the agreed risk acceptance criteria. The Department of Minerals and Energy, (1999, p 9) have documented that risks of harm occurring should be made as low as reasonably practicable, irrespective of any absolute criteria and account should be taken of technological advances when controlling risks.

Although it is sometimes assumed that the level of risk is the primary criteria for decisions this is in fact not the case. The Australian Institute of Health and Safety (AIHS) (2020), states that there is no need to know the magnitude of a risk to consider whether further treatment is reasonably practicable, nor to decide how best to control the risk and that estimating the level of risk may not even be the best way to decide priorities for treatment. As an example, priorities may be set by considering consequences alone, or by considering the extent to which the level of risk can be reduced by the proposed controls rather than the initial level of risk, as there is little point in pouring more resources into a high risk which is already reduced as far as is reasonably practicable even though it remains a high risk. Risk is essentially a subjective concept so decisions about risk are recommended to take into account factors other than estimates of consequence and likelihood (Australian Institute of Health and Safety, 2020).

The OHS Body of Knowledge (Australian Institute of Health and Safety (AIHS), 20, p. 32), states that decisions about acceptability of risk and priorities depend on ethical considerations: i.e., what is the right thing to do and the equity considerations: i.e., who will gain and who will lose. Effective internal and external communication is important to ensure that those responsible for implementing risk management, and those with a vested interest, understand the basis on which decisions are made and why particular actions are required. The Department of Mines, Industry Regulations and Safety (2017b) documents that seeking those with a vested interest input will facilitate the process.

1. Risk Assessment Internationally and in the Australian Mining Industry

Denny et al., (1978) identified that across the globe, laws regulating the health and safety of workers are increasingly including requirements for risk assessment and risk management. Denny et al., (1978) also documented that in the European Economic Community and in Australia, Codes of Practice were developed to include risk assessment as part of the methodology to address areas such as plant safety, and the storage of hazardous chemicals. In the workplace, the risk assessment is conducted to identify the hazards that require more attention, sources, and effort to determine the risk level of each hazard. Alexander (2000) has stretched out the scope of the term *risk* to describe it as not only a hazard but as an unsafe practice. It is a danger that is capable of being insured, or a statistical probability. Today, while some companies do not have a corporate person designated as a risk manager, most companies at least perform the various functional aspects of risk management. Risk assessments have, by tradition, been based on the identification of hazards in the working environment (Lind et al., 2008).

In the Minerals Council of Australia (2002) *Safety and Health Performance Report of the Australian Minerals Industry* published by Minerals Council of Australia for *2001–2002* it was stated that the Australian coal mining industry started to investigate the use of more systematic safety engineering to reduce the highly unacceptable injury and fatality rates occurring in the industry. The report identified that initial interest occurred simultaneously within the regulatory agencies and the coal mining industry with the regulators presenting information on safety and risk management while the industry established a research project to investigate and trial the approaches. Since those early initiatives, risk assessment and management, often using system safety principles, has become an integral part of coal mining in Australia. Some of the initiatives have helped reduce the loss time injury frequency rate (LTIFR). In Australian coal mining from pre-1988 site levels sometimes exceeded 200 LTIFR while in 2001 they were experiencing less than 20 and, in some cases closer to 5 LTIFR. The trend is very positive leading some mining companies to believe that single figure LTIFR's are achievable (Mineral Council of Australia, 2002).

According to Safe Work Australia (2017b) the Australian Government does not regulate work health and safety in the mining industry, but this is regulated by the laws of the government of the State or Territory in which the mining work occurs (Safe Work Australia, 2017b). Table 4 is the complete depiction of the jurisdictions and mining legislative frameworks used in Australian States and Territories.

Table 4

Mining Legislative Framework in Australian States and Territories

Jurisdiction	**Mining OSH legislative** WHS requirements for mining are regulated through the:
New South Wales	Work Health & Safety (Mines and Petroleum Sites) Act 2013 Health & Safety (Mines and Petroleum Sites) Regulation 2014
Victoria	Chapter 5 of the Occupational Health & Safety Regulations 2007.
Queensland	Mining & Quarrying Safety and Health Act 1999 Mining & Quarrying Safety & Health Regulation 2001 Coal Mining Safety & Health Act 1999 Coal Mining Safety & Health Regulation 2001
Western Australia	Work Health & Safety Act 2020 Work Health & Safety (Mines) Regulations 2022 Work Health & Safety (Petroleum & Geothermal Energy Operations) Regulations 2022 Work Health & Safety (General) Regulations 2022
South Australia	Chapter 10 of the Work Health & Safety Regulations 2012
Tasmania	Mines Work Health & Safety (Supplementary Requirements) Act 2012 Mines Work Health & Safety (Supplementary Requirements) Regulations 2012.
Australian Capital Territory	Work Health & Safety Act 2011 Work Health & Safety Regulation 2011
Northern Territory	Work Health & Safety (National Uniform Legislation) Act Chapter 10 of the Mines Work Health & Safety (National Uniform Legislation) Regulations

Based on the mining legislative framework and relative jurisdictions a comparison of Risk Assessment Legislations used in Australian States and Territories is included. The Model Work Health and Safety Act and Regulations (2011) were developed by Safe Work Australia as an example model for Australian legislators to use for their State or Territory occupational safety and health legislation but are not law.

Table 5

Comparative Statement of Mining Legislative Framework in Australian States and Territories

Jurisdiction	Mining Legislative Framework	Safe Work Australia Model WHS Regulation Reference Number	Management of risks to health and safety	Safety Management System / Safety Case	Principal and Major Hazard Management Plan
New South Wales	WHS requirements for mining are regulated through the: Work Health and Safety (Mines and Petroleum Sites) Act 2013 Health and Safety (Mines and Petroleum Sites) Regulation 2014	cl 617 model WHS Regs cl 621 model WHS Regs cl 628 model WHS Regs. The columns provide information about the Risk Assessment and Management as recorded in Health & Safety (Mines & Petroleum Sites) Regulation 2014	In the NSW. mining legislation there is no specific legislation related to mobile plant risk management. General legislation risk management requirements are as follows. In conducting a risk assessment, the person must have regard to the (a) nature of the hazard, and (b) the likelihood of the hazard affecting the health or safety of a person, and (c) the severity of the potential health and safety consequences .(Work Health and Safety Regulation NSW,2014, [Part 2, Div 1 (Sub division 1)]	The safety management system must form part of any overall management system that is in place at the mine or petroleum site. (5) The safety management system must be designed to be used by the operator as the primary means of ensuring, so far as is reasonably practicable— (a) the health and safety of workers at the mine or petroleum site, and (b) that the health and safety of other persons is not put at risk from the mine or petroleum site or work carried out as part of mining operations or petroleum operations. * the safety management system must provide a	A principal hazard management plan must— * describe the nature of the principal hazard to which the plan relates, and * describe how the principal hazard relates to other hazards associated with mining operations or petroleum operations at the mine or petroleum site, and * describe the analysis methods used in identifying the principal hazard to which the plan relates, and * include a record of the most recent risk assessment conducted in relation to the principal hazard, and * describe the investigation and analysis methods used in

				comprehensive and integrated system for the management of all aspects of risks to health and safety in relation to the operation of the mine or petroleum site. * The safety management system must appropriate to the mine or petroleum site having regard to — * the nature, complexity and location of the mining operations or petroleum operations, and * the risks associated with those operations. * The safety management system must be documented [Part 2, Div 1 (Sub division 2)].	determining the control measures to be implemented, and * describe all control measures to be implemented to manage risks to health and safety associated with the principal hazard, and * describe the arrangements in place for providing the information, training and instruction required by clause 39 of the WHS Regulations in relation to the principal hazard, and * refer to any design principles, engineering standards and technical standards relied on for control measures for the principal hazard, and * set out the reasons for adopting or rejecting each control measure considered [Part 2, Div 2 (Sub division 2)]
Victoria	Chapter 5 of the Occupational Health and Safety Regulations 2007	Occupational Health and Safety Regulations 2007 S.R. No. 54/2007,	In the Victorian mining legislation there is no specific legislation related to mobile plant risk management.	(1) In order to assess the risks associated with major mining hazards, the operator of a prescribed	No legal requirement for a hazard management plan.

		Occupational Health and Safety Regulations 2007 S.R. No. 54/2007, Risk Assessment and Management as is described in the Occupational Health and Safety Regulations 2007	General legislation risk management requirements are as follows. In assessing the risks to health or safety associated with a mining hazard, the operator must have regard to — (a) the nature of the mining hazard; and (b) the likelihood of the mining hazard causing, or contributing to, any harm to any person; and (c) the severity of the harm that may be caused [Part 5.3, Div 2 (Sub division 1)].	mine must conduct a comprehensive and systematic Safety Assessment in accordance with this regulation. (2) A Safety Assessment must involve an investigation and analysis of the major mining hazards in order to provide the operator with a detailed understanding of all aspects of risks to health or safety associated with major mining hazards. (3) In conducting a Safety Assessment under this regulation, the operator must (a) consider the major mining hazards cumulatively as well as individually; and (b) use assessment methods (whether quantitative or qualitative, or both) that are	

				appropriate to the major mining hazards being considered [Part 5.3, Div 2 (Sub division 3)].	
Queensland	Mining and Quarrying Safety and Health Act 1999 Mining and Quarrying Safety and Health Regulation 2001	Mining and Quarrying Safety and Health Regulation, 2001, [Part 2 (Div 2)] Information about the Risk Assessment and Management is included in the Mining and Quarrying Safety and Health Regulation 2001	In the Queensland mining legislation there is no specific legislation related to mobile plant risk management. General legislation risk management requirements are as follows. (1) A person who has an obligation under the Act to manage risk at a mine must identify hazards in the person's own work and activities at the mine. (2) The operator must ensure hazard identification for the mine's operations is done during the operations' planning and design. (3) The site senior executive must ensure hazard identification is done — (a)	No legal requirement	No legal requirement

			when operations start at the mine; and (b) during the operations; and (c) when the operations change in size, nature, complexity or another way; and (d) for a hazard caused by a hazardous substance or dangerous good periodically, at intervals not exceeding 5 years [Part 2 (Div. 2)]		
Western Australia	Mines Safety and Inspection Act 1994 Mining industry legislation when the research work was commenced Mines Safety and Inspection Regulations 1995		Mines Safety and Inspection Act 1994, part 6 -Safety in using certain types of plant in mines, contains risk management legislation for mobile that includes the Plant to be maintained and operated in a safe manner, s6.2. Designers to identify hazards associated with plant and to assess risks, s6.3; As a minimum, consideration should be given to the following methods of risk reduction (a) ensuring that the plant is	No legal requirement	No legal requirement

			manufactured, inspected and, where required, tested according to the relevant Australian Standards and having regard to the designer's specifications; (b) ensuring that if after supply to a mine, any plant is found to have a fault that may affect safety or health, as far as is practicable, the person to whom the plant was supplied is advised of the fault and what is required to rectify it; (c) ensuring that there is sufficient access and egress to the parts of the plant that require cleaning or maintenance, and to the operator's workstation for normal and emergency conditions; (d) providing emergency lighting, safety doors and alarm systems, if access to the plant is required as part of its normal operation and persons may become entrapped and at risk of being exposed to hazards due to heat, cold or lack of oxygen;		

			(e) attempting to reduce, as far as is practicable, any risk of exposure to a hazard created by dangerous parts during operation, lubrication, adjustment or maintenance [part 6 (div 2)] General legislation risk management requirements are as follows. An employee at a mine must take reasonable care — (a) to ensure his or her own safety and health at work; and (b) to avoid adversely affecting the safety or health of any other person through any act or omission at work. (2) Without limiting the generality of subsection (1), an employee contravenes that subsection if that employee — (a) fails to comply, so far as the employee is reasonably able, with instructions given by that employee's employer or the manager of the mine for the		

			employee's own safety or health or for the safety or health of other persons; or (b) fails to use such protective clothing and equipment as is provided, or provided for, by the employer as mentioned in section 9(1)(d) in a manner in which the employee has been properly instructed to use it; or (c) misuses or damages any equipment provided in the interests of safety or health; or (d) being an underground worker, fails on leaving work at the end of a shift to report to the person in immediate authority over that employee and, where practicable, the person relieving that employee, on the state of that part of the works where the employee has been working. (3) An employee must cooperate with his or her employer and the manager of the mine in the carrying out by those persons of the obligations imposed on those persons under this Act 1994 of		

			Mining Safety and Inspection [Part 2 (Div. 2)]. Describes legal requirements for risk management s. 17 and follows this with a description of what is reasonably practicable for ensuring health and safety s. 18. Describes the duties of the person conducting the business or undertaking in relation to risk management s. 19; plant designers duties, s. 22; plant manufacturers duties, s. 23; plant importers duties, s.24; plant suppliers duties, s. 25; duties of the person conducting a business or undertaking who commission plant, s. 26; duties of mobile plant workers, s. 28. Describes "Managing risks to health and safety' in chapter 3 of the Regulation. for risk management. [Part 3.1 (Chapter. 3)]. This chapter defines the "Hierarchy of control measures" to use to prevent incidences.		

	Current legislation is the Work Health and Safety Act 2020		1- Part 3.1 applies if it is not reasonably practicable for a duty holder to eliminate risks to health and safety. 2- The duty holder must minimise risks, so far as is reasonably practicable, by doing 1 or more of the following— (a)substituting (wholly or partly) the hazard giving rise to the risk with something that gives rise to a lesser risk. (b) isolating the hazard from any person exposed to it. (c) implementing engineering controls. This chapter defines the duties of duty holder in order to manage risks as follows: (a) eliminate risks to health and safety so far as is reasonably practicable; and (b) if it is not reasonably practicable to eliminate risks to health and safety — minimise those risks so far as is		

	Work Health & Safety Mines Regulations 2022		reasonably practicable. [Part 3.1 (Chapter. 3)]. The safety case is to include: 3 (a) identification all hazards to the health and safety of persons. (b) a detailed and systematic assessment of the risk associated with each of those hazards, including the likelihood and consequences of each potential major accident event; and (c) identifies the safety critical elements that are necessary to minimise that risk so far as is reasonably practicable; and (d) demonstrates that the risk associated with each hazard has been minimised so far as is reasonably practicable; and (e) demonstrates that the methodologies used in the formal safety assessment are appropriate and adequate.		

		Work Health and Safety (Petroleum & Geothermal Energy Operations) Regulations 2022		Division 4, Subdivision 2, 27. Need to submit a safety case to the Regulator to be approved before the facility can operate. Section 33. Implementation and improvement of safety management system. The safety case for an operation must contain evidence showing that there are effective means of ensuring — (a) the implementation of the safety management system; and (b) continual and systematic identification of deficiencies in the safety management system; and (c) continual and systematic improvement of the safety management system. 36. Competence of workers. The safety case	

				for an operation must describe the means by which the operator of the relevant facility will ensure that each worker at the facility has the necessary skills, training and ability — (a) to undertake routine and non-routine tasks that might reasonably be given to the worker (i) in normal operating conditions; and (ii) in abnormal or emergency conditions. 41. Machinery and equipment. (1) The safety case for an operation must specify the equipment required at the relevant facility (including process equipment, machinery and electrical and instrumentation systems) that relates to, or may	

				affect, the health or safety of persons at the facility. (2) Without limiting sub regulation (1), the safety case for an operation must contain evidence showing that the required equipment is fit for its function or use — (a) in normal operating conditions; and (b) in an emergency (to the extent that it is intended to function, or be used, in an emergency). Section 55. The facility may not operate unless the Regulator has checked that the operation will be safe, and the Regulator has approved the safety case presented. Subdivision 6, Section 58. If there is any change in circumstances or operations the operator engaging in an operation	

				for which a safety case is in force must submit a revised safety case to the regulator as soon as practicable for approval by the Regulator for thee facility to continue to operate.	
South Australia	Chapter 10 of the Work Health and Safety Regulations 2012 (SA)	SA Work Health and Safety Regulation 551- Safety Case Outline SA Work Health and Safety Regulation 552- Safety Case Outline content SA Work Health and Safety Regulation 557- Emergency Plan SA Work Health and Safety Regulation 555- Safety Assessment	In the South Australian mining legislation there is no specific legislation related to mobile plant risk management. General legislation risk management requirements are as follows. In order to provide the operator with a detailed understanding of all aspects of risks to health and safety associated with major incidents, a safety assessment must involve a comprehensive and systematic investigation and analysis of all aspects of risks to health and safety associated with all major incidents that could occur in the course of the operation of the major hazard facility, including the following:	No legal requirement	No legal requirement

			(a)the nature of each major incident and major incident hazard; (b) the likelihood of each major incident hazard causing a major incident; (c) in the event of a major incident occurring, its potential magnitude and the severity of its potential health and safety consequences; (d) the range of control measures considered; (e) the control measures the operator decides to implement. In conducting a safety assessment, the operator must (a) consider major incidents and major incident hazards cumulatively as well as individually; and (b) use assessment methods (whether quantitative or qualitative, or both), that are suitable for the major incidents		

			and major incident hazards being considered. The operator must document all aspects of the safety assessment, including (a) the methods used in the investigation and analysis; and (b) the reasons for deciding which control measures to implement as mentioned in Work Health and Safety Regulations SA, 2012, [Part 7 (sec 7)]		
Tasmania	Mines Work Health and Safety (Supplementary Requirements) Act 2012 Mines Work Health and Safety (Supplementary Requirements) Regulations 2012	Regulation 4, Mines Work Health and Safety (Supplementary Requirements) Regulations, State of Tasmania, 2012, pp6 Regulation 5, Mines Work Health and Safety (Supplementary Requirements) Regulations, State of Tasmania, 2012, pp7 Regulation 6, Mines Work Health and Safety	A mine operator must ensure that a risk assessment in respect of the mine is undertaken at the following times: (a) before mining operations at the mine commence; (b) before the introduction, for the first time at the mine, of any plant or substance; (c) before work of a type not previously performed at a mine commences;	No legal requirement	A major hazard management plan may refer to or incorporate, with or without modification, standards or codes of practice or relevant guidance material, as in force at a particular time or from time to time. (3) A major hazard management plan may

		(Supplementary Requirements) Regulations, State of Tasmania, 2012, pp. 8 Regulation 8, Mines Work Health and Safety (Supplementary Requirements) Regulations, State of Tasmania, 2012, pp. 9 Regulation 13, Mines Work Health and Safety (Supplementary Requirements) Regulations, State of Tasmania, 2012, pp. 13	(d) when there is a change at the mine in the type of work, work practices or plant; (e) when new information becomes available concerning work, work practices, plant, or substances, at the mine, that may affect the health or safety of a worker or other person at the mine; (f) whenever a new hazard or potential hazard is introduced or identified at the mine. A risk assessment may be carried out – (a) on individual items of plant or substances; or (b) if multiple items of plant, or substances, of the same design or composition are installed and used under the same conditions – on a representative sample of the plant or substance, unless the risk to health and safety may vary according to who is operating the item or dealing with the substance Mines Work		(a) include trigger points or action points at which actions or procedures are to be taken or implemented if certain criteria specified in the plan are met; and (b) specify the actions or procedures to be taken or implemented at each trigger point or action point as mentioned in Mines Work Health and Safety (Supplementary Requirements) Regulations, State of Tasmania, 2012, [Part 3 (clause2)]. Further the major hazard management plan in respect of the risks to health and safety that are associated with the use at a mine of powered mobile plant as mentioned in Mines Work Health and Safety (Supplementary Requirements) Regulations, State of

			Health and Safety State of Tasmania, 2012, [Part 2 (clause 4)]. A mine operator, as soon as practicable after a risk assessment is carried out in respect of the mine as required under regulation 4 as mentioned above, must make a written record of – (a) the risk assessment; and (b) the measures taken to manage the risk to health and safety to which the risk assessment relates, Mines Work Health and Safety State of Tasmania, 2012, [Part 2 (clause 5)].		Tasmania, 2012, [Part 3 (clause 8)] is to make provision for the following matters: (a) the conditions under which the plant may be used, including reference to conformance to design parameters; (b) avoidance of contact with overhead structures; (c) identification of persons, or classes of persons, authorized to use the plant; (d) the steps to be taken before operating the plant; (e) conditions applying to ensure the safe carriage of persons and loads, including use of seatbelts and operator restraints, maximum carrying capacities and separation of people from loads;

					(f) the safe parking, refueling and recharging of the plant; (g) the arrangements for ensuring that the management of the movement and speed of the plant minimizes the risk to the health and safety of pedestrians and persons operating the plant; (h) the safety fittings, such as lights and alarms, to be required to be fitted to the plant; (i) steps to be taken on discovery of a defect in the plant.

Australian Capital Territory	Work Health and Safety Act 2011 Work Health and Safety Regulation 2011	Work Health and Safety Act 2011 -Major hazard facilities -Chapter 9 (Duties of operators of determined major hazard facilities) Part 9.3 (Determined major hazard facility) —safety case outline Division 9.3.2 Section 551 and Section 552) Work Health and Safety Act 2011-Major hazard facilities- Chapter 9 (Duties of operators of determined major hazard facilities) Part 9.3 (Determined major hazard facility)—management of risk Division 9.3.3 Section 555	In order to provide the operator with a detailed understanding of all aspects of risks to health and safety associated with major incidents, a safety assessment must involve a comprehensive and systematic investigation and analysis of all aspects of risks to health and safety associated with all major incidents that could occur in the course of the operation of the major hazard facility, including the following: (a) the nature of each major incident and major incident hazard; (b) the likelihood of each major incident hazard causing a major incident; (c) in the event of a major incident occurring, its potential magnitude and the severity of its potential health and safety consequences; (d) the range of control measures considered;	No legal requirement	No legal requirement

			(e) the control measures the operator decides to implement. (3) In conducting a safety assessment, the operator must - (a) consider major incidents and major incident hazards cumulatively as well as individually; and (b) use assessment methods (whether quantitative or qualitative, or both), that are suitable for the major incidents and major incident hazards being considered. (4) The operator must document all aspects of the safety assessment, including: (a) the methods used in the investigation and analysis; and (b) the reasons for deciding which control measures to implement (Work Health and Safety Regulation,2011), [Division 9.3.3 (Section 555)].		

From the Table 5 comparisons, it can be concluded that in the past fifty years, there has been a major safety improvement in workplace safety and health in the Australian mining industry as relevant acts and regulations of relevant States and Territories have been implemented by mining companies. However, there are no specific regulations or a code of practice for mining industry mobile plant, with the exception or autonomous trucks. This is a major gap identified during the review of the relevant legislation.

2.8 Inherent Risk Associated with Mining Industry and RCA Techniques and Limitations for Mobile Plant Risk Assessment Internationally and in the Australian Mining Industry

The mining industry has been known for having an unsafe working environment and has been one of the most hazard prone industries (Verma & Chaudhri, 2014). To maintain safety in the workplace, timely assessment of risk associated with different operations performed to extract ore from the ore body has become necessity (Verma & Chaudhri, 2014). Workers in any industry can be adversely affected in a hazardous working environment that can result in work related injuries, fatalities, and loss of workdays (Verma & Chaudhri, 2014). WorkCover Western Australia (2021) reported that in 2019/20 there were 115,68 employees in the Western Australian mining industries and 2,545 workers' compensation claims resulting in $131.6 million being paid for these claims, with an average claims cost of $82,940 per employees. Mobile plant and transport were responsible for 312 (23%) of the claims (WorkCover Western Australia, 2021).

Mining production is associated with many sources of risk. Some of them are of general nature and apply to all enterprises operating in the market economy (Bijańska & Wodarski, 2014). Many accidents and incidents occurred in the mining industries over the years demanding improvement in safety management (Lakshminarayan & Singh, 2000). To access how this can be effectively achieved knowledge of the nature and cause of these accidents is fundamental. Risk analysis plays a central role in the mining safety and health management framework. Lakshminarayan and Singh, (2000) wrote that the most common hazards in the mining industry identified over the years provide very useful information for risk analysis; for example – ground movement hazards, fire hazards, electricity hazards, falls hazards and including health hazards such as dust and toxic substance. Major risks involved in the mining industry appear to be people, ground movement, fall of ground, sides, fall of person from height/level/ and hit by objects (Lakshminarayan & Singh, 2000). Similarly, Safe Work Australia, (2016b) reported that inherent risks associated with working in the mining industry include body stressing, musculoskeletal disorders, slips, trips, falls, being hit by moving objects or machinery and working with high-risk plant.

Kecojevic and Radomsky (2004) studied loader and truck safety and identified that the severity and number of accidents involving loader and trucks were higher when compared to other operations and established fatality categories, causes of accidents and risk control strategies.The study revealed the major hazards resulting in fatal incidents for this equipment were due to failure of the victim to respect the equipment working area, failure of mechanical component, working under an unsupported roof, failure of management to provide safe working conditions or failure of mechanical components.

The purpose of risk identification is to find, recognize and describe risks that might help or prevent an organization achieving its objective. Relevant, appropriate and up-to-date information is important in identifying risks (Standards Australia, 2018, p.11). Using the list of hazards Standards Australia (2018) recommends that the team undertake the risk analysis by identifying possible consequences and the likelihood of adverse events occurring and the potential exposure. There are many ways an exposure or event can be initiated so it is important that all causes are considered (Standards Australia, 2018, pp 8).

Australian Standard AS 4804:2016 *Occupational health and safety management systems -General guidelines on principles, systems and supporting techniques* describes a systematic approach that can assist mine owners and employees to both meet the minimum regulatory requirements and lead to sustained improvement in safety and risk management performance. Standards Australia (2016b) documents that the guidelines can assist an organisation to establish its own safety management system or improve an existing safety management system. However, Standards Australia (2016c) does not prescribe the type, format or style of a safety management system that should be used as this Standard is aimed at a company of any size or type. A safety management system (SMS) for a mine is a tool that assists mine operators to systematically achieve and maintain a predetermined standard for managing safety and health and brings together the policies and procedures required to effectively mitigate (i.e. lessen the severity) the risks associated with the mining operations (Standards Australia, 2016c).

From the review of the published literature, it can be concluded that mining companies are recommended to follow a strict regime with reference to risk assessment of mobile plants and that involves a detailed and systematic examination of each activity, location, or operational system to identify hazards. The precautionary risk assessment reduces the likelihood and potential consequences of the risk of an identified hazard causing harm and requires reviewing current or planned approaches to controlling the hazard to prevent harm with the requirement for new, or better, hazard risk control measures to be added if needed.

A detailed review of published literature on Risk Assessment techniques has been conducted to identify the suitability of these risk assessment techniques for mobile plant risk assessment. As specified in the System Safety Engineering manual (1983) there are many different risk assessment techniques; each has its own specific purpose and outcome. The in-depth study and findings of these risk assessment techniques has provided a platform to develop a THIP (Triage Hazard Identification and Prevention Model) as no suitable technique has been found which is primarily focussing on mobile plants risk management to prevent injuries and fatalities. Table 6 includes examples of common Risk Assessment techniques used in industry and their limitations in relation to mobile plant.

Table 6

Commonly used RCA Techniques and Limitations for Mobile Plant Risk Assessment.

Technique	Description	Limitations for mobile plant risk assessment & risk control
Event and causal factors (ECF) charting	An ECF chart is a flowchart that depicts the time sequence of a series of events and surrounding conditions leading up to the event causing the injury (Carhart & Yearworth, 2010). Events are displayed in cause-effects diagram (Standards Australia, 2016).	Identifies some causal factors but does not necessarily determine the root causes (Energy Institute, 2008; Mahto & Kumar, 2008). This technique is too complicated for solving simple problems (Gravois, 2007).
Multilinear events sequencing (MES) and sequentially timed events plotting (STEP)	MCF and STEP are methods of data collection and tracking for the analysis of complex focus events (Benner, 1985). The results of this technique are displayed as a time-actor matrix of events (Morrison, 2004).	This technique is over-complicated for simple problems and injuries analysis. It needs explicit notation for recording the state of an on-going inquiry (Johnson, 2003; Johnson, et al.2003).
The 'why' method	The 'why' method is a technique of RCA analysis which guides through a causal chain by asking the question of why a number of times (usually 5) (Standards Australia, 2016a).	Is heavily dependent on the knowledge and expertise of the people answering the questions, with expertise in both technical failure modes and human error often required to reach the root cause (Phimister, et al., 2003).
Causes tree method (CTM)	CTM is a systematic technique for analysing and graphically depicting the events and conditions that contributed to a focus event (Bahr, 1997).	It is difficult to apply a CTM when an event occurs as a result in a change of quality in several areas (Pranger, 2009), where no single causal factor is a necessary causal factor (Katsakiori et al., 2009).
Why-because analysis (WBA)	WBA is a method of establishing the network of causal factors responsible for a focus event using a two factor comparison test. The *why because* graph is a depiction of a network of factors (Ayeko, 2002).	In this technique, as the facts are not structured, WBA provides limited guidance on corrective action in the case where recurrence needs to be prevented (Wisdom et al., 2012).

Technique	**Description**	**Limitations for mobile plant risk assessment & risk control**
Fault tree method	Fault tree, or success tree, is a method to determine critical paths to success or failure with the help of a logic tree diagram (Attwood et al., 2006).	Has no underlying model of causation. Provides no guidance on how to seek causal factors (Harms-Ringdahl, 2004). Requires an experienced practitioner (Wang et al, 2010).

Joy (2004) conducted an in-depth review of occupational safety risk management in Australian mining and documented that most Australian state mining regulators, in 2004, required risk assessment for development of management systems and other applications. Joy (2004) identified that many mining companies had gone beyond regulatory expectations, developing procedures and resources in the area that clearly indicate a ‘good-business’ belief behind the effort. According to Joy’s research findings published in his paper titled *Occupational Safety Risk Management*, the most common risk assessment techniques used by employers and employees in Australian mining are as follows.

· *Informal risk assessment* (RA) — general identification and communication of hazards and risks in a task by applying a way of thinking, often with no documentation.

· *Job safety/hazard analysis* (JSA/JHA) — general identification of hazards and controls in a specific task, usually for determining the basis of a standard work operation practice (SOP).

· *Preliminary hazard analysis/hazard analysis/workplace risk assessment and control* (PHA/HAZAN/WRAC) — general identification of priority risk issues/events, often to determine the need for a further detailed study.

· *Hazard and operability st*udy (HAZOP) — systematic identification of hazards in a process plant design.

· *Fault tree analysis* (FTA) — detailed analysis of contributors to major unwanted events, potentially using quantitative risk analysis methods.

· *Event tree analysis* (ETA) — detailed analysis of the development of major unwanted events, potentially using quantitative methods.

· *Failure modes, effects and criticality analysis* (FMECA) — general to detailed analysis of hardware component reliability risks (Joy, 2004)

When comparing table 6 and techniques described by Joy (2004) it can be identified that most of the risk assessment techniques are similar apart from some details. For instance, risk assessment techniques like multi-linear events sequencing (MES) and sequentially timed events plotting (STEP) are methods of data collection that track information. This type of risk assessment might not be suitable for mobile plant operators to perform while in the field. Therefore, these techniques are not listed as being used by Australian miners. Failure modes, effects and criticality analysis (FMECA), Event tree analysis (ETA), Fault tree analysis (FTA), Hazard and operability study (HAZOP) are listed in table 6 and by Joy as being broadly used in mining industry in Australia and internationally. Considering the limitations mentioned for each risk assessment technique in table 6, it can be concluded that initial risk assessment techniques including Informal risk assessment (RA) and Job safety/hazard analysis (JSA/JHA) are the most suitable technique for mobile plant operators to perform in the field before executing the work to keep them safe from accidents.

Through the review of published literature conducted as part of this research, it was identified that in the majority of the cases, the risk assessment technique used by Australian mining industry is a Qualitative Risk Assessment. From the review of published literature, it can be concluded that in Australian mining industry most of the time the main objective of Risk Assessment is to manage priority risks. This is the primary objective and does not require a quantitative risk assessment approach for an effective outcome. The literature showed that another reason for using a qualitative risk assessment approach is the wealth of industry experience at the management, supervisory and operational levels that can suggest event likelihood and subjective consequences during prior risk assessment sessions. The following table 7 analyses publications on the risk assessment techniques frequently used in the Australian mining industry.

Table 7

Analysis of Risk Assessment techniques frequently used in Australian mining industry.

Reference	Risk Assess Technique	Overview of the Technique	Use in Mining Industry	Risk Assessment Technique Process	Technique Strengths/ Limitations
Baybutt, P. (2013). Elliott & Owen, 1968. Lawley, 1974.	**Hazard & Operability Study (HAZOP)**	The HAZOP study is used to identify hazard scenarios that impact receptors such as people, the environment and property, as well as operability scenarios where the concern is with the capacity of the process to function properly. It involves work study and critical examination	HAZOP analyses are planned to identify potential process hazards resulting from system interactions or exceptional operating conditions. Used when there is a major change to operations planned and before a shut down.	HAZOP studies focus on investigating deviations from design intent. By definition, deviations are potential problems. For example, lack of flow in a transfer line or over pressuring a storage tank. Deviations are generated by applying guide words to process parameters at different locations, called nodes, throughout the process	Strengths: a. Offers a creative approach for identifying hazards, predominantly those involving reactive chemicals. Is particularly useful in early design stages so that risks can be controlled effectively. b. Thoroughly evaluates potential consequences of process failure to follow procedures. c. Recognises engineering and administrative controls, and consequences of their failures. d. Provides an understanding of the system to team members. Limitations: a. HAZOP studies rely on heuristics (practical methods) rather than algorithms (maths calculations) which is both a strength and a weakness. b. The structure of a HAZOP can lead to a trap of the rote generation of process deviations

					which diminishes creative and imaginative which is important in hazard analysis. The many aspects of design intent that must be considered and challenges in generating deviations make HAZOP studies complex, regardless of the complexity of the process on which a study is performed. HAZOP studies take longer because they involve a detailed search for scenarios.
Yan & Xu (2019)	**Preliminary Hazard Analysis (PHA)**	As a risk assessment method first implemented by USA Department of Defence in 1966. It is used before production. PHA is an effective method to make assessment of potential hazards. It can be utilized as a complement to risk management to identify, describe and rank major hazards, influence design,	A PHA is used when developing a work place safety system for risk control and mitigation. It is a method to identify and evaluate hazards in a system so prevention measures can be set according to assessment results. However, assessment may not be	PHA is a qualitative risk analysis method used to identify and analyse possible hazards. It is used before design, construction and production of a system. Includes considering occurrence conditions for accidents, including human error and consequences caused by accidents can be identified and analysed. As a result, possible losses caused by unsafe technical measures, the usage of hazardous materials, technology or devices, and the thoughtlessness of	<u>Strengths</u> 1. Since the hazard analysis is made during the development of the system, critical segments of a system can be enhanced so the design of the system can be more reasonable, and scientific. 2. Targeted risk control measures can be adapted to production processes so that the hazardous section risks will be controlled effectively. Hence, the probability and severity with respect to the hazard caused will be reduced. 3. With regard to risks that cannot be controlled completely, safety measures can be proposed

		assign responsibility, time and resources for hazard control. Failure Modes & Effect Analysis and/or Energy Trace and Barrier Analysis are included as part of a PHA. A PHA is widely applied in various fields. For example, Qu et al. (2013) utilized PHA to distinguish and identify three potentially dangerous factors in stevedoring processes of a LNG terminal.	comprehensive enough (Yan & Xu, 2019)	system will be determined (Yan & Xu, 2019)	by a PHA to reduce risk to a tolerable target. <u>Limitations:</u> As a qualitative risk analysis method, PHA can estimate hazards in the assessed system. The estimation cannot be accurate and precise enough since hazards are ranked based on their linguistic descriptions. As a result, quantitative rankings of hazards are required to promote the accuracy and precision of PHA results (Yan & Xu, 2019)
Eun-Soo Hong et al., 2009.	**Event tree analysis (ETA)**	Event tree analysis (ETA) is an inductive logic and Diagrammatic method for identifying the various possible outcomes of a given initiating event. For an initiating event, if two-state modelling is employed (one failure	In this method, an initiating event such as the malfunctioning of a system, process, or construction is considered as the starting point and the predictable accidental	ETA is an inductive analysis that models graphs, with the help of a decision tree, the possible results of an initial event that are capable of producing consequences. ETA is a system model representing system safety based on the safety of sub-events. It is called an event tree because the graphical	<u>Strengths</u> 1. Accounts for event time. 2. Complex domino effect models for models in the analysis of error trees. 3. Events can be quantified in terms of consequences (successes and failures). 4. The initial program, collateral track, branch point, and accident sequence can be tracked graphically.

		state and one success state), then an event tree can be constructed as a binary tree with nodes representing a set of possible failure and success states and a system analysis.	results, which are sequentially propagated from the initiating event, are presented in order graphically	presentation of sequenced events grows like a tree as the number of events increase.	Limitations: 1. This analysis is limited to one initiating event. 2. A special mode is required to account for system dependencies. 3. The quality of the assessment depends on good documentation. 4. The requirement of this study is a qualified and experience analysed.
Zhang et al., (2014)	**Fault Tree Analysis (FTA)**	Fault Tree Analysis (FTA) is one of many symbolic logic analytical techniques. It involves development of a graphic model of the pathways within a system that can lead to a foreseeable, undesirable loss event, which is referred to as the ''Top Event,'' as it is located at the top of the Fault Tree (FT)	The FTA is a systematic safety analysis tool that proceeds deductively from the occurrence of an undesired event to the identification of the root causes of that event. This technique has been extensively used in risk and safety analyses	It is not a model of all possible causes for system failure, but rather includes those faults that contributed to the undesired *Top Event*. The pathways interconnect contributory events and conditions using a set of standard logic symbols. The paths are so defined that all possible events or actions leading to the occurrence of the *Top Event* are sufficiently described. Such definition allows better understanding of how accidents occurred, the functional relationships between failures and	Strengths 1. This technique directs the analyst to deduce failures deductively. 2. It pinpoints the aspects of the system that are suitable for understanding the mechanism of probable failure. 3. Provides graphical assistance that allows those responsible for managing the system to visualize the danger; such persons, not otherwise associated with changes in the design of the system. 4. Provides an approach to the analysis of system reliability (qualitative, quantitative). 5. Allows the analyst to pay attention to one particular system failure at a time.

				identification of cause-and-effect relationships.	6. Provides the analyst with a true understanding of system behaviour. <u>Limitations:</u> 1. Requires a skilled analyst to conduct. 2. Focuses only on one particular type of problem in a system, and many error trees are needed to overcome various failure modes. 3. As this technique is based on graphical models it can be complex if the system has multiple failures.
Tay & Lim, (*2*006).	Failure mode and effects analysis (FMEA)	Failure mode and effects analysis (FMEA) is a widely used quality improvement tool to identify the potential failure modes for measuring reliability of a product or a process. FMEA is performed by developing a risk priority number (RPN), which is the product of severity, occurrence, and detection ratings	FMEA is a technique used in the mining industry to identify and eliminate known or potential failures to enhance reliability and safety of complex systems and is intended to provide information for making risk	Summary of Traditional FMEA procedure. 1. Define scale Table of Severity, Occurrence and Detection. 2. Study intent, purpose, goal, & objective of a product / process. Usually identified by interaction among components / process flow diagram followed by task analysis. 3. Identify potential failures of product/process which includes problems, concerns, & improvement opportunities.	<u>Strengths</u>: 1. FMECA can be used for systems where safety data is unavailable or unreliable. 2-It is simple analysis technique with features of cost effectiveness and efficiency. <u>Limitations:</u> 1. Limited ability to handle operational interfaces and with issues of frequent failures. 2. Missing components are not checked.

			management decisions.	4. Identify consequence of failures to other components / next processes, operation, customers & government regulations. 5. Identify potential root cause of potential failures. 6. First level method / procedure to detect / prevent failures of product/process. 7. Severity rating: rank seriousness of effect of potential failures. 8. Occurrence rating: estimation of frequency for a potential cause of failures. 9. Detect rating: likelihood of the process control to detect a specific root cause of a failure. 10. RPN calculation: product of three inputs: rating, severity, occurrence, detection. 11. Correction then end.	3. Vulnerabilities of common causes may be missed

From the Table 7 comparisons, it can be concluded that each risk assessment technique has its strengths and limitations and that almost the same risk assessment techniques have been used internationally for the last twenty years. However, by critically analyzing the process of risk assessment techniques as listed in table 7 it is revealed that not all of the frequently used techniques are suitable for the mobile plant operators. For example, the methods to perform the assessment are lengthy. However, by comparing table 7 and table 6 it is apparent that the only suitable technique for mobile plant operators in table 7 is the Preliminary Hazard Analysis (PHA) as it has a strong emphasis on the first step of risk identification. From the review of published literature related to risk assessment techniques, it was concluded that risk identification is a major step that should be undertaken correctly to prevent accidents. Therefore, the Preliminary Hazard Analysis (PHA) would be a best technique for mobile plant operators to routinely use to prevent accidental situations and potential incidents.

1. Future of Risk Assessment, Risk Management and Identified Knowledge Gaps

The future of risk assessment and risk management was discussed by Aven et al. (2014). Reflections on this topic were identified in Venkatasubramanian (2011); Pasman and Reniers (2014); Society for Risk Analysis (2015) and in Khan et al. (2015). These authors theorized that humans face emerging risks related to an activity when the background knowledge is weak but contains indications / justified beliefs that a new type of event (new in the context of that activity) could occur in the future and potentially have severe consequences to something humans value. Weak background knowledge results in difficulty specifying consequences and possibly in fully specifying the event itself; i.e., difficulty specifying scenarios. These authors agreed that there is a need to further develop risk assessments that are able to capture these challenges linked to knowledge dimension and the time dynamics.

According to Aven (2016) risk assessment and risk management are established as a scientific field and provide important contributions in supporting decision-making in practice. Basic principles, theories and methods exist and are developing. Aven, (2016) identified that the key challenge was related to the development of the risk field. In his publication named "Risk assessment and risk management: Review of recent advances on their foundation" Aven (2016) emphasized having a focus on knowledge and lack of knowledge characterizations, instead of accurate risk estimations and predictions, to meet situations of large uncertainties.

Today risk assessments are well established in workplace safety and health situations with considerable data and clearly defined boundaries for their use. Statistical and probabilistic tools have been developed and provide useful decision support for many types of risk applications. Risk decisions are, to an increasing extent, about situations characterized by large uncertainties and new risks are emerging. Such situations call for different types of approaches and methods. There is a need for the risk management field to develop suitable frameworks and tools for this purpose (Society for Risk Analysis, 2015). There is a general research focus on dynamic risk assessment and management rather than static or traditional risk assessment (Aven, 2016). The concept of emerging risk has gained increasing attention in recent years. Flage and Aven (2015) performed an in-depth analysis of the emerging risk concept and in particular its relation to black swan type of events through the known/unknown. Black swans are common in Australia, but are rare in Europe, and to the authors Flage and Aven (2015) black swan events were due to unexpected risks.

Zio (2018) conducted a detailed analysis of workplace risks in his article "The Future of Risk Assessment" and described risk assessment in the category of a mature discipline. The structured performance of a risk assessment guides analysts to identify possible hazards/threats, analyse their causes and consequences, and describe risk, typically quantitatively and with a proper representation of uncertainties. He also wrote that in the assessment and the analysts make assumptions and simplifications, that for a risk assessment it was necessary to collect and analyse data, develop and use models to represent the phenomena studied. For example, the failure modes of components due to a given earthquake, the heat fluxes on a structure due to a fire and the response of operators to an accident are all the results of conceptual models that attempt to mimic how a real accident would proceed, based on the knowledge available. According to Zio (2018), in this evolving scenario, risk assessment remains a fundamental technical framework for the systemic analysis of the risk associated to an industrial activity.

According to Dekker (2011), new technology has been introduced to improve mining and mineral processing, but unless how it works is properly understood, there is the danger of creating new risks, not from malfunctioning systems but from complex systems functioning as designed, just not as predicted (Dekker 2011). Latimer (2015) gives an example of this in the recent accident between an autonomous haul truck and a water cart. The autonomous haul truck performed as it was programmed, however the driver of the water cart was not aware that the vehicle was about to turn across its path (Latimer 2015).

Gaps in knowledge that need to be addressed, based on the detailed literature review of Risk Assessment findings, are:

1. In intergenerational decision making situations, what frameworks and perspectives are available to use? What are the other choices? When do some different frameworks work better than others? How do we capture key knowledge issues and present and future uncertainties? What maintenance tasks do we have for future generations?
2. - How can we describe and represent the results of risk assessments in ways that are beneficial to decision makers, to clearly present the assumptions made and their justification with respect to the knowledge on which the assessment is based?
3. - How can we display risk information without misinterpreting what we know and don't know?
4. - How can we accurately represent and account for uncertainty in the right way to justify confidence in the outcome of risks and their management?
5. - How can we state how well expert judgment is, and how can we improve it?
6. - In the near misses analysis, how should we arrange the multi-dimensional space of causal proximity between scenarios to measure "how close an incident is to an actual accident"? "

The next section of this review of published literature provides an analytical and critical assessment of the published causes of mobile plant accidents at mining sites in Western Australia.

SECTION TWO

Causes of mobile plants accidents at mining sites in the Western Australian

2.10 Introduction

Mining is an activity that inherently involves hazards such as interaction between people and large mobile machines, the presence of dangerous gases, and the risk of geotechnical failures. Cliff (2016) undertook a study examining occupational health and safety within the mining industry. The analysis investigated mining fatalities and injury rates across a broad range of perspectives, including both coal and metalliferous mining sectors. Safe Work Australia (2019) found that between 2003 and 2018 the most common causes of work-related fatalities in Australia were vehicle collisions [31% of injury fatalities (44)], being hit by moving objects [17% (24)], falls from heights [13% (18)], being hit by falling objects [10% (15)]. These results indicate that Australian workers are consistently being killed by the same types of events over time.

Harris (2012) in a case study titled *Application to Fires on Mobile Plant* stated that awareness of potential risks and the availability of effective controls are key considerations to the management of unwanted events in any sector, including open pit mining operations.

According to Safe work Australia (2020) each year Australian workers lose their lives whilst undertaking work-based activities. In a little over a decade, occupational fatality rates have decreased from 2.7 per 100,000 workers in 2003 to 1.6 per 100,000 workers in 2015 (Safe Work Australia, 2016a). In 2018 the work-related fatality rate was 1.1 per 100,000 workers (Safe Work Australia, 2019) with the Australian mining industry fatality rate being higher at 3.7 fatalities per 100,000 mine workers. It is of concern that in the last few years some industries' rates are appearing to plateau (at a relatively high rate) or creep up – including those for mining (Safe Work Australia, 2016a). In the year 2006–07 there were 4275 claims (3.2% of all claims) associated with use of mobile plant; of these, nearly 50% involved sprains and strains, 17% involved contusions or open wounds, and 13% involved fractures, dislocations or amputations. A total of 70% of the claims involved two or more weeks' absence from work. Seven people died during 2006–07 as a result of work-related use of mobile plant. Safe Work Australia (2019) provided key statistics for injury fatalities by occupation for the year 2018. Table 8 from this publication reveals that the fatalities in the occupation of heavy machinery operators and drivers were amongst the highest in 2018 and that the number of fatalities for machinery operators and drivers was 6.2 fatalities per 100,000 workers.

Table 8

Work-related injury fatalities by mechanism of fatal injury, 2018

Occupation	Number of fatalities	Fatality rate (fatalities per 100,000 workers)
Machinery Operators and Drivers	51	6.2
Labourers	36	2.9
Technicians and Trades Workers	27	1.5
Managers	16	1.0
Professionals	8	0.3
Community and Personal Service Workers	4	0.3
Clerical and Administrative Workers	1	0.1
Sales Workers	1	0.1
Total	**144**	**1.1**

Note: From Key WHS statistics Australia 2019, (p. 4) by Safe Work Australia, 2019, Australian Government. (https://www.safeworkaustralia.gov.au/system/files/documents/2002/key_whs_statistics_australia_2019.pdf) Copyright 2019 Safe Work Australia

Table 9 from Safe Work Australia in 2019 shows that the number of fatalities of machine operators and drivers were highest. There were total of 51 fatalities in the year 2018. The majority of these fatalities were caused by mobile plant and transport (71%) (Safe Work Australia, 2019). These statistics reveal that in 2018 vehicle collisions contributed to 31

% of the total work-related injury fatalities. It was reported that although there has been a reduction in the number of fatalities over time, the same types of events (or mechanism of incident) are associated with worker fatalities (Safe Work Australia, 2019).

Table 9

Work-related injury fatalities by mechanism of fatal injury, 2018

Mechanism of incident	Number of fatalities	% of injury fatalities
Vehicle collision*	44	31%
Being hit by moving objects	24	17%
Falls from a height	18	13%
Being hit by falling objects	15	10%
Being trapped between stationary and moving objects	7	5%
Being trapped by moving machinery	7	5%
Other mechanisms	29	20%
Total	**144**	**100%**

Note: From Key WHS statistics Australia 2019, (p. 3) by Safe Work Australia, 2019, Australian Government. (https://www.safeworkaustralia.gov.au/system/files/documents/2002/key_whs_statistics_australia_2019.pdf), Copyright 2019 Safe Work Australia

From the above analysis of data, it is evident that vehicle collisions are a major cause of workplace incidents in Australia. The Annual Statistical Report of Workers' compensation in WA 2017/2018 by Work Cover WA, (2021) data indicates that mining accounts for 9% of the total claims lodged in 2019/120 in the WA workers' compensation scheme (WorkCover WA, 2021). From the statistical data provided by Work Cover, it is apparent that in the last four year an increasing trend has been observed in mining industry employee injuries with a total of 1,365 lost time claims lodged in mining during the 2019/20 financial year. Further technicians and trade workers were accounted for the largest proportion of lost time claims around 24% across all occupation in which the average proportion of machinery operators and drivers were contributing around 17%. Therefore, mobile plant still represents a serious risk to the health and safety of Australian workers (WorkCover WA, 2021).

2.11 Mining in Western Australia.

In Australia, minerals have been part of the continent's industry since man's first appearance (Mining in Australia, 2019). Minerals were used to colour paints in ancient rock art that is an integral part of Aboriginal heritage Minerals began to be mined in Australia in large quantities from the early days of European settlement at Sydney Cove (Mining in Australia, 2019). Until the early 1960s it was believed Australia lacked sufficient reserves of iron ore for domestic use (Mining in Australia, 2019). Once export controls of iron ore were lifted the development of the Pilbara iron ore region in Western Australia commenced (Mining in Australia, 2019). Aided by information from the Bureau of Mineral Resources (now Geoscience Australia), the pace of exploration was stepped up (Mining in Australia, 2019). Discoveries of the 'new' metals - bauxite (the source of aluminium), nickel, tungsten, rutile (the source of titanium), uranium, oil and natural gas followed a resurgence of interest in Australia's mineral resources. Production of other minerals also increased and Australia became a major raw materials exporter, especially to Japan and Europe (Mining in Australia, 2019).

Aboriginal people, even though some of them were miners (Australian Mining History, 2012) did not use mobile plant. Coal was discovered in the Collie Basin in Western Australia in 1883 and in 1898, when the railway was extended to Collie, the first commercial mining began in Western Australia (State Library of Western Australia, 2020). The first mobile plant used at the Collie coal mine was a cart that was pulled by pit horses to take the coal from the mine to the rail shuttle cars. To increase production, in the 1950s mobile plant used in coal mining included excavators to dig the coal out of the ground, front end loaders to load the coal into trucks, and the coal was then transported by trucks to the rail cars to the coal purchasers (State Library of Western Australia, 2020).

During the 1800s and 1900s, most miners in Western Australia were individual prospectors and were responsible for their own safety and health at their workplace. Gradually, individual mining was replaced by company mining as a more specialized and profitable way of mining (Jansz & Gilbert, 2017). Table 10 shows the fatality numbers for the Western Australian Mining industry during the early 1990s.

Table 10

Western Australian Mining Industry Fatalities 1901-1918

Year	Fatalities	Workforce	Incident rate per 1,000 workers
1901	45	16, 755	2.68
1902	39	17, 525	2.22
1903	42	17, 329	2.42
1918	23	17, 790	1.29

Note. From Risk management in the Western Australian mining industry (p. 5) by Jansz & Gilbert, 2017, World Safety Journal. 26(2), 2-11. Copyright 2017 World Safety Organisation.

2.12 Mobile Plant Injuries in Mining Internationally

Mining is a highly hazardous industry throughout the world. The Australian mining industry is no exception to this as miners work with a range of workplace hazards that can cause not only injuries and ill health, but also death (Walters et al., 2014). Philips (1996), in an analysis of South African mining accident records, ranked accidents associated with transport and the use of heavy plant and machinery as a close second to accidents resulting from falls of ground. Similarly, Oberholzer and Thorpe (1995) in their report on SIMRAC Project COL 203 *Quantify the nature and magnitude of the contribution of human and engineering factors to the risk of injury or fatality caused by underground machinery or transport and delineate the essential causes* quoted accident statistics which showed that transport and machinery related accidents had the highest significance in terms of the number of accidents and the number of injuries. One of the recommendations produced by this project was that increased research effort should be applied to the study of transport and machinery related accidents. Similar accident patterns have also been reported in the UK by Rushworth et al. (1995), in Australia by Davies (1993) and in the USA in several reports by the US Bureau of Mines e.g., Randolph (1993).

In the late 1980's the importance of human behavior as a significant contributory factor in the etiology of mining accidents became widely recognized. Sims et al. (1986) showed, for example, that 55% of the haulage and transport accidents reported in the UK Chief Inspector of Mines Annual Report were directly attributable to *human failings*. At about the same time, in a review of human error and accidents, the US Bureau of Mines (Sims et al, 1986) concluded that up to 85% of mining accidents maybe due to human error. Twenty-seven years ago, Peake and Ritchie (1993) in their report on SIMRAC Project OTH 003 titled *Establish the primary causes of accidents on mines other than gold, coal and platinum,* concluded that, while failures of a mechanical or environmental nature are major contributors to an accident, the human factor, which is the least understood and the least predictable, has an influence on the greatest number of accidents.

2.13 Primary Causes of Mobile Plant Incidents in Mining

Mining is correctly regarded as a high hazard industry with its reputation built on a litany of catastrophic events (Walters et al., 2014). Some of the major mining disasters that have happened in Australia include those at Mount Kembla in 1902, Mount Lyell in 1912, Bellbird Colliery in 1923, Kianga in 1975, Appin colliery in 1979, Moura No.4 in 1986, Bulli colliery in 1987, and Moura No.2 in 1994 (Walters et al., 2014).

Mobile equipment offers many benefits, such as improving work efficiency and reducing manual handling, but can also pose major occupational hazards. In the mining industry, collisions involving large vehicles are commonplace. For example, Australian mining data suggests that approximately 35% of mining fatalities are due to vehicle interactions and 53% involved pedestrians and vehicles (Bell, 1990). Collisions are not only potentially fatal to mine workers, but also have significant financial costs due to repairs to equipment and lost production. Due to the high percentage of incidents that are due to equipment collisions, proximity warning and collision detection systems are being increasingly used with mobile mining equipment (Horberry et al., 2011).

An analysis of fatal truck-related accidents by Md-Nor et al. (2008) during the period 1995–2006 revealed the three most frequent causes of the haul truck related fatalities as: (i) failure of victims to respect haul truck working area, (ii) failure to provide adequate berms, and (iii) failure of mechanical components. Another study within the period of 1995–2002 (Kecojevic & Radomsky, 2004) categorized the major causes of fatalities as follows: (i) failure of mechanical components (22%); (ii) lack of and/or failure to obey warning signals (20%); (iii) failure to maintain adequate berm (13%); (iv) inadequate hazard training (10%); and (v) failure to recognize adverse geological conditions (10%). Kecojevic and Radomsky (2004) associated 70% of all fatalities to the above five categories, which are consistent with the results of studies for periods 1995–2006 and the current study of the Resources Safety incident data base January 2007 to December 2016. Ruff et al. (2011) studied the equipment-related fatalities for the period 2000–2007 and found that, for mobile equipment, the most frequent fatalities were related to loss of control or visibility issues during the operation of the equipment.

In 2015, Department of Commerce Work Safe, Western Australia issued a Safety Alert to explain the contributory factors that lead to mobile plant incidents in mining. The safety alert named “Vehicles and mobile plant causing deaths at workplaces” documented that common element of many recent fatal and serious injuries has been people near vehicles or mobile plant (Department of Commerce Work Safe, Western Australia, 2015). People who work with or near vehicles and mobile plant are most at risk. Serious and fatal incidents can occur during pedestrian movement near vehicles or plant, reversing and manoeuvring, arrivals or departures, loading or unloading, hitching or unhitching trailers, lowering ramps, mounting or dismounting from vehicles, securing of loads, movement of materials and maintenance work plant (Department of Commerce Work Safe, Western Australia, 2015).

The contributory factors for mobile plant incidents were related to movement and speed of vehicles and plant at the workplace if not managed in a way to minimise the risk of injury to pedestrians and operators. If the design of the workplace was inadequate for safe reversing and manoeuvring of vehicles or mobile plant. If vehicle size was inappropriate for the design of the workplace. If the design of the workplace was such that arrivals and departures expose persons to the risk of collision. If there were inadequate systems of work for segregating pedestrians from vehicles and mobile plant. If there was inadequate communication systems between the operator and other persons i.e. the spotter or hitcher. If there was inadequate signage and road markings to instruct operators and pedestrians. If there were operators or other persons standing too close to mobile plant while loading, unloading or manoeuvring vehicles. If there were operators or other persons standing or moving through the fall zone of ramps of vehicle. If there were persons working underneath vehicles or mobile plant while the load was not adequately supported. If operators and other persons were not provided with appropriate information, instruction and training (Department of Commerce Work Safe, Western Australia, 2015).

2.14 Methods and Techniques for the prevention of mobile plant incidents in Australian Mining Industry

In the 1990s, significant improvements occurred in Australia through internal and external regulations to manage safety and health at the workplace in the mining industries (Walters et al., 2014). These improvements were incorporated into the policy and mission statements of the companies as *zero harm* objectives and established a greater accountability for safety and health performance for all levels of mine management. Workplace safety and health practices focused on promoting positive safety attitudes and behaviour of the employees at the workplace, emphasised safe work practices and improvements in safety outcomes. These approaches included monitoring, evaluation and continuous improvement of safety and health at the workplace (Walters et al., 2014).

Research conducted by Horberry (2011) in his publication named, *Safe design of mobile equipment traffic management systems,* identified the importance of mobile equipment to most industrial operations, the relatively high incident rates being frequently experienced and the attention paid to other relevant aspects (e.g. the safe design of vehicles). Horberry (2011) wrote that designing safe traffic management systems was a comparatively neglected research area. This concluded that more work in improving mobile equipment safety should start from a problem-centred and/or operator-centred philosophy. Horberry

(2011) concluded that many industrial domains are changing due to the increased uptake of automation or intelligent safety systems, whilst at the same time new operational methods for manufacture, mining, storage, service, transport or maintenance are being introduced and that such developments will undoubtedly change the uses of industrial mobile equipment, but the need to develop and maintain safe and efficient traffic management systems will remain.

To effectively prevent accident recurrence, a reliable accident cause analysis is a vital process that can identify hazards in the system and reduce exposure risks, ultimately minimising accident losses and improving safety performance (He et al., 2019). For the analytic process, it is critical to identify root causes to prevent and avoid mine accidents from the organisational perspective. Many accidents have occurred because organisations have ignored the warning signs of precursor incidents or have failed to learn from the lessons of the past (Cooke & Rohleder, 2006). A positive safety culture can help prevent work-related injuries and major disasters (Frazier et al., 2013). Safety culture has been recognised as a crucial factor in influencing the state of safety in enterprises, which provides a global characterisation of some common behavioural preconditions to disasters and accidents in high-risk socio-technical systems (Martyka & Lebecki, 2014; Pidgeon, 1991).

In the Western Australian mining industry, to maintain safety, compliance and more transparent services with the stakeholders the Department of Mines and Petroleum promoted the use of a risk-based approach to workplace safety and health, and reinforced compliance with people in the workplace following the implementation of safety regulation and standards (Department of Mines and Petroleum, 2016b).

A Model Work Health and Safety Act was developed by Safe Work Australia in 2011 for implementation in all Australian States, Territories and in New Zealand (Cliff, 2012). With the proposed introduction of Model Health and Safety Act by the Western Australian government, legislation is expected to reduce the recurrence of fatalities, however, in the publication 'Work-related injury fatalities – Key WHS statistics Australia 2018' (Safe

Work Australia, 2020, the latest statistics available) the states with the highest number of fatalities per 100,000 workers, New South Wales [47] and Queensland [39], had both implemented the Model Health and Safety Act in 2012. In this year (2018) the work-related fatality rate per 100,000 workers in Western Australia was 13 which was less than states that had introduced this Model Act (Safe Work Australia, 2020).

2.15 Section Summary and Recommendations

This section of the literature review has summarized information related to the causes of mobile plant accidents in the Western Australian mining industries. It has reported on the published literature related to mobile plants injuries and fatalities internationally and in Australia. The methods and techniques for the reduction of mobile plant accidents in mining industries were presented. It is concluded that the mining industry presents job hazards which can be more extreme than in some other industries and, as a result, extraordinary efforts from the mining companies are needed to reduce the risk of harm form work related hazards and reduce work related accidents and fatalities. Many industrial domains are changing due to increased implementation of automation or intelligent security systems, while at the same time, new operational methods for production, mining, storage, maintenance, transportation or maintenance are introduced. Such a development will undoubtedly change the use of industrial mobile equipment but the requirement to develop and maintain safe and effective motion control systems will definitely remain.

Based on the detailed review of the published literature related to mobile plant accidents in mining industry, it is recommended that

1. Mine sites must ensure that adequate safe work procedures are developed for workplaces and followed by employees, contractors, and other people affected by the mine site work.
2. More frequent refresher trainings for all mobile plant operators mentioning the most recent incidents in WA mining industry due to humans' errors and emphasize on the importance of compliance with regards to systems and procedures to reduce incidents due to human negligence.

3. Preventive and predictive maintenance for equipment used in the mining industry must be carried out as scheduled.
4. The employer must ensure that workers are properly trained and experienced enough to operate the equipment /machinery at the site as required.
5. Ensure that the mobile equipment at sites is designed for the workplace use and that adequate communication facilities are available at the mine site, especially for the underground environment.

The next section of this report describes the research methodology.

3. METHODOLOGY

3.1 Introduction

The aim of this research was to improve the safety performance of mobile plant operators in the Western Australia mining industry. The scope of this research was to look at risk assessment techniques used for the safe operation of mobile plant in order to improve the safety performance of mobile plant operators at workplaces in the Western Australia mining industry. This included identifying mineworkers' opinions on safety and risk control factors related to the use of mobile plant in their workplace. To assist with achieving the research aim the Resource Safety database reported incidents, accidents and fatalities on mining sites was analysed to identify common themes related to the causes of mobile plant injuries and incidents. The mobile plant incident investigations were reviewed to identify incident causes and appropriate risk control measures to assist with enabling reducing the occurrence of low frequency high consequences injuries related to mobile plant to improve work related safety, mining industry workers' productivity and industry profits.

This chapter provides a description of the research methodology and includes the study design of the four phases of the research. It describes the research setting, subjects, method of data collection, data analysis and interpretation and the ethical considerations that have guided this research. A mix method research methodology was chosen for this research, as it was the most relevant design to meet the research aim and achieve the four research objectives. The mixed method research approach includes both quantitative and qualitative data analysis methods.

3.2 Mixed Methods Research

Mixed methods research is the most effective research method to use in order to conduct research involving the collection of data, analyses of data and the integration of quantitative and qualitative data (Johnson, 2003; Nutting et al., 2009). Wisdom et al. (2012, p.290), report that using the mixed method research approach is beneficial "because of its logical and intuitive appeal, providing a bridge between the qualitative and quantitative paradigms" which is what was required in this study.

Achterbosch et al. (2017) report using mixed methodology research, state the specific design (sequential explanatory) and provide methodological references. These authors described the integration and the justification for using mixed methodology for their research by stating, "during the first phase, the collection and analysis of quantitative data occur. The second phase builds upon the results of the first through the collection and analysis of qualitative data. This strategy is especially useful in examining results from the quantitative data in more detail via the qualitative approach." (Achterbosch et al., 2017, p. 848). Mixed methods research strategies refer to combining qualitative and quantitative methods. The goal of mixed method is not to take the place of the former approach but attempts to maximize the strengths and minimize the weaknesses of qualitative and quantitative research strategies (Johnson & Onwuegbuzie, 2004, p.15).

When conducting and reporting mixed methods research, three key elements are considered (Creswell & Plano Clark, 2018). First, a mixed methods study should have at least two methodological components, one qualitative and one quantitative. Each component refers to at least a specific research question/objective, a research design and techniques for collecting and analysing data (Pluye & Hong, 2014). Second, it is recommended to use a mixed methods study design to plan and organize the procedures (Creswell & Plano Clark, 2018). Several mixed methods designs have been developed. The importance of the mixed methodology research approach was well described by Gray (2014) in the article *Doing Research in the Real World*. Gray (2014) documented that when undertaking mixed methodology research, it is equally important for the researcher to declare their philosophical position, (1) considering the fact that it affects not merely the data collection and analysis, but also (2) the interpretation of results. The concept of the research philosophy as defined by Bahari (2010) in *Qualitative Versus Quantitative Research Strategies* is associated with the development and nature of knowledge.

Broadly speaking, the combination of quantitative and qualitative research has been acknowledged to impart greater benefits than one method on its own (Greene et al., 1989).

This includes recognising five rationales of why researchers adopt a mixed methods approach, as described below:

1. *Triangulation* – The results derived from one method corroborate the findings from the other approach (Greene et al., 1989).
2. *Complementary* – The results derived from one method (e.g., quantitative) are used to elaborate and validate the results from the other method (Hanson et al., 2005).
3. *Development* – The results derived from one method are used to develop or inform the other phase of the study, particularly in the context of instrument development (e.g., the quantitative dataset being used to design the qualitative inquiry questions) and sampling (e.g., a sample from the quantitative phase being used to facilitate samples for the qualitative phase (Hanson et al., 2005).
4. *Initiation* – A particular approach is used to reveal the paradoxes and contradictions from the results of the other method (Hanson et al., 2005).
5. *Expansion* – The breadth and depth of the research can be extended using another method for varying components of inquiry (Greene et al., 1989).

All of these elements above were applied in this research as the researcher analysed a large data base using quantitative statistics and interviewed the participants at the mining sites and asked for their experience as mobile plant operators, mobile plant maintenance workers, or mobile plant supervisor in their work place. Themes were extracted from the qualitative data collected through personal interviews and focus group interviews with the participants. NVivo version 12 was used to identify and analyse the common results themes.

3.2.1 Research Paradigm

Understanding research philosophy is very useful due to several reasons. As documented by Easterby Smith et al. (2002, p.27), there are three main reasons why one should understand philosophy in research. (1) It can help to clarify research designs, (2) which design will work and will not, and (3) to identify and even create designs that may be outside his or her experience.

Usually the qualitative observations of an event or phenomenon is the first stage for most mixed-methods research (Lieber, 2009) and this assists with identifying themes to be explored in relation to what is being studied (Yin, 2009; Yin, 2011). Qualitative analysis is used for exploratory studies to define a problem and identify potential solutions (Lieber 2009). Triangulation is used in mixed method research to obtain information from a variety of data sources in order to examine the same phenomenon using different sources of information. This allows the identification of a phenomenon more accurately and provides convergent validation (Driscoll, et al., 2007; Migiro & Magangi, 2011).

In quantitative research numerical data is collected to empirically understand the phenomenon of interest, and the knowledge claim is based on the paradigm of positivism (Creswell, 2009). Positivists believe that reality is static, and that objective knowledge is obtained through scientific experimentation (Gray, 2014). The outcomes and perceived risk factors are strictly selected and controlled, before determining the relationship between them. Quantitative researchers are always interested in capturing and analysing these variables. They decide on which variables are to be investigated, which form of measurement and analysis will be needed to answer the research questions as well as the hypothesis and provide credible empirical outcomes (Creswell, 2014).

In the case of a qualitative approach, non-numerical (i.e., textual) data is collected and the knowledge claim is supported by a constructivist paradigm (Creswell, 2003; Gray, 2014). In this paradigm, "reality is a social construct and so is constantly changing" (Sale et al., 2002, p.29). During the data collection and analysis process, the relationship between the researcher and the participants is paramount in achieving optimal outcomes (Onwuegbuzie & Leech, 2005). Furthermore, textual data is collected from those who have experienced the phenomenon and express their willingness to provide deeper insights into it (Yilmaz, 2013). The analysis of the textual data is guided by the participants' perceptions of reality, as well as the interpretive lens of the researcher (Gray, 2014). Contrastingly, mixed methods research builds on knowledge from a pragmatic viewpoint (Onwuegbuzie & Leech, 2005). The researcher chooses the best data collection instruments, variables, and units of analysis in order to answer the research problems of interest in the best possible manner without allegiance to either positivism or constructivism (Tashakkori & Teddlie, 1998). The pragmatic paradigm underpinning the current study allows for the identification and use of both appropriate quantitative and qualitative techniques to investigate recordable injuries along with the associated risk factors.

Table 11

Mixed Method Research Summary

What is Mixed Method Research: 1. It is a combined method using both quantitative (pre-determined) and qualitative (emerging) research methods. 2. Mixed method approach is used if the problem is to generalize the findings and develop the reason for a phenomenon or concept for individuals.
Method: 1. Identifies the shared experience of individuals, the essence of an individual experience, thus the nature of individual experience and how the individual experienced it. 2. It uses multiple forms of data drawing on all possibilities 3. Bases knowledge claims on pragmatic grounds 4. Employs strategies of inquiry involving either the simultaneous or sequential collection of data 5. Collects both numeric information and text information
Analysis: **Stages of analysis:** 1. Sequential procedures – to elaborate the findings of one method with another method 2. Concurrent procedures – to converge quantitative and qualitative data to provide a comprehensive analysis **3.** Transformative procedures – uses a theoretical lens as an overarching perspective within a design that contains both quantitative and qualitative data

3.2.2 Mixed Method Approach

Mixed method approach is well defined by Creswell (2003). In table 4 below, Creswell identified five mixed methods design typologies that researchers need to use when answering research problems necessitating a combination of quantitative and qualitative approaches. Creswell (2003) stated that when a researcher adopts a mixed methods approach, they are required to identify the type of design suitable for their research problem as well as the rationale for their selection.

Table 12

Types of mixed methods designs as dictated by the four criteria

Mixed Methods Design	Descriptions
Sequential Explanatory Design	Quantitative data collection and analysis is completed first, followed by qualitative data collection and analysis. Priority is given to the quantitative approach, after which the two data sets are integrated at the interpretation stage.
Sequential Exploratory Design	First, qualitative data is collected and analysed, then quantitative data is collected and analysed. Priority is given to the qualitative approach, after which two data sets are integrated at the interpretation stage.
Sequential Transformative Design	In this scheme, the two data sets are collected and analysed independently of each other. Integration occurs at the stage of interpretation. However, any of these approaches can be used in the first place, or priority can be given to either a qualitative or a quantitative approach.
Concurrent Triangulation Design	Quantitative and qualitative datasets are collected and analysed together with the same priorities to confirm and validate findings. Integration occurs at the stage of research interpretation.

Concurrent Nested (Embedded) Design	Under this strategy, both data sets are collected and analysed simultaneously. However, one predominant method guides all research. This may mean that one method answers primary questions, while the other addresses secondary questions. The two data sets can be combined, or the results can be presented side by side, particularly in the case of separate questions.
Concurrent Transformative Design	Within this strategy, quantitative and qualitative data sets are collected simultaneously and the priority may be the same or unequal. Integration often occurs in the analysis stage, but sometimes in the interpretation stage.

3.3 Research Design

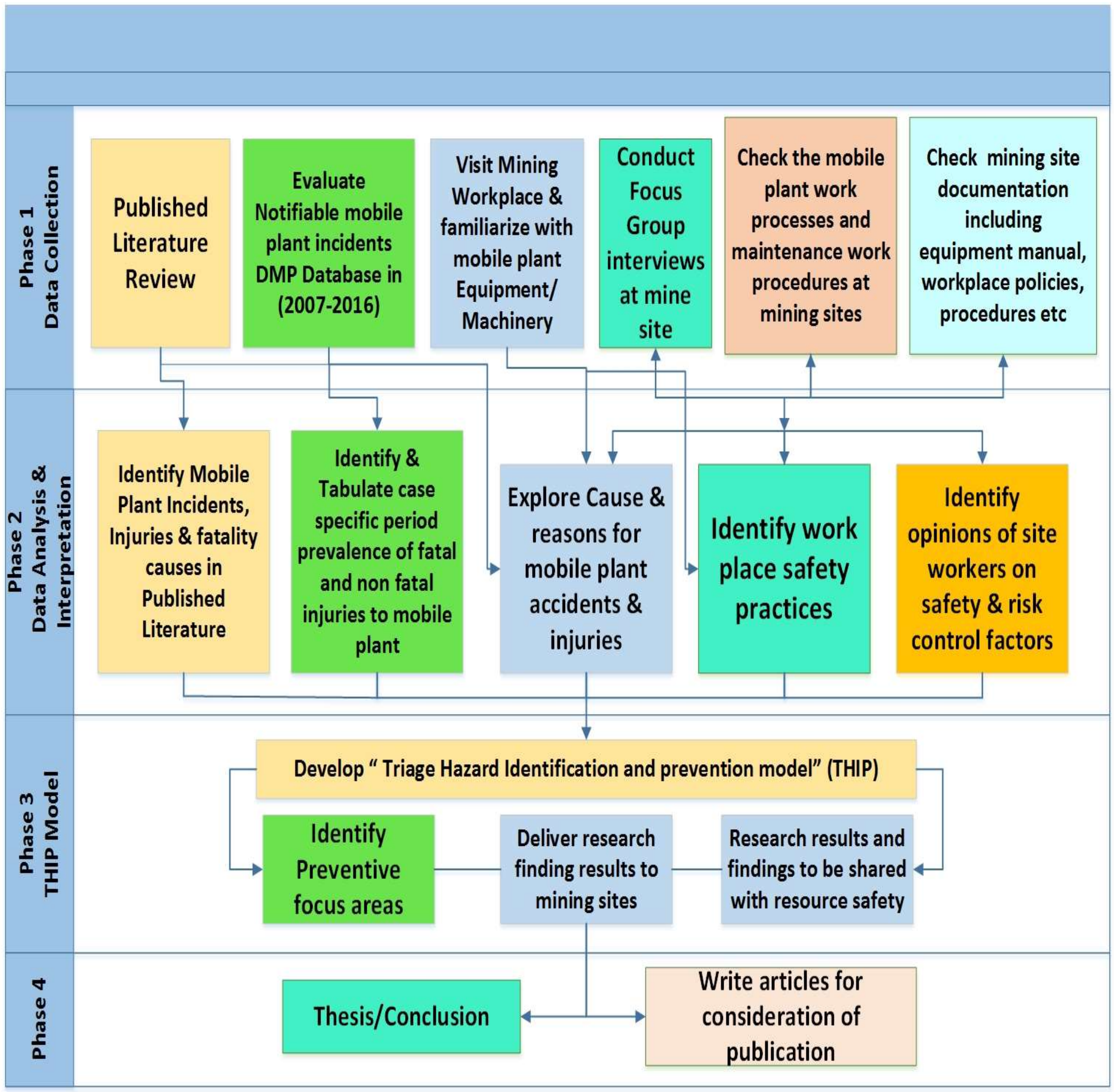
The present research was conducted using a concurrent embedded mixed methods design. The reason for the selection of this typology is that it allows nesting of both quantitative and qualitative research as well as simultaneous collection of the datasets. However, the weighting of the quantitative and qualitative approach in this design is not equal, given that one method plays a predominant role while the other renders support (Creswell, 2009). In this research, the qualitative approach has been embedded in the primary approach (i.e., the quantitative). The main purpose of this design is to apply the quantitative method to analyse the Resources Safety Database for notifiable incidents and injuries related to mobile plant in Western Australian mining along with the concomitant contributing risk factors.

The next step was to check the mobile plant work processes and maintenances work procedures at mining companies' workplaces, to conduct qualitative face-to-face interviews with individuals and focus group interviews to better understand the challenges faced by the mobile plants operators and workers at site. The rationale for using a concurrent embedded strategy in this study, which was as a form of 'development' study identified by Greene et al. (1989) is that it implies samples from one phase represent the sample frame for another phase of the study.

The proposed study initially analysed the Resources Safety notifiable incident data base incidents reported between 1-1-2007 and 31-12-2016 (10 years of notifiable incident reports) and then incident data from 2017 to 31/3/2020 were analysed to get more updated information. A review was conducted of published literature related to mobile plant incidents. The use of mobile plant at mining worksites was observed and related documents were reviewed. Focus group and individual interviews with mobile plant operators, mobile plant supervisors and mobile plant maintenance workers was undertaken to learn about causes of mobile plant accidents and risk control measures in current use. The concurrent embedded design was undertaken within a structure of four research phases, as shown in figure 9.

Figure 9

Research Concurrent Embedded Design



3.3.1 Phase 1: Data Collection

The first phase, initial analysis to find causes of mobile plant accidents, was conducted through a review of published literature to identify what was currently known about the causes of these accidents and risk control measures. The Department of Mines and Petroleum (DMP) [which on 1st July 2017 became the Department of Mines, Industry Regulation and Safety] Resources Safety Division Notifiable Incident Database was chosen for analysis as it includes all notifiable incidents related to mobile plant in the Western Australian mining industry. A ten-year period (from 1-1-2007 and 31-12-2016) was reviewed, as this provided a comprehensive amount of data to analyse. Under the *Mines Safety and Inspection Act 1994* and Mines Safety and Inspection Regulations 1995, for a mining operation (including exploration operations), the following must be reported to Resources Safety immediately they occur (Resources Safety, 2015) and are included in the database that was analysed:

1. accidents involving injury to person(s).
2. Occurrences (also referred to as notifiable incidents for reporting purposes) are unplanned incidents that do not necessarily result in injury to a person or damage to property [Mines Safety and Inspection Regulations 1995, s.78 (3) (j)]. For example, loss of control of heavy earth-moving equipment, including failure of braking or steering.

Data collected between 2007 and 2016 by the DMIRS in the Resources notifiable incident database was analysed. The data collected was de-identified for the researcher and did not include any identifying name of companies or individuals. Analysis was conducted as a quantitative analysis using descriptive statistics (number and percent of mobile plant accidents and incidents reported) and through a qualitative approach as well, with pattern matching used to identify and analyse the cause of each reported accident and incident. For the qualitative data the research supervisor, who also had access to the de-identified database, checked analysis themes discovered by the researcher and consensus was achieved for the themes identified as contributing risk factors for mobile plant reported incidents. This provided inter-rate reliability.

A detailed analysis of causes of incidents and injuries related to mobile plants from the Resources Safety Database was performed and tabulated in the form of graphs and tables for cause-specific period prevalence of fatal and non-fatal accidents and injuries. This assisted in achieving objective one, which was to analyse the Resources Safety Notifiable Incident Database to determine the causes of mobile plant accidents in the Western Australian mining industry between 2007 and 2016. Incident rates per 1,000 employees and frequency rates per million hours worked were calculated for WA mining industry mobile plant incidents. This database contained all notifiable incidents including all mobile plant accidents whether there was an employee injury or not.

The number of incidents reported to Resources Safety for the 10 years between 2007 and 2016 was 23,405 and included 11 fatalities. This database contained the following sub-categorization of mobile plant incidents for analysis.

1. Crane Incidents
2. Light Vehicle Incidents
3. Truck/Mobile Equipment Collisions
4. Truck/Mobile Equipment Contact with Person
5. Truck/Mobile Equip. NOC (Not otherwise classified)
6. Truck/Mobile Equip. Over Edge
7. Truck/Mobile Equip. Rollover

A detailed analysis of causes of incidents and injuries related to mobile plants from the Resources Safety Database was performed and tabulated in the form of graphs and tables for cause-specific period prevalence of fatal and non-fatal accidents and injuries. This assisted in achieving objective one, which was to analyse the Resources Safety Notifiable Incident Database to determine the causes of mobile plant accidents in the Western Australian mining industry between 2007 and 2016. Incident rates per 1,000 employees and frequency rates per million hours worked were calculated for WA mining industry mobile plant incidents.

Objective two was to observe mobile plant in use in mining workplaces to identify what strategies are in place to promote mobile plant safety and any safety barriers. This was achieved through analysis of mining workplace and work processes observations to understand the types of mobile plant used, how they were used and maintained in the workplace and by identifying what workplace safety practices were used in relation to mobile plant maintenance and workplace use. This significantly assisted with exploring the causes and reasons for mobile plant accidents and injuries in the mining industry that were recorded in the Resources Safety database. In addition, the compilation and interpretation of the results of focus group and individual interviews provided information related to identifying opinions of site workers on safety and risk control factors.

3.3.1.1 Development of Interview Questions

The third research objective was to conduct focus group interviews with mobile plant operators to identify their opinions on safety and risk control factors related to the use of mobile plant in their workplace. Research interview questions were developed based on the findings of both the sections of the comprehensive literature review. The first literature review section was on the Risk Assessment Techniques used in mining companies for the prevention of mobile plant incidents, and the second was on the causes of mobile plant injuries and fatalities in mining industries.

The comprehensive literature review helped to create content validity. Questions were then constructed based on the findings of the literature review and the researcher's past experience of five years of hands-on working in a Petro-chemical company that had many similarities related to mobile plant equipment to the Western Australian mining companies. It was determined that sufficient information to achieve the research aim would not be obtained by having interview questions with only fixed response questions with True/ false, Yes/no, Rank ordering, Agree/disagree or Multiple choice. Interview questions requiring these type of answers were not included as the researcher wanted to obtain narrative data to provide comprehensive information about the causes of mobile plant incidents in mining companies.

The primary objective of using qualitative interviews was well defined by Roberts (1997) who documented that the primary objective has always been to help provide a comprehensive understanding through participants' own experiences of why the phenomenon of interest occurred in the first place. That is, the focus is placed on meanings derived from those at the receiving end of the phenomenon (Al-Busaidi 2008).

Thirteen questions were included in the pilot study with the questionnaire separately designed for:

1. Mobile Plant Supervisors
2. Mobile Plant Operators
3. Mobile Plant Maintenance Workers

The first 3 questions asked for demographic information and included the respondents' employment position, amount of time the person had performed this work for and how long they had worked for their current employer. The answers to these questions provided background information and experience level of the person interviewed and had face validity. The next ten questions were related to the respondent's work with mobile plant equipment to identify hazards, risk control measures used, challenges and opportunities for improvements. Best practice for mobile plant use safety was also identified through the questions asked and answers provided. The last question was an open-ended question that allowed the participant to tell the researcher anything else that should be considered in relation to mobile plant equipment use, maintenance and safety at their workplace. This allowed participants to let the researcher know any other factors that should be considered and added to the richness of the qualitative data collected.

After it was created the draft questionnaire was reviewed by three mining safety professionals for appropriate content to achieve the research aim and to obtain consensual validity. No additional questions were suggested. At a mining site these questions were then asked to 9 employees (3 mobile plant supervisors, 3 mobile plant operators and 3 mobile plant maintenance workers) to allow the researcher to check that the participants understood the questions, check the validity and reliability of the questions and to gain practical exposure to the hazards involved while using mobile plants at this mining site. The questionnaire was then finalized after several minor changes that included correction of any words in the questionnaire that participants did not easily understand. This questionnaire was then provided to mobile plant supervisors, mobile plant operators and mobile plant maintenance workers who were chosen, using random numbers, from each of the 4 participating mine sites from the people available in each group at each mine site.

3.3.1.2 Research Setting and Selection of Mining Workplace for Data collection

The setting for this research was the Western Australian mining industry. The research mining workplaces were four WA mining companies and permission to collect information related to mobile plant used in the mining workplace was granted by each of these companies. See permission letters in Appendix 1.

The selection criteria for participating mining companies was being a typical Western Australian large or medium-sized mining company that used mobile plant. Four mine sites were selected to provide a range of mobile plant equipment currently in use in the Western Australian mining industry. Researched mine sites included companies with open cut iron ore mining, open cut and underground gold mining, and underground nickel and copper mining. Researching multiple mining companies enabled a variety of workplaces to assess to identify best practices, where there are differences and where there are opportunities for improvements related to the use and maintenance of mobile plant equipment. Appendix 5 has a list of observations that were given permission to be undertaken.

One of the participating mining companies requested a traffic management plan to be developed as part of the mobile plant research work at this mine. The researcher spent three days at this mine site observing mine traffic movements and met with the safety personal to gather the relevant information to develop the customized *Traffic Management Plan* for this mine site. See Appendix 6 for the traffic management plan developed for, and now used, at this work site.

3.3.1.3 Interview Technique and Data Collection Procedure

Qualitative research instruments used for data collection included interviews, observations and analysis of documents. Interviews are the most common techniques used to gather research information. There are three types of interviews: structured, semi-structured and unstructured, described in some publications as structured, informed and guided, respectively (Grbich, 1999).

For this research a semi-structured interview technique was used (see interview questions in Appendix 4). A semi-structured interview is characteristically based on a flexible topic guide that provides a loose structure of open-ended questions to explore experiences and attitudes. It has the advantage of great flexibility enabling the researcher to enter new areas and produce richer data. In addition, it helps the researcher to develop a rapport with the informants (Pope et al., 2002). Semi-structured interviews elicit people's own views and descriptions and have the benefit of uncovering issues or concerns that have not been anticipated by the researcher (Pope et al., 2002).

In depth and semi-structured interviews, including one to one and focus group interviews, were conducted by the researcher during the visit to the mining companies. Grbich (1999) stated some benefits of the focus group interviews are that they have the advantage of being more time efficient as more people can be interviewed for the same amount of time and also provide a richer source of data. Grbich (1999) also wrote that focus group interviews tend to document the 'public' rather than the 'private' views of the individuals. As some people do not interview well in group situations (Grbich, 1999) the researcher also conducted one to one interviews as well as the focus group interviews.

Corbin and Strauss (2008) and Patton (2002) discussed the potential impact of the interview on the participants. Patton (2002, p. 405) stated: "Interviews are interventions. They affect people. A good interview lays open thoughts, feelings, knowledge, and experience, not only to the interviewer but also to the interviewee." No participants reported any adverse feelings after their interview.

The researcher visited the mining companies to collect data and conduct interviews. Prior to interviews the participant information sheet (see Appendix 2) and consent form (see Appendix 3) were distributed to the mobile plant operators and workers who were randomly selected by the area supervisor to participate in this research. However, due to participants' engagement at work especially mobile plant operators and maintenance workers, it was not possible for the management of visited mining companies to spare 3 to 4 participants at a particular time in order to conduct focus group interviews. Therefore, one to one interviews were also conducted at the visited mining companies in order to collect data for research analysis. At each mine site focus group and one to one interviews were conducted with mobile plant operators, mobile plant supervisors and maintenance workers with an average duration of 60 minutes for each group interview. This information was added to the information obtained from analysing the Resources Safety Database, particularly in relation to safety risk control measures for mobile plant equipment commonly used in the Western Australian mining industry. See Appendix 4 for the questions asked to each focus group and one-to-one interviewed participants at all four mining companies.

A total 6 focus group interviews and 27 one to one interviews were conducted by the researcher with mine workers. During the interview, participants were able to answer the questions documented in Appendix 4 as well as express their opinions and describe workplace experiences concerning hazards and precautions being taken prior to operate mobile plant equipment at site. There were a total of 42 participants that included 17 participants of 6 focus group interviews and 27 individual employees during the visit to their mining sites. Interviews were undertaken with people whose work involved the use of mobile plant in mining and included operators, mobile equipment maintenance workers, safety personal and site supervisors. The research participants were 15 mobile plant operators, 12 mobile plant maintenance workers, 8 operation and maintenance supervisors and 7 site safety supervisors who worked for Western Australian mining companies.

Once the consent form had been signed, the interview was conducted by the researcher either at the participants' work places or in the mine site office. Sometimes the researcher conducted the interviews in the office near mining areas as in this way there was less interruption in the work of mobile plant workers. During each interview, all questions were asked according to their order on the interview sheet (see Appendix 4) and the participants were able to describe their workplace experiences. All interviews were recorded with the participants' consent. Having one researcher conduct interviews ensured the reliability of the information collected. Field notes were written immediately after each interview. The participants were given a copy of all transcribed material to check its accuracy and to have the opportunity to correct the transcription if they felt the original transcript was not accurate. This ensured data validity and reliability.

Visiting four mine sites enabled the researcher to assess and identify best practices at a variety of workplaces, where there were differences and where there were opportunities for improvements related to the use and maintenance of mobile plant equipment. The amount of time spent at each mine site was determined by the mining company management staff. At Mining Company A the researcher spent four days. At Mining Company B three days, Mining Company C two days and at Mining Company D a one day visit was conducted by the researcher. During each mine site visit the researcher became familiar with the different types of mobile plant equipment/machinery being used on each site. The planned mobile plant information and relevant data required to conduct this research analysis was collected during the site visits.

3.3.2 Phase 2: Data Analysis and Interpretation

Qualitative research studies typically produce a very large amount of data that needs to be managed efficiently (Murphy et al., 1998). For this research 23,405 accidents and incidents in the Western Australian mining industry were collected by Resources Safety in their Notifiable Incident Database between the years 2007 to 2016. The researcher had Resources Safety permission to analyse this data that had not been previously analysed to identify mobile plant incidents. See permission letter in Appendix 1.

3.3.2.1 NVivo 12 data analysis

The qualitative interview data for this research that included focus group and one to one interviews, was analysed using NVivo version 12 for windows. NVivo is a text analysis software package that has pattern matching, coding and modelling capacities to assist the researcher to achieve deeper insights when analysing the interview data. Zamawe (2015. p. 13), described NVivo 12 as a software that supports qualitative research and "has features such as character- based coding, rich text capabilities and multimedia functions that are crucial for qualitative data management."

Some of the main features of NVivo 12, and an explanation about these features, are as follows:

1. **Coding and stripes:** Coding is a way of collecting all of the topic information, themes and references, which can help to make nodes. Stripes are a colourful bar that shows all coding.
2. **Charts:** Provides visual coding, usually in the form of a bar graph.
3. **Word tree:** Creates a tree map with words that are on the same branch having a relationship to each other.
4. **Word cloud:** Displays the word frequency of participants' responses or word frequency in documents and so on, with the most commonly used words being the largest in writing and at the centre of the word cloud.
5. **Explore diagram:** Focuses on one item. This item is at the centre of the diagram with spokes radiating out from this central item to all items that are connected to it. This display enables the connection between items to be explored.
6. **Comparison diagram:** Helps to visualise the differences and similarities between nodes and research items**.**
7. **Mind maps:** A brainstorming device used by the researcher in NVivo. Mind maps are used by the researcher to create a whole central topic and then create other ideas like a map.
8. **Project maps:** Has shapes that represent research items and uses spokes to show the links between these items. Project maps are used to explore and organise the research results, develop ideas, build theories, develop explanations and make decisions about the research findings.
9. **Concept map:** Creates a map with knowledge and ideas, which connect with the theories in the research.
10. **Cluster analysis:** An exploratory technique used to identify patterns in node contents. The more similar the contents in the nodes are, the closer the nodes are grouped together in the cluster map. This can be used to identify diversity and similarities in information included in each node, and provide a similarity index for words, coding and attributes.

11. **Hierarchical chart:** This is a tree map diagram, or a sun burst diagram, which helps to compare, categorise and visualise themes and data in the form of a chart (Bazeley, 2015).

Pattern matching, coding and modelling capacities of NVivo 12 were used to identify patterns of responses in interview question answers to determine causes of mobile plant incidents. Corbin and Strauss (2008) stated that coding into categories and concept analysis from the collected data is an early data analysis process. During this data analysis process and progress the coding process moves from a dominance of descriptive categories to grouping. Analysis of qualitative data using NVivo 12 software enabled the researcher to achieve objective three of this research, to conduct focus group interviews with mobile plant operators to identify their opinions on safety and risk control factors related to the use of mobile plant in their workplace and add to the information obtained from the Resources Safety notifiable incident database, from published literature and from the findings of mining workplaces and work processes observations.

3.3.3 Phase 3: Develop a THIP (Triage Hazard Identification and Prevention) model

The fourth research objective was to develop a Triage Hazard Identification and Prevention Model to improve hazard awareness and control selection for prevention of work place incidents associated with mobile plant to contribute to preventing low frequency severe consequence injuries related to mobile plant. Previously there was no specific model related to the causes of Western Australian mining industry mobile plant related injuries and fatalities and their prevention. Therefore a review of current Root Cause Analysis Techniques was conducted through a comprehensive literature analysis, detailed analysis of Notifiable Incident Data base from the Resources Safety data, work process and the actions of people observations, review of relevant documents including equipment manuals, exploration of the causes and reasons for mobile plants accidents and injuries and the information obtained when visiting mining sites and conducting focus workplace policies and procedures a framework was developed to provide a comprehensive description of the components that contributes to injuries, fatalities, and the policy tools by which occupational safety and health can be influenced.

Based on the collected and analysed data the “Triage Hazard Identification and Prevention Model” was developed as an innovative approach in order to minimize the occurrence of mobile plant related hazards, injuries and fatalities. It was innovative because it was the first risk assessment and risk control model that was primarily focusing on mobile plants hazards and their prevention. This model was developed based on the findings of this research.

3.3.4 Phase 4: Reporting of Results

During this phase, the research findings and results were written and discussed in comparison to the findings of the review of published literature. Conclusions were drawn and recommendations made.

3.3.4.1 Rigorousness of qualitative research

The methodology for measuring reliability and validity of quantitative research is different from that of qualitative research. According to (Leininger, 1988, p. 68), validity “refers to gaining knowledge and understanding of the true nature of a particular phenomenon and reliability focuses on identifying and documenting recurrent, accurate and consistent or inconsistent factors”. The advocates of qualitative research quality have identified four key methods of achieving rigorous and trustworthy research: credibility, transferability, dependability, and confirmability (Guba, 1981; Shenton, 2004; Ortlipp, 2008; Hadi & Closs, 2016). In this research, a number of techniques were employed to ensure that all qualitative data collected conformed to the true value of rigorousness and trustworthiness as shown in table 13. The trustworthiness of this researcher was inspired by Guba’s (1981) and Shenton’s (2004) model of trustworthiness.

Table 13

Model of trustworthiness.

Criterion	Trustworthiness Criteria	How researcher achieved trustworthiness
Internal Validity	Credibility	During the data collection process, the researcher ensured the following steps to increase credibility of this research. 1. Before data collection, the researcher thoroughly read the safety rules of each mining site. 2. Informed consent was obtained and signed by each interview participant to ensure only genuinely willing participants were interviewed. 1. During the data collection, every interview was recorded with participant consent for further analysis.
External Validity	Transferability	1. When the researcher was analysing the DMP data and writing the results of the qualitative data analysis, critical attention was paid to specific information about, and detailed descriptions of study location, method, subject (s) and the researcher's role in the study. This was important because it allows other readers to judge whether they can transfer this approach to their own situation.
Reliability	Dependability	2. The researcher reviewed all planned steps for the research and compared them with the actual steps undertaken. An effective appraisal of the study was completed. 3. In this research, there were standard questions for all interviewed participants. Reliability was enhanced by having a questionnaire to ensure that all questions could be easily understood by all research participants. 4. The data used for analysis in the research was taken from t reliable DMP database and on-site observations of the researcher to ensure reliability.
Objectivity	Conformability	1. Self-reflection to identify the researcher's personal biases.

Note. Adapted from 'Criteria for assessing the trustworthiness of naturalistic inquiries', by Guba, in *Educational communication and technology*, vol. 29, (pp.75-91), 1981

3.3.4.1.1 Generalisability of Research

Maxwell and Chimel (2014) documented that generalizability of research allows the reader to determine transfer of knowledge as the researcher explained the variables under which those incidents exist. The proposed research has been undertaken on four different mining sites included open-cut and underground mining sites that allowed the researcher to gain a good exposure to different types of mobile plants being used and the hazards involved while driving mobile plant. As this research was conducted at more than one mine site this assists with the application of the research findings being able to be generalised to other mine sites that use similar mobile plant mining equipment. Furthermore, the researcher also gained awareness of the different types of risk assessment techniques being followed by mining companies in Western Australia. This generalised approach in the research methodology has provided significant benefit in determining the different types of hazard prevention techniques used in the Western Australian mining industry as well as in identifying challenges faced by each of the visited mining companies. This approach assisted in identifying suggestions for improvement in risk control measures for mobile plant safety at each of the visited mining company and this will be ultimately helpful in reducing the incidents related to mobile plant in Western Australian mining companies. Conclusions have drawn from information gained at all mining sites visited and this has extended the generalisability of the results.

3.3.4.1.2 Reflexivity

Reflexivity allows the researcher to explain why they are using a mixed methods approach, theoretical viewpoints and assumptions that may influence the research process (Corbin & Strauss, 2008). Teddlie and Tashakkori (2009) outline the importance of reflecting during the course of the study. The researcher, during the site visits, reviewed different documentation related to mobile plant hazards, maintenance and preventive regimes employed by each mining company visited while conducting the research. A reflective approach was used throughout the study to consider what had been learnt through the observations, interpretation and any potential biases that may be present. At the mining companies visited, the researcher gained exposure of the pros and cons of the FIFO (fly in and fly out) work life. Prior to interviewing mine workers the researcher was of the opinion that since mining jobs, especially the trade jobs, are highly paid the workers would be satisfied with the fly in fly out life style. However, this assumption was not fully correct because during the interviews with the mining workers they stated that although the workers are paid handsomely the FIFO (fly in and fly out) life style has a significant adverse impact on their mental health. This highlights one of the reasons why a mixed method approach was used in this research so that both quantitative and qualitative data could be obtained and reflected upon which helped immensely in generating new knowledge and practical recommendations from the findings of this research.

3.4 Ethical Consideration

Ethics approval from the Curtin University Ethics Committee was obtained prior to the research being conducted. The purpose and their role in the research were explained to the participants.

* Written consent was obtained prior to data collection from each person who volunteered to take part in this research.

* Confidentiality: The data collected from the mine site did not include any identifying names and research results were reported as group data only.

* Right to withdraw: Participants had the right to refuse to answer any question or withdraw consent at any point without coercion or pressure.

Participant information sheet and informed consent form are attached as Appendixes 2 and 3.

3.5 Summary

The concurrent embedded mixed method approach was determined to be the best method to use to conduct this research as this research involved analysing a large database and the qualitative data gathered from mining site visits and interviews. The literature review, pilot study with the mobile plant operators, workers and the supervisors who understood the hazards of using mobile plants and the safety precautions, as well as the database analysis, all helped to develop and refine the interview questions asked of the research participants. The use of data analysis in the quantitative phase and NVivo 12 helped facilitate the attainment of the research objectives and ensure rigorousness.

The next section of this report includes the analysis of the notifiable incidents related to mobile plant in the Western Australian mining industry for a period of ten years from 1-1-2007 and 31-12-2016 included in the Resources Safety Notifiable Incident Database

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4. DATA ANALYSIS OF NOTIFIABLE INCIDENTS RELATED TO MOBILE PLANT IN THE WA MINING INDUSTRY

1. Introduction

Research objective one was to analyse the Resources Safety notifiable incident database to determine the causes of mobile plant accidents in the Western Australian mining industry between 2007 and 2016 and to tabulate cause-specific period prevalence of fatal and non-fatal accidents and injuries. This chapter meets objective one as it includes the data analysis of the Resource Safety Database of Notifiable Incidents related to mobile plant in the Western Australian mining industry between 1st of January 2007 and the 31st of December 2016 in order to identify the cause of fatalities, injuries, potential accidents and near miss due to the mobile plants in Western Australian mining industry. The Department of Mines and Petroleum (DMIRS) on the 1st July 2017 became the Department of Mines, Industry Regulation and Safety (DMIRS) as a result of merging the Department of Commerce and Department of Mines and Petroleum. DMIRS mission was to support a safe, fair and responsible future for the Western Australian community, industry and resources sector. The 10-year period (from 1-1-2007 to 31-12-2016) was chosen as this has provided the researcher with 10 years of notifiable incidents to analyse to achieve objective one. Further to this, in order to analyse the up to data and incidents related to mobile plant, database from 1-1-2017 to 31-3-2020 was also requested and provided by the Department of Mines, Industry Regulation and Safety. The data base from these three years was also interpreted and analysed to identify hazard types and the causes of incidents, injuries and fatalities. It was identified that the causes of incidents, injuries and fatalities were similar to those of the previous 10 years indicating that data saturation had been achieved as no new themes were emerging.

Notifiable incidents are the occurrences of incidents reported as defined Under the *Mines Safety and Inspection Act 1994* and the Mines Safety and Inspection Regulations 1995 for a mining operation (including exploration operations). Guidelines issued by the

Department of Mines, Industry Regulation and Safety in the Mines Safety and Inspection Act 1994, endorsed by the Mining Industry Advisory Committee, state that a 'notifiable incident' is to be reported to the Regulator immediately after becoming aware it has happened. If the Regulator asks for written notification this is to be provided within 48 hours of the request and the incident site to be preserved until an Inspector arrives or directs otherwise (subject to some exceptions). Failing to report a 'notifiable incident' is an offence and penalties apply (Accident and Incident Reporting Guideline, Resource Safety, 2017). In Australia each state and territory has Work Health and Safety Regulators who are committed to preventing work-related injuries and deaths.

2. Resource Safety Database Analysis

The Resources Safety Notifiable Incident Data base was de-identified and provided to the researcher to examine the causes of the notifiable incidents that occurred in the Western Australian mining industry between 2007 and 2017. In order to get better understanding of the database, the researcher visited the Resources Safety office and had a detailed meeting with Inspectors about the specific parameters, data coding, categorization and sub-categorization of the database. This provided an in-depth knowledge of the data in the database for the researcher to use to perform an analysis of all notifiable incidents that involved mobile plant.

1. Setting Specific parameters in the database

Analysing raw incident data required setting specific parameters for the information stored in the database. First the specific parameters were selected from the main database on the basis of the requirement of the research. Columns selected for the setting of specific parameters were:

2. Date of incident
3. Location (Underground or Surface Mining)
4. Severity (Fatal, Fatal Potential, Severe, Moderate, Minor, No Injury)
5. Number of Injuries / Fatalities
6. Primary Incident cause

7. Secondary Incident cause

8. Tertiary Incident cause

9. Incident Summary

10. Incident Description

The exported information from the database was tabled into an excel spreadsheet and then, as programmed, the incident data was automatically tabled into various columns for every event.

1. ***Data Coding***

Data coding is an important part of data analysis that allows the detailed investigation of the data set. Therefore, data coding of the extracted data sheets was undertaken considering the following investigative questions for each incident to be coded.

1. What were the Primary causes (hazard type) of the mobile plant incidents in Western Australia?
2. What was the number of incidents related to mobile plants each year from 2007 to 2016?
3. What was the number of mobile plant incidents each year when categorizing it into hazard type?
4. What was the frequency and causes of underground and surface mining incidents related to mobile plant?
5. What were the total number of fatalities from 2007 to 2016 related to mobile plant incidents in the Western Australian mining industry?
6. What were the primary causes of fatalities related to mobile plant in the Western Australian mining industry?

These questions not only provided more context but enhanced the quantitative aspects of the data. For example, the analysis determined the frequency of incident types and hazards. Calculating the frequency substantiated the impact of each occurrence and its results. In addition, the method of coding gave rise to more structure allowing more effective data analysis. Structure increased the researcher's understanding of the mobile plant incidents causes by highlighting key themes. These themes provided a clear link between incidents and their associated hazards. For example, the researcher found that road conditions and network communication losses were the major contributors to truck lane breaches.

2. Resource Safety Database Analysis – Snapshot from 2007 to 2016

After coding extracted data entered between 2007 and 2016 from the Resources Safety notifiable incident database analysis was conducted to determine the descriptive statistics of number and percent of mobile plant accidents and incidents reported. Qualitative data analysis was also conducted with pattern matching used to identify and analyse the cause of each reported accident and incident. Consultation with the Department of Mines, Industry Regulation and Safety Inspectors identified that notifiable mobile plant incidents provided the most relevant information to assist with meeting the research objective one as notifiable incidents include all mobile plant accidents whether there was an employee injury or not.

The following results related to mobile plant incidents in Western Australian mining industry were extracted from the database that was further used by the researcher to perform an in-depth analysis and graphical representation of the analysis findings. These results were that:

1. Total number of incidents reported to Resources Safety for the 10 years between 2007 and 2016 was **23,405**.
2. Total number of mobile plant incidents in the span of 10 years from 2007 to 2016 were **4,613**
3. Out of 4,613 mobile plant incidents there were **4,066** *surface mining* incidents with **8 fatal incidents** and **547** *underground mining* incidents with **3 fatal incidents** over the span of ten years.
4. Highest number of injuries recorded was in sub-category Truck/Mobile Equipment and that was **1,867**.
5. **11 fatalities** were reported to Resource Safety in Western Australia due to mobile plant incidents between 1-1-2007 and 31-12-2016.

Data analysis of the injury frequency rate of incidents related to mobile plants was one strategy used to achieve objective one of the research. Areas and the main causes that contributed to the incidents leading to injury and fatalities were also analysed. This further assisted the researcher in achieving objective three of the research to develop the Triage Hazard Identification and Prevention (THIP) model as an outcome of the research. The database included the following sub-categorization of mobile plant incidents.

1. Crane Incidents
2. Light Vehicle Incidents
3. Truck/Mobile Equipment Collisions
4. Truck/Mobile Equipment Contact with Person
5. Truck/Mobile Equip. NOC (Not otherwise classified)
6. Truck/Mobile Equip. Over Edge
7. Truck/Mobile Equip. Rollover

3. Total Recordable Incidents from 2006 to 2016

Mining industry is classed as a high-risk work environment with mechanical tooling, heavy machinery and hazardous environment both for underground and surface mining. Data extracted from spreadsheet was first analysed with reference to the incident type category. There were seven incident types for mobile plant in the main database and these were reviewed for further use in the detailed analysis. The number of each type of incidents are recorded in Table 14.

Table 14

Number of Incidents recorded from 2007 to 2016 as per hazard type

S.No	INCIDENT TYPE	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
1	Crane incidents	49	30	49	58	56	51	88	47	60	41
2	Light Vehicle Incident	52	64	64	76	75	71	89	75	54	58
3	Truck /Mobile Equip. Collision	57	118	87	110	106	113	118	98	81	84

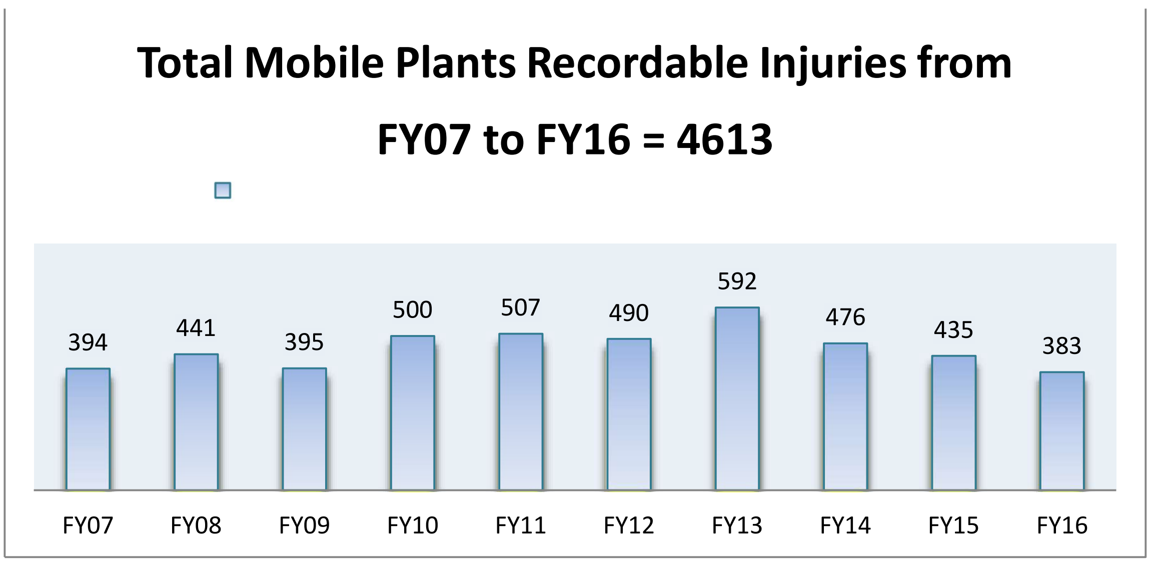
4	Truck /Mobile Equip. Contact with Person	0	14	13	17	10	4	8	7	4	3
5	Truck /Mobile Equip. NOC (Not otherwise classified)	178	161	145	202	192	205	243	190	184	167
6	Truck /Mobile Equip. Over Edge	20	9	12	17	33	16	20	24	27	14
7	Truck /Mobile Equip. Rollover	38	45	25	20	35	30	26	35	25	16
	TOTAL INCIDENT PER YEAR	**394**	**441**	**395**	**500**	**507**	**490**	**592**	**476**	**435**	**383**

Following is the graphical representation of total recordable injuries related to mobile plant from 2007 to 2016. The highest number of injuries, 592, occurred in 2013. See figure 10.

Figure 10

Total recordable mining industry injuries related to mobile plant from 2007 to 2016

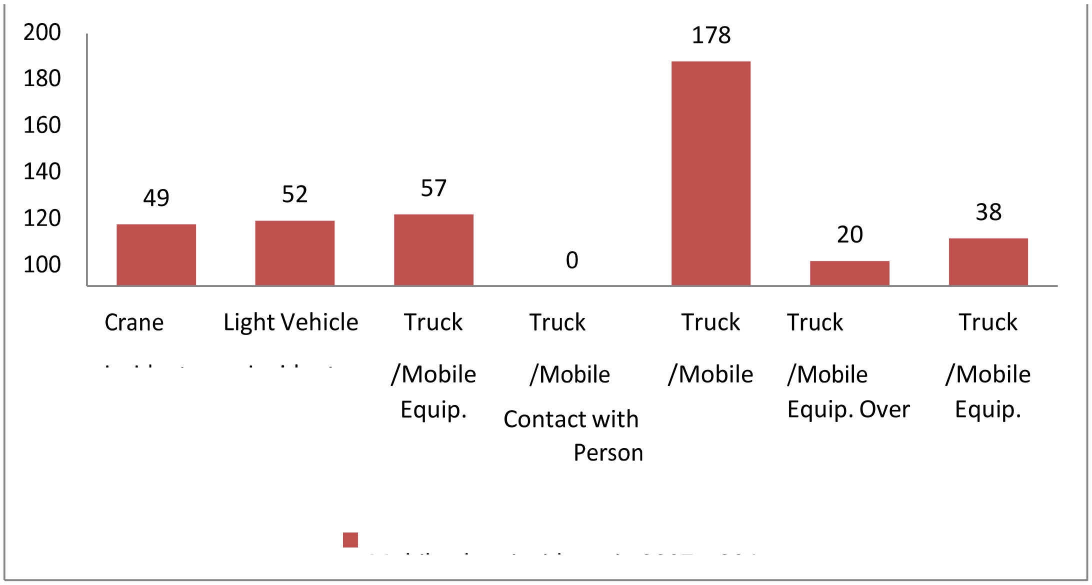
1.



In 2007 the total recordable incidents related to mobile plants were 394 and the highest number was recorded in the sub-category Truck /Mobile Equip. NOC (Not otherwise classified) which was 178. Following is the graphical representation of the incident types recorded in 2007.

Figure 11

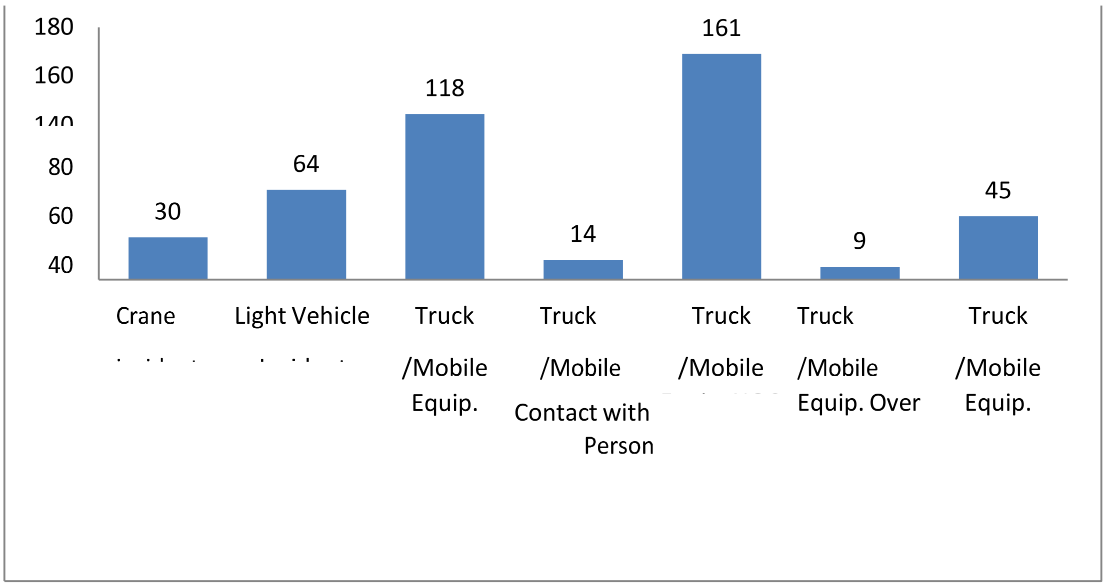
Graphical Representation of Mobile plant incidents in 2007



In 2008, total recordable incidents related to mobile plants were 441 and the highest number was recorded in the sub-category Truck /Mobile Equip. NOC (Not otherwise classified) which was 161. See figure 12.

Figure 12

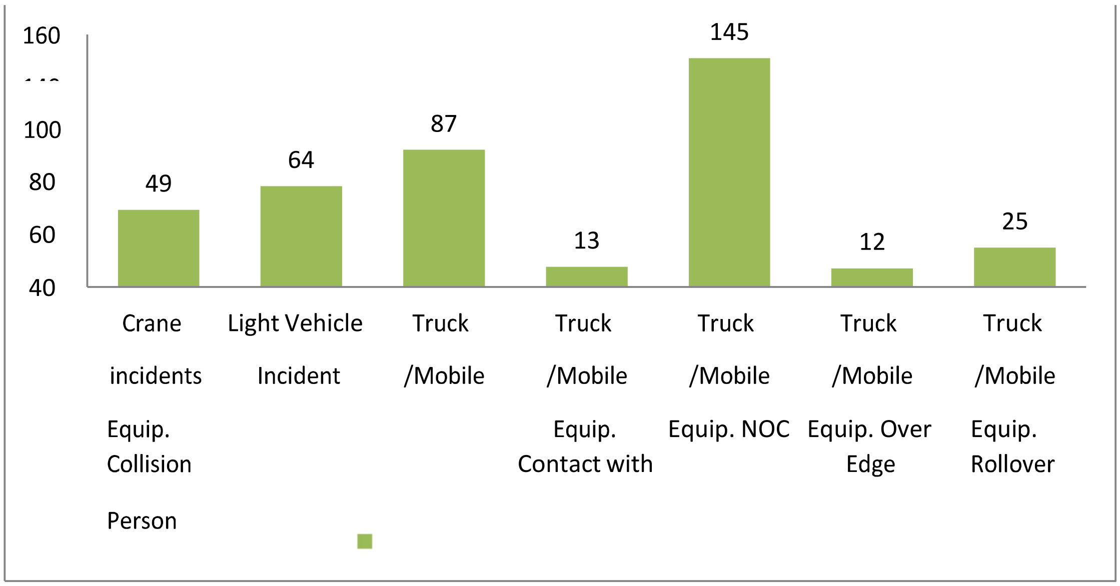
Graphical Representation of Mobile plant incidents in 2008



In the 2009, total recordable incidents related to mobile plants were 407 with the highest number recorded in the sub-category Truck /Mobile Equip. Not otherwise classified (NOC) which was 145. See figure 13.

Figure 13

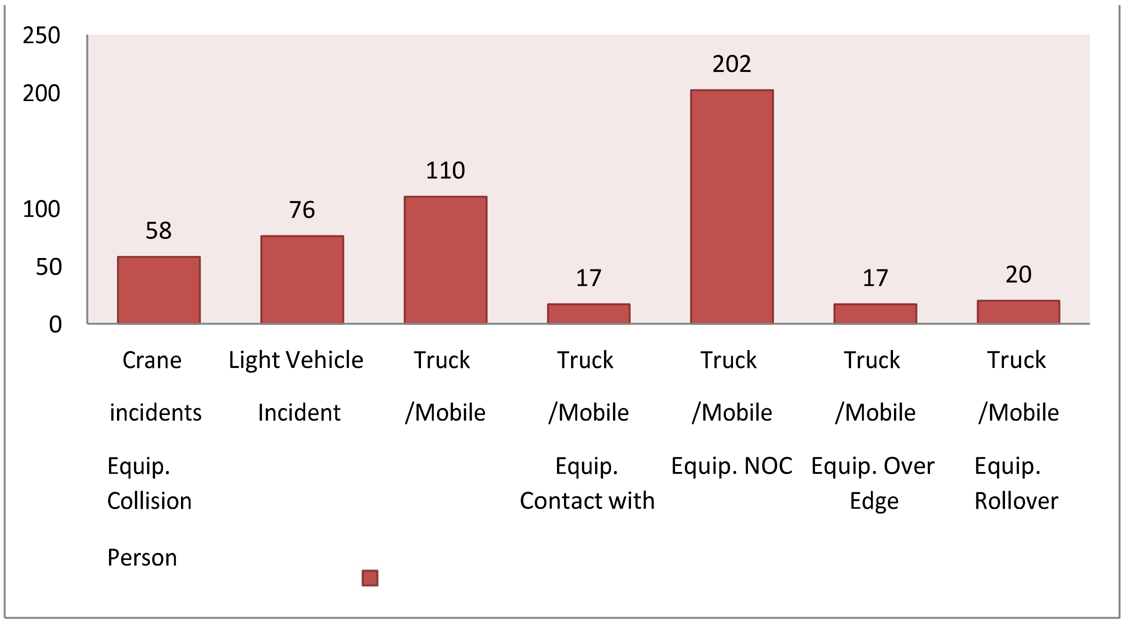
Graphical Representation of Mobile plant incidents in 2009



In 2010, total recordable incidents related to mobile plants were 500 with the highest number recorded in the sub-category Truck /Mobile Equip. Not otherwise classified which was 202. See figure 14.

Figure 14

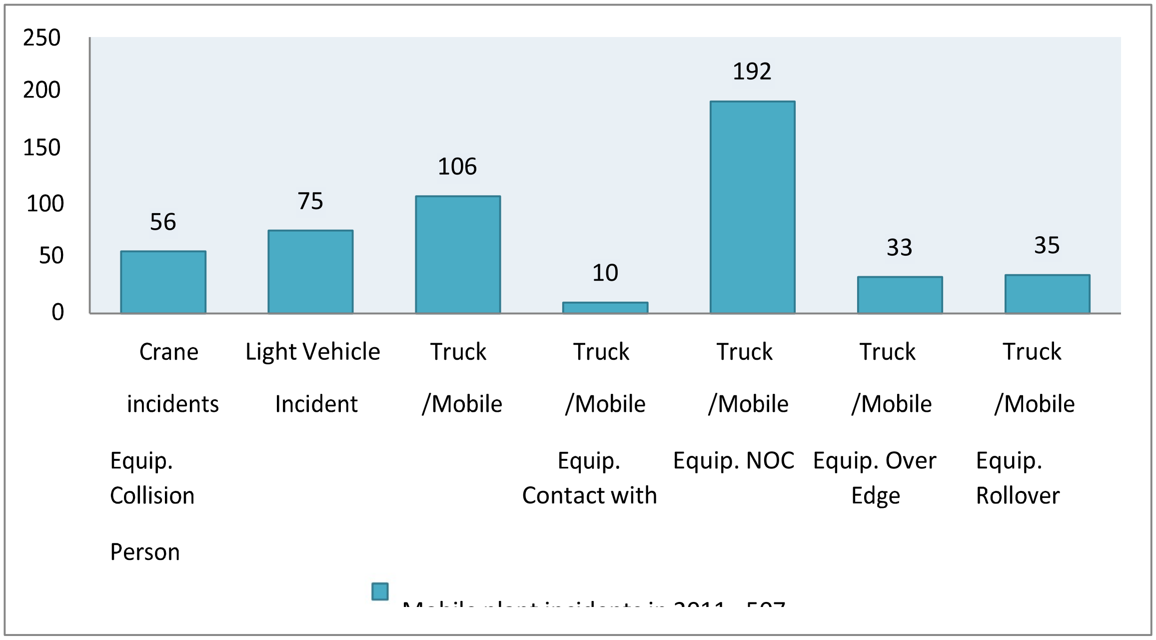
Graphical Representation of Mobile plant incidents in 2010



In 2011 the total recordable incidents related to mobile plants were 507 with the highest number recorded in the sub-category Truck /Mobile Equip. Not otherwise classified which was 192. See figure 15.

Figure 15

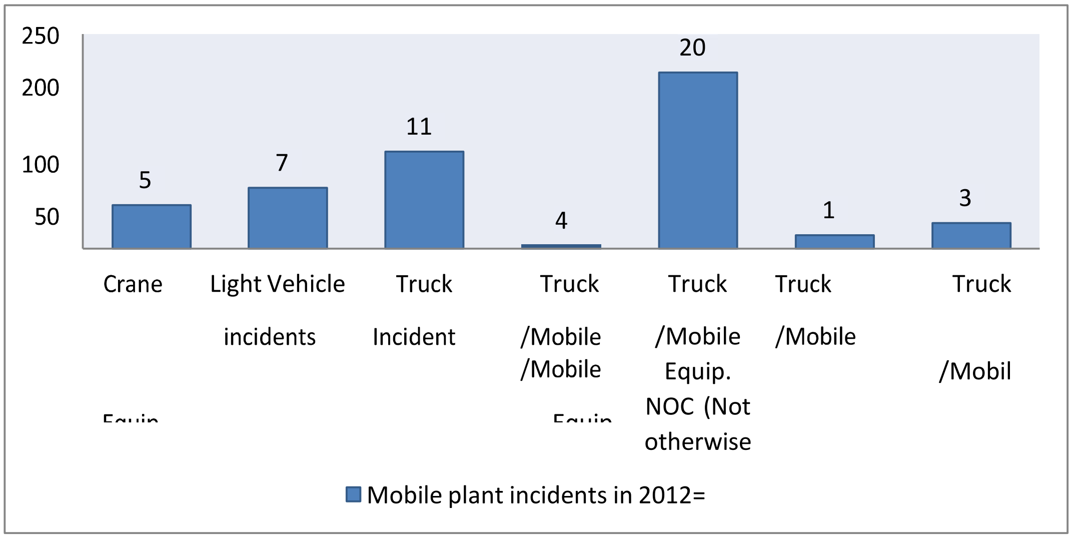
Graphical Representation of Mobile plant incidents in 2011



In 2012 the total recordable incidents related to mobile plants were 490 with the highest number recorded in the sub-category Truck /Mobile Equip. Not otherwise classified which was 205. See figure 16.

Figure 16

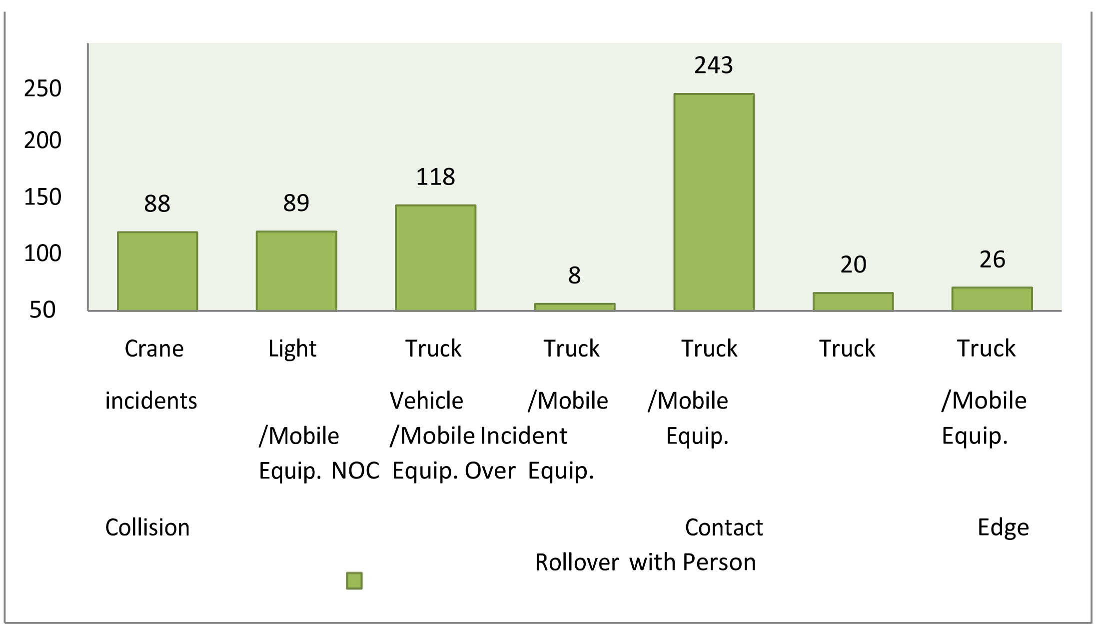
Graphical Representation of Mobile plant incidents in 2012



In 2013 total recordable incidents related to mobile plants were 592 with the highest number recorded in the sub-category Truck /Mobile Equip. Not otherwise classified which was 243. See figure 17.

Figure 17

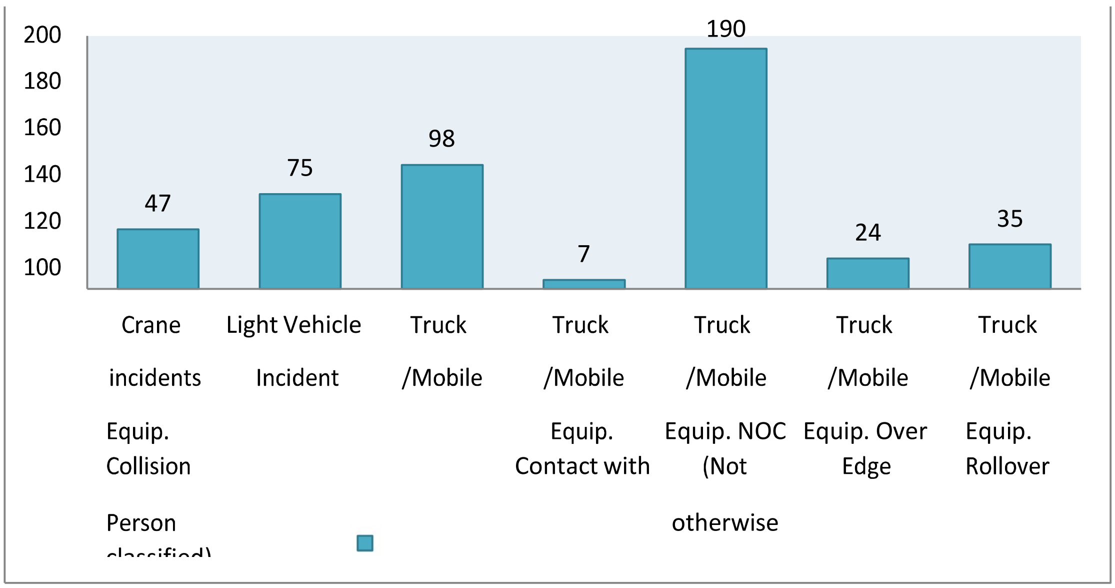
Graphical Representation of Mobile plant incidents in 2013



In 2014 the total recordable incidents related to mobile plants were 476 with the highest number recorded in the sub-category Truck /Mobile Equip. Not otherwise classified which was 190. See figure 18.

Figure 18

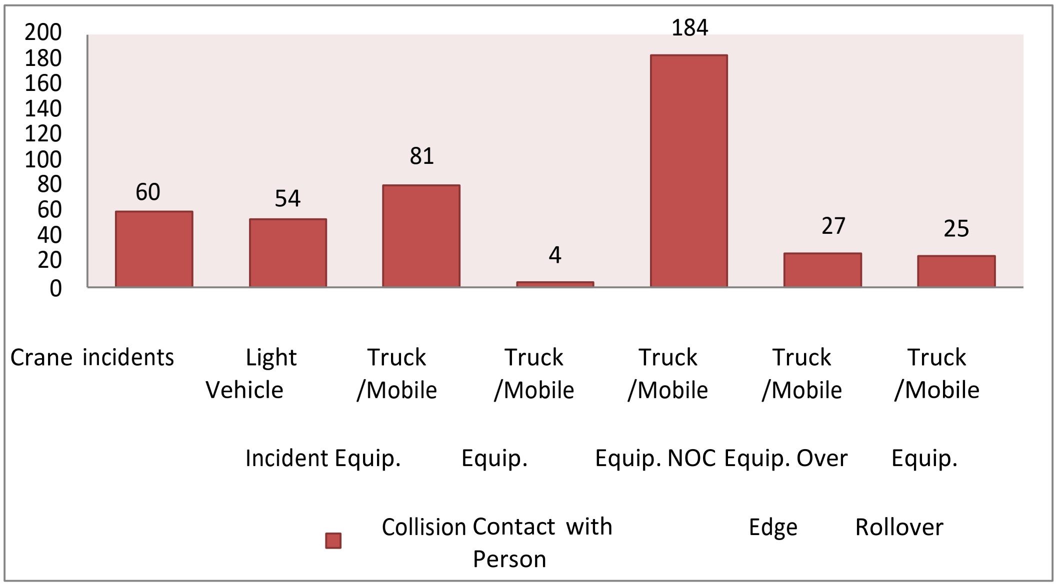
Graphical Representation of Mobile plant incidents in 2014



In 2015 the total recordable incidents related to mobile plants were 435 with the highest number recorded in the sub-category Truck /Mobile Equip. Not otherwise classified which was 184. There were 435 mobile plant incidents in 2015. See figure 19.

Figure 19

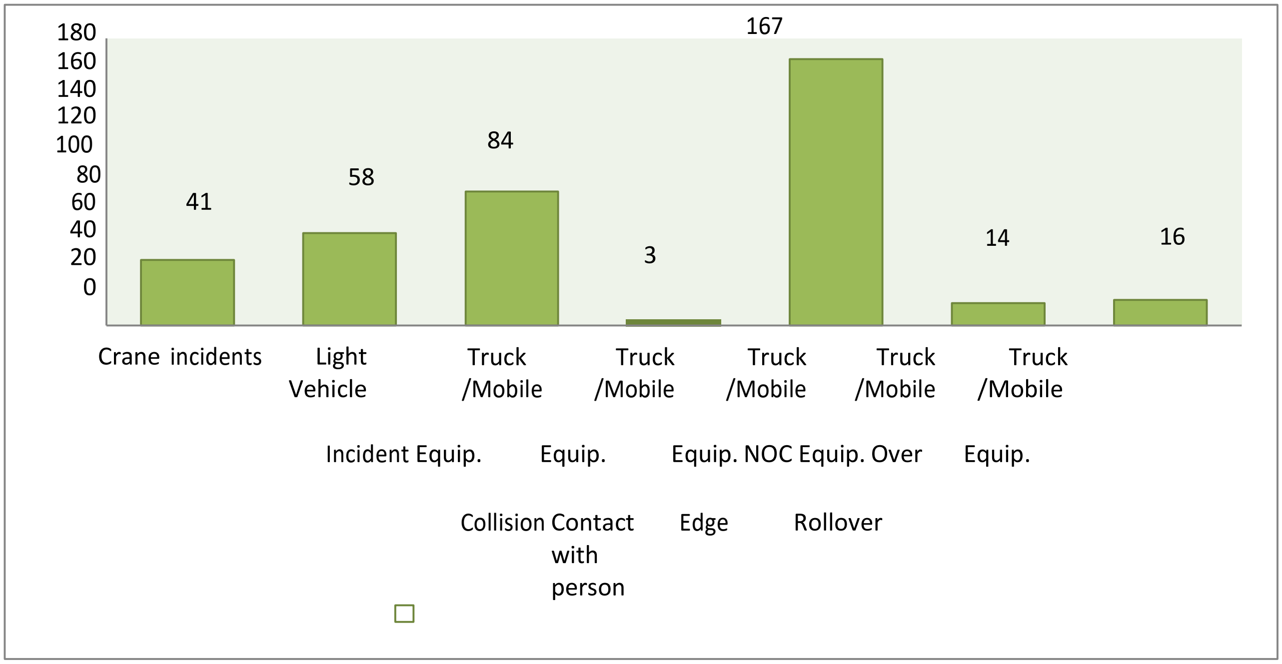
Graphical Representation of Mobile plant incidents in 2015



In 2016 the total recordable incidents related to mobile plants were 383 with the highest number recorded in the sub-category Truck /Mobile Equip. Not otherwise classified which was 167. See figure 20.

Figure 20

Graphical Representation of Mobile plant incidents in 2016.



Total Recordable Incidents related to mobile plants by Hazard Type from 2007 to 2016

Data extracted from the Resource Safety database was categorized with hazard type and the seven hazards were recorded as directly related to mobile plant incidents. As shown in table 16 from the period of 2007 to 2016, out of 4613 recordable incidents, sub-category titled "Truck /Mobile Equip. NOC" had highest 1867 numbers of incident. The second highest was the sub-category "Truck/Mobile Equipment collision with 972 incidents.

Table 15

Total Recordable injuries related to mobile plant by hazard type from 2007 to 2016

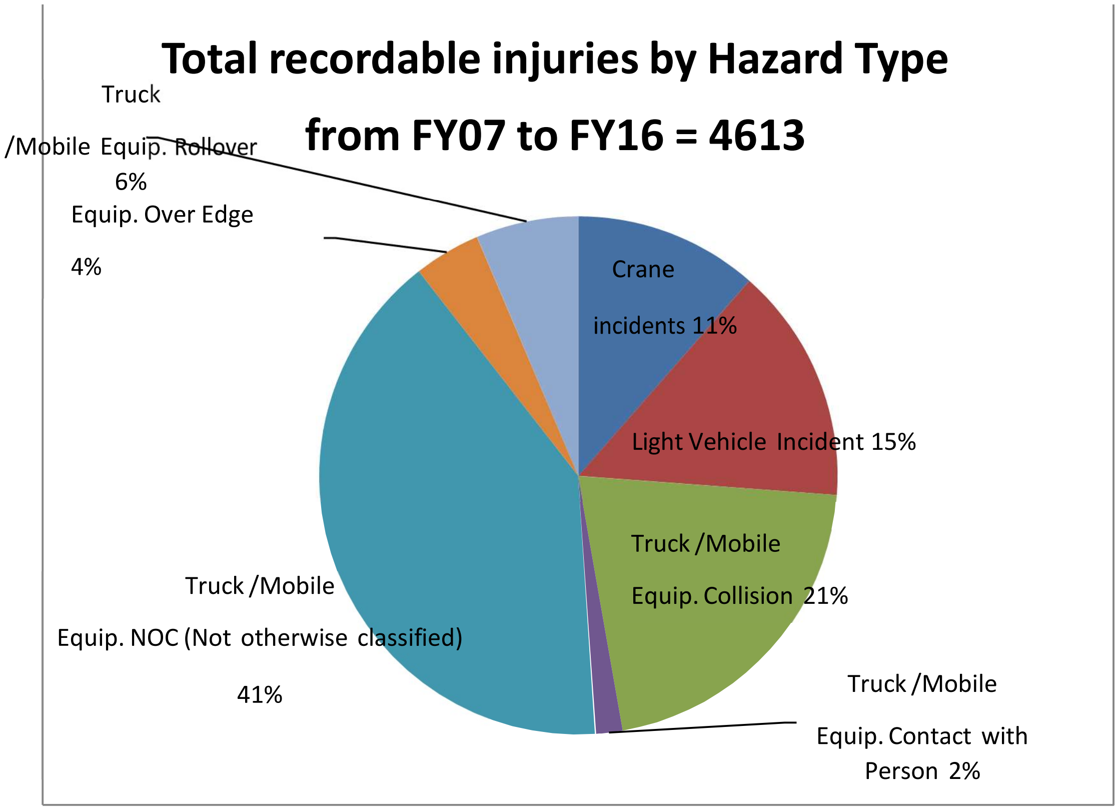
S.No	HAZARD TYPE	Total recordable injuries by Hazard Type	Percentage (%)
1	Crane incidents	529	11.5
2	Light Vehicle Incident	678	14.7
3	Truck /Mobile Equip. Collision	972	21.1
4	Truck /Mobile Equip. Contact with Person	80	1.7
5	Truck /Mobile Equip. NOC (Not otherwise classified)	1867	40.5
6	Truck /Mobile Equip. Over Edge	192	4.2
7	Truck /Mobile Equip. Rollover	295	6.4
	Total recordable Injuries by Hazard Type	**4613**	**100%**

As shown in table 16 from the period of 2007 to 2016, out of 4613 recordable incidents, sub-category titled "Truck /Mobile Equip. NOC" had highest 1867 numbers of incident. The second highest was the sub-category "Truck/Mobile Equipment collision with 972 incidents.

The researcher further analysed the extracted data with hazard type to obtain more information. Figure 21 includes the percentage of incidents with the sub-category "Truck-mobile Equipment-NOC" which included 41% of reportable incidents related to mobile plant used in the Western Australian mining industry. "Truck-mobile collision" had the next highest number with 21%," Light-vehicle collision had 15% and "Crane-incident" had 11%.

Figure 21

Percentage of total recordable injuries by hazard type from 2007 to 2016



1. <u>Total Recordable Fatalities related to mobile plants from 2007 to 2016</u>

The number of fatal incidents each year are recorded in table 16. The most fatal incidents (3) were recorded in the year 2015. In 2007, 2010 and in 2011 there were 2 fatal incidents. In 2008 and in 2014 there was one fatal incident related to mobile plant.

Table 16

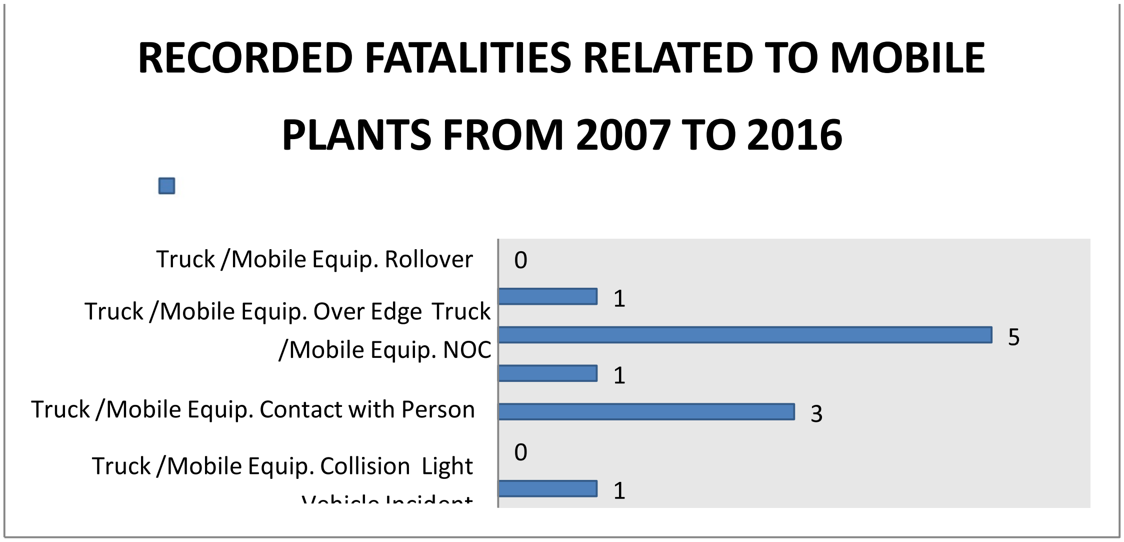
Mobile plant fatalities from 2007 to 2016

Year	Number of fatal incidents FY07 to FY16 = 11
2007	2
2008	1
2009	0
2010	2
2011	2
2012	0
2013	0
2014	1
2015	3
2016	0
Total	**11**

Further analysis related to the hazard type is included in figure 22 with graphical representation of recorded fatal incidents related to mobile plant from 2007 to 2016. Recorded fatal incidents by Western Australian mining companies were 11 in total with "Truck and Mobile Equipment" sub-category having the highest number (5) of incidents over the ten years. The sub-category "Truck/Mobile Equipment Collision" had the second highest number (3) of incidents followed by one incident in the category of crane incidents, Truck/Mobile Equip over edge and Truck/Mobile Equipment collision.

Figure 22

Recorded fatalities related to mobile plants from 2007 to 2016



2. <u>Total Recordable Fatalities with mining type related to mobile plants from 2007 to 2016</u>

Mining in Western Australia is both underground and surface mining depending on the type of extraction. The Resource Safety database had a column in which the type of mining was recorded. This assisted the researcher to gain an in-depth understanding of the hazards involving in surface and in underground mining. There were 4,613 mobile plant incidents recorded in Western Australia by mining companies from 2007 to 2016. Of the 4,613 incidents there were 4,066 surface mining incidents with 8 fatalities and 547 reported underground mining incidents with 3 fatal incidents over the span of 10 years.

Table 17 shows the eight fatal incidents in surface mining with 4 related to sub-category "Truck/Mobile Equipment NOC", 2 related to "Truck/Mobile Equipment Collision" and 1 in the hazard category of crane incidents and "Truck/Mobile Equipment contact with person. Of the 3 fatal incidents that took place at underground mine sites there were one each in sub-categories 3, 5 and 6.

Table 17

Mobile plant fatalities distribution from 2006 to 2016 as per mining type

No	HAZARD TYPE	Surface Mining	Underground Mining
1	Crane incidents	1	0
2	Light Vehicle Incident	0	0
3	Truck /Mobile Equip. Collision	2	1
4	Truck/Mobile Equip. Contact with Person	1	0
5	Truck /Mobile. Equip. NOC	4	1
6	Truck /Mobile Equip. Over Edge	0	1
7	Truck /Mobile Equip. Rollover	0	0

Figure 23 is the graphical representation of the surface and underground mining fatal incidents that occurred during 2007 to 2016.

Figure 23

Mobile plant fatalities from 2006 to 2016 as per Mining type

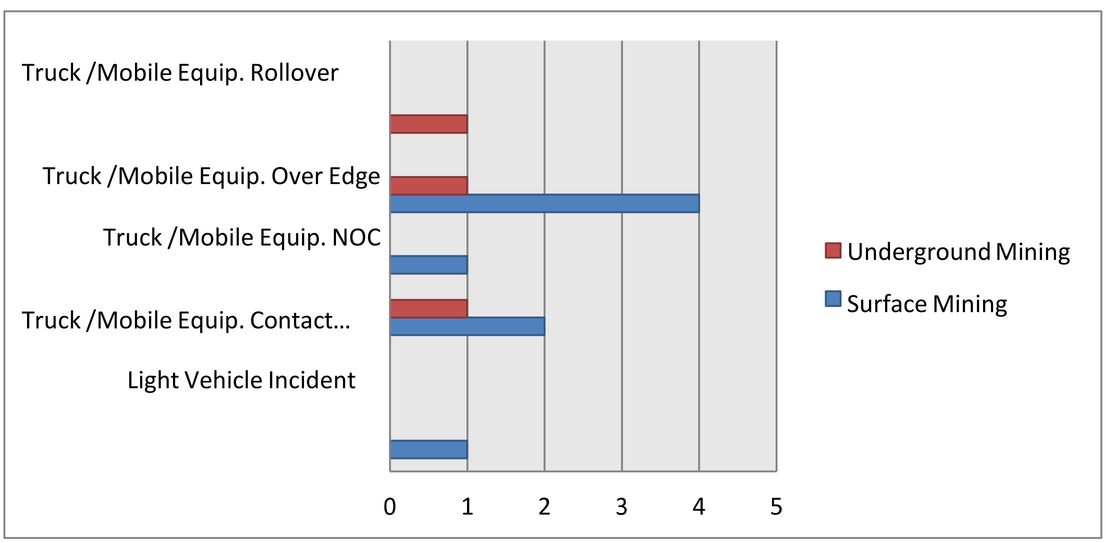


Table 18 shows that the three causes of underground fatal incidents were due to vehicle collision, vehicle roll over and machine movement crush.

Table 18

Underground mobile plant fatalities by hazard type from 2006 to 2016

No	Date of Incident	DMP Notifiable incident sub-category	Location	Severity
1	26/03/2007	1 Truck /Mobile Equip. Collision	UNDER	FATAL
2	11/04/2010	1 Truck /Mobile Equip. Over Edge	UNDER	FATAL
3	15/05/2015	1 Truck /Mobile Equip. NOC	UNDER	FATAL

Analysis of causes of above ground fatalities identified that the eight fatalities were due to Vehicle Collision, Crane incident, tyre unloading, maintenance procedure deficiency, vehicle over-edge, vehicle roll-over, incident due to under suspended load and machinery movement crush. See table 19.

Table 19

Surface mobile plant fatalities by hazard type from 2006 to 2016

No	Date of Incident	DMP Notifiable Incidents Sub-category	Severity
1	21/02/2007	Truck /Mobile Equip. NOC	FATAL
2	04/09/2008	Truck /Mobile Equip. Collision	FATAL
3	24/12/2010	Truck /Mobile Equip. NOC	FATAL
4	07/07/2011	Crane Incident	FATAL
5	16/08/2011	Truck /Mobile Equip. NOC	FATAL
6	26/05/2014	Truck /Mobile Equip. Contact with Person	FATAL
7	20/01/2015	Truck /Mobile Equip. NOC	FATAL
8	06/09/2015	Truck /Mobile Equip. Collision	FATAL

2. Resource Safety Database Analysis – Snapshot from 2017 to 2020

Further to the above analysis, significant incidents from 1-1-2017 to 31-3-2020 were also analysed in order to include mobile plant accidents and fatalities that occurred in the Western Australian onshore mining industry up until 31-3-2020. This additional data was provided by the Department of Mines, Industry Regulation and Safety (DMIRS). The following results related to mobile plant incidents in the Western Australian mining industry were extracted from DMIRS database to enable the researcher to perform a comprehensive analysis and graphical representation.

2. Total number of significant incidents reported to DMIRS between 1 - 1 - 2017 and 31-3-2020 was 3,906.
3. Total number of mobile plant incidents in the span of 3 years from1-1- 2017 to 31-3-2020 was 1,154.
4. Highest number of mobile plant related injuries recorded was 537 in the sub-category Truck/Mobile Equipment.
5. Out of the 1154 mobile plant incidents there were 1034 surface mining incidents with 5 fatal incidents, and 120 significant underground mining incidents with zero fatal incidents over the span of these three years. Of the fatal incidents two were in the year 2018, two in 2019 and one in January 2020.

The 2018 mobile plant fatal incidents are analysed in table 22. In relation to the other fatalities, on the 20 June 2019

> a 44-year-old truck driver was fatally injured when the Caterpillar 775G dump truck he was driving out of the pit crossed a windrow and fell down the pit wall to the bench below. The loaded truck had just reached the second narrow point in a section of the ramp that was reduced to a single lane. The truck's right-side wheels rode up and over the windrow and the truck slid over the edge falling 15 meters to the bench below. There was no demarcation or signage indicating any reduction in road width, the size and shape of the windrow at the narrow point was not ideal, and material had built up on the inside edge of the windrow, limiting its effectiveness. (Department of Mines, Industry Regulation and Safety, 2018a, p.

4)

This was followed by on the 11 September 2019 when

> a 57-year-old truck driver was fatally injured when the mechanism used to open and close a tarpaulin cover on a road train trailer failed while he was in the process of closing the cover. He was operating it by a switch adjacent to the trailer's front end. The top roller bar of the cover-closing system broke, and the supporting arm it was attached to at the front of the trailer swung through a downwards arc, ending near the location of the switch. It appears it may have struck the driver. The driver was found unconscious, and later died in hospital. (Department of Mines, Industry Regulation and Safety, 2020, p. 4)

On the 27 January 2020

> a 64-year-old contractor received fatal crush injuries in an incident involving the tele handler he was operating at a mine. It appears the worker may have been trying to exit the tele handler when he fell to the ground. The vehicle continued to move, and while apparently attempting to regain control of it the individual became caught and crushed between the vehicle and a fence. Medical care was provided, but the worker later died in hospital. (Department of Mines, Industry Regulation and Safety, 2020, p. 4)

In 2019 and in 2020, until 31/3/2020 the only Western Australian mining industry fatalities were related to mobile plant safety. In 2019-2020 in Western Australia there was an average workforce of 121,088 people employed in surface mining, 11,056 in underground mining and 3,584 in mining exploration (Department of Mines, Industry Regulation and Safety, 2020).

Data extracted from the Resource Safety database from 1-1 2017 to 31-3-2020 was categorized with hazard type and the seven hazards were recorded as directly related to mobile plant incidents.

Table 20

Total recordable mobile plant injuries by hazard type from 1-1-2017 to 31-3-2020

No	Hazard Type	Total Recordable Injuries by Hazard Type	Percentage (%)
1	Crane incidents	191	16.5
2	Light Vehicle Incident	18	1.56
3	Truck /Mobile Equip. Collision	260	22.5
4	Truck /Mobile Equip. Contact with Person	9	0.8
5	Truck /Mobile Equip. NOC	537	46.5
6	Truck /Mobile Equip. Over Edge	40	3.5
7	Truck /Mobile Equip. Rollover	99	8.6
	Total recordable Injuries	**1154**	**100%**

Following is the graphical representation of total recordable injuries related to mobile plant from 2017 to 2020. The highest number of injuries, 537, was in the sub-category of Truck/Mobile Equipment NOC (not otherwise classified).

Figure 24

Graphical distribution of mobile plant significant incidents from 2017 to 2020 as per Equipment type

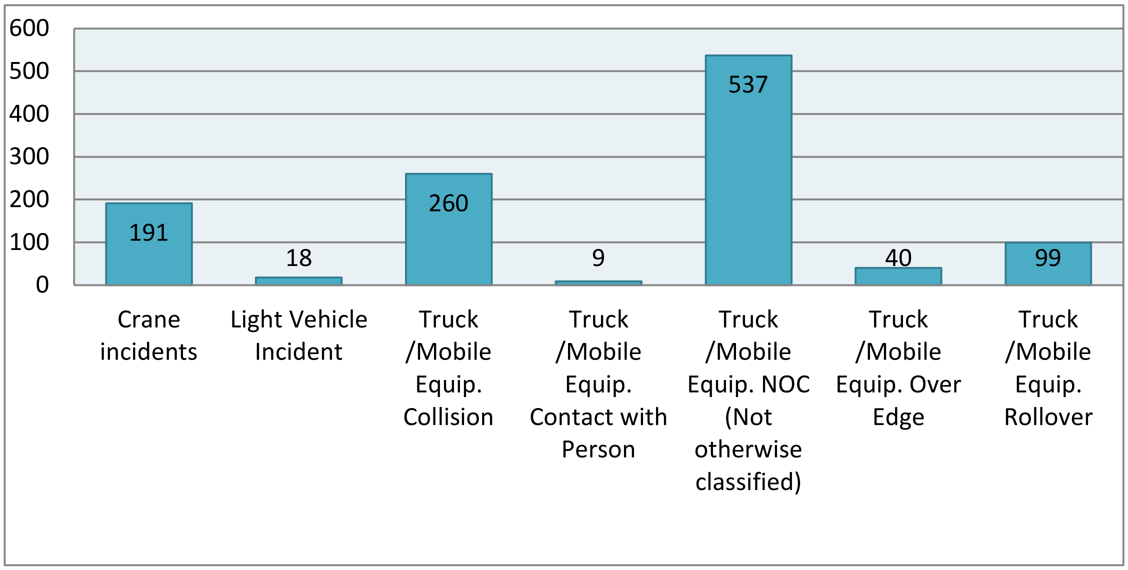


Figure 25

Percentage distribution of mobile plant injuries by hazard type from 2017 to 2020

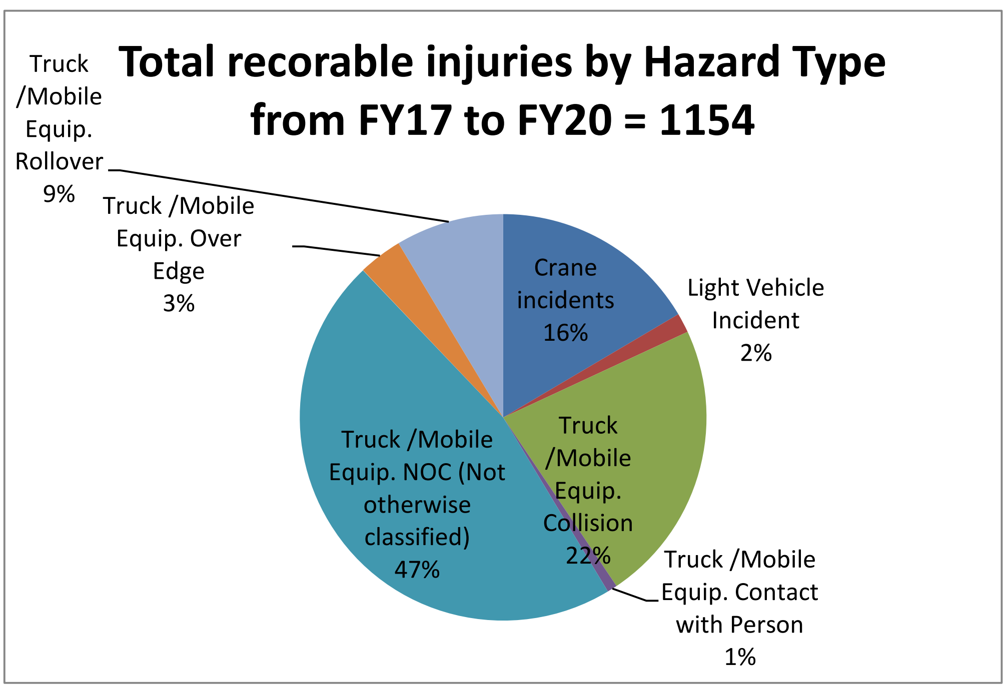


Figure 25 includes the percentage of incidents from 2017 to 2020 with the sub-category "Truck-mobile Equipment-NOC" which included 47% of reportable incidents related to mobile plant used in the Western Australian mining industry. "Truck-mobile collision" had the next highest number with 22% and "Crane-incident" had 16 %. These percentages of significant incident categories are similar to what occurred in 2006 to 2017.

4.3 Comprehensive Analysis of fatal Incidents related to mobile plants from 2007 - 2020

The analysis of extracted data related to mobile plant from the significant incident database offered insights that has helped to achieve research objective one. In order to understand the causes that lead to fatal incidents related to mobile plants in the Western Australian mining industry from 2007 to 2020, analysed data was recorded in tables 21 and 22.

Table 21

Notifiable Mobile Plant Incidents Analysis from 2007 to 2016

Incident Date Mobile Equipment name	Database. Hazard Type	Incidents Detail	Injury or Incident Outcome	Relevant WA Mines Safety & Inspection Act 1994 section	Key Findings
3/26/2007 **Concrete Agitator Truck**	**Vehicle Runaway** Sub-category "Truck /Mobile Equip. Collision"	Driver lost control of the concrete agitator truck while driving down a decline, approximately 850 m (vertical) below the surface and struck the sidewall.	Multiple injuries. Fatal.	Serious or appears to be serious injury (including fatality). (s.76 (2a)). Loss of control, failure of braking or steering of heavy earth moving equipment. (s.78 (3j))	The key findings after the analysis of incident were: 1-There was no accurate assessment of driving speed and gear selection, therefore it was recommended that the driving speed and the gear
2/21/2007 **Haul Truck**	**Tyre unloading** Sub-category "Truck /Mobile Equip. Collision"	Unloading of haul-truck tyres from a delivery truck (loaded in four groups of three, in a vertical and upright position). Released the tie-down holding the tyres and climbed onto the tray to retrieve the tie-down chains (tyres not supported	Multiple injuries. Fatal.	Serious or appears to be serious injury (including fatality). (s.76 (2a)).	The key findings after the analysis of incident are: 1-Lackof written work procedures

Incident Date Mobile Equipment name	**Database. Hazard Type**	**Incidents Detail**	**Injury or Incident Outcome**	**Relevant WA Mines Safety & Inspection Act 1994**	**Key Findings**
		Database of unloading commenced). Load moved, knocked the driver from the truck. Tyres fell, landing on top of the truck's driver			3. The injuries can be prevented if the tyres are transported flat.
25/8/2008	**Tyre inflation – high pressure** Changing a dump truck tyre	Replacement tyre had just been inflated (while being held in a vertical position) by the tyre handler. (Maintenance worker.) Mobile maintenance supervisor was about to turn the valve stem off.	Fatal head injuries	Serious occurre nce. (s.79)	The key findings after analysis of the incident are: 1. There were violation safety precautions taken as maintenance worker was standing between arms of tyre handler during inflation. 2. No use compatible bolt
9/4/2008 **Light Vehicle and Haul Truck**	**Vehicle Collision** Sub-category "Truck /Mobile Equip. Collision"	An apprentice (heavy duty fitter) was driving a light vehicle back to the workshop after visiting a dozer. Light vehicle drove into a haul truck as the truck moved past a T-junction, at a give way sign, to join the main traffic flow. The truck driver	Fatal – multipl e injuries	Serious or appears to be serious injury (including fatality). (s.76 (2a))	The key findings after the analysis of incident were: 1. Strict procedures to be placed to issue pit permits to only people who will drive in the pit area. 2. Lack of spacing between vehicles to

Incident Date Mobile Equipment name	Database. Hazard Type	Incidents Detail	Injury or Incident Outcome	WA Mines Safety & Inspection Act 1994 section	Key Findings
		truck that turned into the T-junction. The turning haul truck shielded the light vehicle from view.			
12/24/2010 Haul Truck-High pressure suspension cylinder – struck by	**Maintenance Procedure deficiency** Sub-category of "Truck /Mobile Equip. NOC (Not otherwise classified)"	Incident took place in the maintenance workshop while working on front suspension of a haul truck and working on a suspension cylinder. The original equipment manufacturer (OEM) procedure requires the high-pressure nitrogen gas to be released before the cylinder is removed from the truck or dismantled. A sudden release of high-pressure gas occurred and a component of the	Fatal – chest injuries.	Serious or appears to be serious injury (including fatality). (s.76 (2a	The key findings after the analysis of incident were: 1. There was lack of following of OEM's maintenance procedure which ultimately resulted in a fatal incident. 2. There was a potential
4/11/2010 Loader	**Vehicle over edge** Sub-category of "Truck /Mobile Equip. Over Edge"	An operator was operating a loader in the underground preparing area for surveyors to enter the workplace, Loader fell 24m into a stope void (no safety bund across the access to	Fatal. Multiple injuries	Serious or appears to be serious injury (including fatality). (s.76 (2a))	The key findings after the analysis of incident were: 1- There was no physical barrier in place near the edge of the stope void

Incident Date Mobile Equipment name	Database. Hazard Type	Incidents Detail	Injury or Incident Outcome	Relevant WA Mines Safety & Inspection Act 1994 section	Key Findings
		removed at the stope edge and no painted bogging marks).			edge to alert operator to the hazard 2-The loader operator did not detect the location of the stope void.
7/7/2011 **Mobile pick-and-carry crane**	**Vehicle Rollover Struck by moving equipment Crane (a combination of design and engineering factors caused instability)** Sub-category "Crane Incidents"	The belt splicer was working in the conveyor belt storage area assisting with the lifting of materials. The belt splicer was struck by the boom of the mobile pick-and-carry crane (crane toppled and boom trapped the belt splicer, who was not part of the work crew involved with the crane operations).	Fatal. C crush injury	Serious or appears to be serious injury (including fatality). (s.76 (2a))	Establish exclusion zone for crane activity
8/16/2011 **Loader**	**8/16/2011 Under suspended load.**	Fitter was replacing the main cylinder for loader bucket using an overhead travelling crane to lift the cylinder. The cylinder for the loader bucket slipped on the rigging chains, crushing the fitter.	Fatal. Crush injury to the head.	Serious or appears to be serious injury (including fatality). (s.76 (2a))	The key findings after the analysis of incident were that the OEM's maintenance procedure was not followed resulting in a fatal incidents. It is recommended to conduct

Incident Date Mobile Equipment name	Database. Hazard Type	Incidents Detail	Injury or Incident Outcome	Relevant WA Mines Safety & Inspection Act 1994 section	Key Findings
	Sub-category Truck /Mobile Equip. NOC (Not otherwise classified)				maintenance work in accordance with the original equipment manufacturer's procedure. 2. Regular training of fitters engaged in high-risk work for rigging was recommended.
5/26/2014 Fork lift, soft sling and mobile pick-and-carry crane	**Machinery Movement-Crush (Fork lift mast movement identified crush zone)** Sub-category "Truck /Mobile Equip. Contact with Person.	Crane operator decided to drive a forklift up the ramp into the gold room to remove a bag with broken straps. The forklift became stuck on the ramp crest at the entrance to the gold room. The crane operator intended to attach a sling from the forklift to the mobile pick-and-carry crane hook and stood on the forklift dashboard plate to reach the hook. The crane operator slipped on to the tilt-cylinder lever that activated the forklift post. The crane operator was crushed between the mast and the cab frame.	Fatal. Crush injury	Serious or appears to be serious injury (including fatality). (s.76 (2a)) Incidents affecting registered plant. (r.6.36)	The key findings after the analysis of the incident were: 1-The worker positioned himself between the mast and the frame of the forklift, in a marked crush point. It is recommended to use correct lifting points on the forklift, use a two-legged chain slings instead of a soft sling and not to stand in the crush zone at the forklift mast.

Incident Date Mobile Equipment name	Database. Hazard Type	Incidents Detail	Injury or Incident Outcome	Relevant WA Mines Safety & Inspection Act 1994 section	Key Findings
9/6/2015 **Hauling waste rock. Dump truck**	**Vehicle rollover- falls.** Sub-category Truck /Mobile Equip. Collision	Haul truck driver drove into the hard-rock windrow beside the road causing the truck to tip onto its right side. The haul truck driver fell through the window frame to the ground. He was not wearing a seatbelt.	Multiple injuries and cardiac arrest. Fatal.	Serious or appears to be serious injury (including fatality). (s.76 (2a)), 13. Loss of control, failure of braking or steering of heavy earth moving equipment. (s.78 (3j))	Key findings after analysis of the incident were: 1-There is a requirement for strict rules to wear a seat belt as per with Mines Safety and Inspection Regulations 1995 specifications. 1. Requirement of close follow-up on reported hazards. 2. Improper wearing of seat belt. 3. Lack of maintaining fatigue management protocols
1/20/2015 **Bulldozer**	**1/20/2015 Maintenance Procedure deficiency.** Sub-category. Truck /Mobile Equip. NOC (Not otherwise classified).	Motor mechanic was removing front belly plate on a bulldozer for cleaning. Front belly plate of a bulldozer weighing 220 kg (additional 266.8 kg soil weight).Come-along was attached to left-hand side track. The motor mechanic removed one bolt from the right-hand side and three bolts from the left-hand side of the	Fatal – crush injury	Serious or appears to be serious injury (including fatality). (s.76 (2a))	Key findings after incident analysis were: 1-A stored energy hazard was left uncontrolled as no support was installed between the ground and the belly plate. 2-The worker was beneath the belly plate when it fell. It is recommended to provide safe work procedure for the

Incident Date Mobile Equipment name	Database. Hazard Type	Incidents Detail	Injury or Incident Outcome	Relevant WA Mines Safety & Inspection Act 1994 section	Key Findings
		belly plate. The left-hand side of belly plate fell, landing on the motor mechanic's chest. A hinge was broken through at the rear bolt hole but was not visible as it was covered with mud.			removal of the belly plate. 3. Lack of pre-starting checks. It was recommended to clean and inspect machine components before starting work.
5/15/2015 **Elevated work platform (EWP) movement under-ground**	**Machinery movement crush** (underground)(Elevated work platform (EWP)) Subcategory Truck /Mobile Equip. NOC (Not otherwise classified)	Mobile processing unit (MPU) operator was attempting to reach the final ring of drilled holes from inside the EWP's charge-up basket. MPU operator was crushed between the backs and the basket when he leaned on the controls. The EWP's basket was accidentally activated, moving upwards.	Fatal. Crush injury	Serious or appears to be serious injury (including fatality). (s.76 (2a))	Key findings after the analysis of the incident were: 1. The worker was leaning over the front of the charge-up basket, in a restricted working space, when the basket moved upwards. 2. Work from a charge-up basket is often undertaken at the front of the basket, so the worker can reach the charge- up hose. 3. The control panel is located at the front of the basket.

Incident Date Mobile Equipment name	Database. Hazard Type	Incidents Detail	Injury or Incident Outcome	Relevant WA Mines Safety & Inspection Act 1994 section	Key Findings
14/1/2015 **Load Haul Dump Truck**	**Underground Rock fall (Single-boom jumbo drill bolt rock fall)** Sub-category of Truck/Mobile Equipment NOC (not otherwise classified)	Load-haul dump (LHD) operator had just placed a rock bolt into the centraliser of a single-boom jumbo drill in preparation to install the bolt into the backs (ceiling) of the drive. The truck driver was preparing to lift the other end of the rock bolt into the jumbo slide. A piece of loose rock came off the face and hit the part of the rock bolt protruding from the front of the jumbo's centralizer, causing the bolt to cantilever upwards and strike the truck driver in the face. The truck driver lost consciousness and fell to the ground, hitting the back of her head on the pile of rock on the floor.	Multiple facial fractures: nasal bone, jaw, orbital floor, scalp laceration.	Potentially serious occurrence. (s.79)	Key incident analysis findings were: 5. Compliance with safe work practice (SWP) on mechanical scaling face is not to be scaled until the backs and walls have been secured" 6. Compliance with SWP on installing ground support with jumbo. The boom is to be maneuvered to a position under bolted ground as close as possible to the front of the jumbo with the slide angled towards the rear of the jumbo for the off sider or operator to load the bolt. For the rock bolts used in the incident, the

Incident Date Mobile Equipment name	Database. Hazard Type	Incidents Detail	Injury or Incident Outcome	Relevant WA Mines Safety & Inspection Act 1994 section	Key Findings
10/21/2013 **Dump Truck**	**Vehicle Collision.** Sub-category "Truck /Mobile Equip. Collision"	The driver's truck collided with the rear of another dump truck that was parked in the queue waiting to be loaded. Nose to tail contact made with the rear, right-hand side of the parked truck. Tray of the parked truck intruded into the cabin, pinning and crushing the driver's legs and lower body against the rear of the cabin.	Crush injuries & compound fracture to left leg requiring surgical amputation below the knee. Severely injured right leg (e.g., degloving injury and fractures). Significant pelvic injuries, kidney damage & continuing infection in lower limbs.	Potentially serious occurrence. (s.79	Key incident analysis findings were: 1. There was no system of work in load-and-haul operation to control over- trucking. 2. Signs should have been posted for prevention of truck parking on bends, particularly sharp bends. 3. Investigation needs to be done to identify driver view obscuration hazards [e.g., rollover protection system (ROPS) pillar, side mirror of truck] and

Incident Date Mobile Equipment name	Database. Hazard Type	Incidents Detail	Injury or Incident Outcome	Relevant WA Mines Safety & Inspection Act 1994 section	Key Findings
2/19/2013 **Mobile Crane**	**Crane Rollover.** Sub-category "Crane Incidents"	Crane and its load became unstable and resulted in the crane tipping over (90°) onto its right-hand side. While conducting a lift of a Cedar Rapids screen with a 25-ton Franna, the load shifted causing the crane to roll over onto its side. The operator suffered from emotional shock, and nil injury. The crane was immediately isolated by personnel arriving at the scene.	Minor bruising.	Potentially serious occurrence. (s.79), 15. Incidents affecting registered plant. (r.6.36)	Key incident analysis findings were: 1. Safe work method statement (SWMS) needed to be implemented for lift plans 2. Maximum deration factor should be used when loads are to be pick and carried. 3. Prior to work verify the competency of

Table 22

Notifiable Mobile Plant Incidents Analysis from 2017 to 2020.

Reference	Incident Date/ Hazard Type	Incidents Detail	Injury or Incident Outcome	Key Findings	Recommendation
Significant Incident Report No 280, Mines Safety Significant Incident reports. Department of Mines, Industry Regulation and Safety (2020b).	**5/3/2020** Bulldozer operator crushed between ladder and handrail. Mobile plant fitted with a hydraulic access ladder or staircase.	Bulldozer operator sustained serious injuries to the leg after being crushed between a hydraulic access staircase and handrail that were attached to the bulldozer. The bulldozer operator had just completed a pre-work inspection of the job site with the leading hand and was accessing the bulldozer via the stairs when the stairs began to raised unexpectedly. The operator attempted to get clear of the moving stairs by jumping to the platform alongside the operator's cabin but was trapped between the handrail and moving staircase.	Crush injuries to leg.	Key incident analysis findings were: 1. The modifications on the wiring of the bulldozer might trigger the hydraulic access ladder as those were not complaint with the requirement of installation. 2. Poor wiring termination on a modification done to the bulldozer allowed the switching wire for the	1. Ensure that all modifications to plant are assessed, undertaken and tested by competent persons prior to being put into operation. 2. Undertake an inspection and audit of plant with an actuated ladder or staircase to ensure that non-compliant or poorly installed wiring cannot

Reference	Incident Date/ Hazard Type	Incidents Detail	Injury or Incident Outcome	Key Findings	Recommendation
Significant Incident Report No 277, Mines Safety Significant Incident reports. Department of Mines, Industry Regulation and Safety (2019a).	**20/6/2019 Vehicle over edge-** Haul truck over open pit wall edge	Truck was exiting the pit when it failed to negotiate a narrowing section of roadway on the ramp. The right wheels rode up over the crest edge windrow leading to the truck straddling the windrow before it teetered and fell over the edge. The truck did not change the angle of approach to avoid the 'step in'. Incident occurred between dawn and sunrise when the light is changing, affecting visibility. The driver died after his 110-ton haul truck fell 15 meters down the pit wall of the quarry	The driver died after his 110 tons haul truck fell 15 meters down the pit wall of the quarry	Key incident analysis findings were: 1. Size and shape of the windrow, as well as adjacent material build up, assisted the truck's wheels to ride up over the windrow. 2. There was no demarcation or signage in the near area. 3. Truck did not change the	1. Analysis of haul route should be done to identify if there are any areas or features, like narrow sections and curves, that may pose a higher risk and adjust windrows. 2. Design and construct adequate windrows to control operational hazards considering dimensions (shape, batter angle, height), location & construction material. 3. Larger barriers to be placed in high-risk areas to prevent vehicles from going over the edge. Windrow should delineate where the truck should be on the haul road and be an adequate distance from the edge. 4. Design of windrows and traffic management of vehicles operating around windrows should take into account the angle at which equipment operates and any vehicle blind spots in relation to the windrow. 5. Regularly inspect and maintain windrows.

Reference	Incident Date/ Hazard Type	Incidents Detail	Injury or Incident Outcome	Key Findings	Recommendation
20/4/2018 **Significant Incident Report No. 271. Mines Safety Significant Incident reports. Department of Mines Industry Regulation and Safety (2018d)**	**Machine movement** Near miss when latch fails and gate swings open on a haul truck	A worker was exposed to potentially serious injuries when a handrail latch failed, causing a handrail gate to swing open. The truck was in the queue to receive a load when a trainee operator and the trainer stepped out of the cab to hold a discussion. The trainee was leaning over the handrail outside the cab near the emergency ladder when the latch failed. The trainee lost his balance and grabbed the handrail. The trainer reacted immediately and grabbed the trainee's arm to prevent him from falling.	No fatal injury	The site's routine maintenance program and prestart inspection regime for the plant didn't prompt workers to inspect the latch.	Implement a safe system of work to periodically check the condition of handrails and any securing mechanisms to ensure they are serviceable. This may include inspections during maintenance and pre-starts. Develop a safe system of work to review and action any relevant literature and guidance issued by sources including OEMs, regulators and other relevant/professional bodies. Engage a competent person(s) to check if edge protection installed on mobile plant is fit for purpose prior to its introduction to a mine site and periodically during its life cycle

Reference	Incident Date/ Hazard Type	Incidents Detail	Injury or Incident Outcome	Key Findings	Recommendation
7/9/2018 **Significant Incident Report No. 271. Mines Safety Significant Incident reports. Department of Mines, Industry Regulation & Safety (2019a)**	**Vehicle runaway - excessive speed** Haul truck operator loses control descending ramp on haul road. Fatal accident	The haul truck travelled at excessive speed, measured at 79km/h, when descending the ramp and collided with a windrow causing the vehicle to take flight and roll over. The haul truck operator was ejected from the truck during the incident and was found deceased at the scene.	Fatal - multiple injuries including a fractured skull and spinal injuries	The truck exceeded the speed at which the electric braking system could stop it. The service or mechanical brake was not engaged for an emergency stop. The truck was fully loaded descending a long slope. Immediately preceding the crest of this long slope there was another crest followed by a short downhill and then an uphill section in the form of a saddleback.	1. Ensure compliance with the mine standard for the safe operating ramp speed for a loaded haul truck. 2. Use the retard speed control device to descend long ramps. 3. Activate service brakes as soon as trucks exceeds the mine standard.

From the analysis of data from 2006 till 2017, that is compared with an additional three years three months (1-1-2017 to 31-3 2020) significant reportable incidents related to mobile plant, the primary and contributory causes of mobile plant incidents evaluated was still the same with the reoccurrence of incidents related to vehicle-vehicle collision the most common. This provided conformation that data saturation was achieved by analyzing the 10 years of significant incidents. There were incidents related to fire on mobile plants and machine movement crush also reported in the last three years that were mainly due to procedural non-compliance.

1. ***Results of Comprehensive Analysis of fatalities from 2007 to 2020***

The above comprehensive analysis of fatalities from 2007 to 2020 was aimed at investigating the causes of mobile plant incidents in Western Australian to achieve objective one of the research. It is evident from the above statistics of the Department of Mines, Industry Regulation and Safety data that cause of around 85% of the mobile plant incidents involved human error. Nevertheless, the majority of accidents cannot be solely attributed to adverse working conditions. For instance, a study by the United States Bureau of Mines found that nearly 85% of all mining accidents identified human error as a causal factor (Rushworth et al., 1999). After analyzing the incidents, it can be clearly stated that in order to improve safety and reduce the mobile plant incidents, there is a need to be more focus on the ways to reduce human error as a cause of mining accidents.

4.3.1.1 Primary Causes of Mobile Plant Incidents in the WA Mining Industry

The study assessed the fatal incident from 2006 to 2020 and found the following primary causes of mobile plant incidents in Western Australian Mining industry.

1. Vehicle Collision, Vehicle Over-edge, Vehicle Rollover & Vehicle Runaway.
2. Maintenance Procedure deficiency.
3. Machinery movement – crush.
4. Underground (UG) Rock fall.

5. Tyre.

Accidents and occupational diseases produce direct and indirect costs. Indirect costs are more difficult to quantify and they account for a higher proportion than direct costs (Hamalainen et al., 2004).

4.3.1.1.1 Vehicle Collision, Vehicle over-edge, Vehicle Rollover & Vehicle Runaway

A total of 2217 incidents, out of total 4613, recorded in the Resources Safety database were related to vehicle collisions, vehicle over-edge, vehicle rollover or vehicle runaway. There were around 678 incidents related to light vehicle collision, 972 in the category of truck/mobile equipment collision, 80 in the sub-category of truck/mobile equipment contact with person, 1867 in truck/mobile equipment NOC (not otherwise classified), 192 were in truck-mobile equipment over-edge and 295 in truck-mobile equipment roll over contributing 36% of overall incidents related to mobile plants in the Western Australian mining industry. While analysing the incidents the primary vehicle activity that accounts for the largest number of collisions was reversing. This included vehicle-on-vehicle collisions and vehicle-on-other collision. Approximately a third of the vehicle-on-vehicle collisions that occurred while reversing were with a parked-up or stationary secondary vehicle.

Primary mobile equipment involved in reportable incidents were surface loaders and dozers. The main areas of mine involved were stockpiles and waste dumps. It was also observed that visibility and communication issues account for two thirds of vehicle collisions in the Western Australian mining industry. Included were incidents due to communication breakdown, rear view unchecked and visibility obscured. Kecojevic and Radomsky, (2007) recommended the following.

(1) That in the case of restricted visibility due to inclement weather, equipment operators should turn on all exterior lights and keep the cab windows free of condensation or other obstructions that affect visibility.

(2) Signs or signals that warn of pedestrians should be installed where persons routinely cross plant roadways on foot.

(3) Operating speeds should be consistent with conditions of the roadway, visibility and possible pedestrian traffic.

(4) Equipment operators should keep buckets, forks or booms close to the ground when travelling.

(5) In the case of restricted visibility due to inclement weather, equipment operators should turn on all exterior lights and keep the cab windows free of condensation or other obstructions that affect visibility.

(6) Signs or signals that warn of pedestrians should be installed where persons routinely cross plant roadways on foot.

(7) Operating speeds should be consistent with conditions of the roadway, visibility and possible pedestrian traffic.

(8) Equipment operators should keep buckets, forks or booms close to the ground when travelling (Kecojevic et.al, 2007).

Many of the mobile plant accidents occurred when the vehicles were travelling with a load, negotiating a bend or turn or while travelling on a ramp. Light vehicles and surface haul trucks were the primary vehicles involved in these incidents. Kecojevic and Radomsky (2004) stated that at surface mining operations throughout the world, loaders and trucks are a primary means of material loading and haulage. As the size, use and technological complexity of these units have increased, so has the concern regarding loader and truck safety and the severity and number of accidents involving loaders and trucks is higher when compared to all other mining accident types. (Kecojevic et.al, 2007).

Areas of mines where most of the vehicle collisions occurred were roads, declines, waste dumps, intersections, pit floors and benches, stockpiles, yards and sheds, ROM pads and ramps. Vehicle to vehicle collisions also occurred in sheds, and combined waste dumps. The main activity in these areas was dipping dirt from haul trucks. Wheels dozers, loaders and light vehicle were the secondary vehicles involved in vehicle collision in the areas mentioned above. It was also identified that combined intersections, ramps, roads and go-lines were the areas where the vehicle-to-vehicle incident ratio was the second highest cause of mobile plant incidents. In these areas most collisions were with a secondary vehicle which was parked or stationary.

Head-on collision at an intersection was also a cause of mobile plant incidents. Declines in the pit-floor or activities as well were areas where vehicle collision incidents occurred. The most predominate reported incidents in these areas were associated with haul trucks being loaded by shovels or diggers. According to the report related to Vehicle collision issued by Department of Mines and Petroleum in 2016a, surface haul truck was the most common vehicle involved in collisions from January 2015 to December 2016, with 51 incidents as the primary vehicle and 31 as the secondary vehicle. Underground haul trucks account for 21 collisions, with 16 incidents as the primary vehicle and five as the secondary vehicle (Department of Mines and Petroleum, 2016a). During analysis it was observed that a significant number of mobile plant incidents were related to vehicle run-away and these types of incidents took place mainly at ramps and declines. Mainly haul-trucks were involved in these types of incidents. Leaving the vehicle with the engine running, non-compliance of seat belts and run-away precautions like brake and chock, absence of bunds to prevent vehicle runaway and non-compliance of safe ramp operating speed and wrong assessment of the appropriate gear for declines were the major contributory factors leading to incidents related to vehicle-runaway.

In terms of percentage, around 80% of incidents occurred in surface mining and 20% took place underground. On the surface, while most collisions occurred on roads (includes vehicle-on-vehicle and vehicle-on-other collisions), pit floors and benches were common areas in mines for vehicle-on-vehicle collisions which were observed during data analysis of reported incidents. A number of incidents were related to haul-trucks. One of the reasons for fatal accidents was caught in between the headboards of two haul trucks and the primary finding were the non-compliance of normal vehicle spotting procedure from a position on the ground, lack of radio and hand communication and standing in the crush zone.

Analysing the primary and contributory cause of the fatal haul truck open pit fall incident in significant incident report 277 (DMIRS, 2020), it was identified that there was no demarcation or signage in the near area, the truck did not change the angle of approach to avoid the 'step in' by the truck and that there was poor visibility as the incident occurred between dawn and sunrise when the light was changing.

It was observed that many vehicle collision incidents were due to loss of control and resulted in a collision. Careful selection of low gear and operating at low speed on downhill run with a full load can minimize these types of incidents. In a few incidents there were collisions of trucks with protruding loads that were a hazard if documented procedures were not followed. These collisions can be reduced by parking vehicles in designated areas with exclusion zones and use of warning lights and signal lights for protruding loads. In order to minimize these types of incidents mine managers should review their site procedures for 'spotting' haul trucks and other large vehicles. In general terms, a safe location should be selected for the spotter. This would commonly be a position on the ground, in direct line-of-sight of the driver where the spotter could not be trapped or run over.

There were a significant number of incidents related to truck and light vehicle collisions in the past thirteen years. Spacing of vehicles is recommended to address blind spots around haul trucks. The main causation factors for vehicle-on-vehicle collisions observed were associated with a parked-up or stationary secondary vehicle, due to communication breakdowns, failures to stop, give way or slow down and due to obscured visibility. According to the incident report issued by Department of Mines and Petroleum in 2016b, in order to avoid vehicle collision clear and consistent hand signals or radio contact should be established. Mine managers should review their procedures for parking vehicles in the vicinity of haul trucks and other large earthmoving vehicles. Clear access should be maintained for maintenance and service equipment. The limited visibility from the driver's cabin should be considered and the risk of driving over an employee or other vehicles addressed. Further mine managers should also review their practices for jump-starting large earthmoving vehicles and consider the use of dedicated service vehicles equipped with battery packs, or the use of mobile battery carts (Department of Mines and Petroleum, 2016b).

Close interactions occurred frequently in the loading area and on intersections. While heavily focused on the task, clean-up machines operators can lose track of their proximity to other machines. For example, while watching the blade, a grader operator reversed out in front of a haul truck. In incidents analysed, trucks drove into Active Mining Areas (AMAs) when they were not permitted. Light vehicles (LV) had closed the area to conduct workplace inspections, operator change outs, or equipment breakdowns. Mobile plant drivers entered the area if the driver did not hear the radio call or identify a light vehicle in the area. Manual trucks frequently made contact with haul road delineation. Truck drivers either misjudged the corner or did not identify the divider. The intent of dividers is to prevent haul class equipment from cutting corners and contacting smaller equipment.

In the Western Australian mining industry significant incidents examined the procedural violations of the company manual were mainly traffic management failures. In 2016 the Department of Mines and Petroleum conducted an investigation into whether procedures were followed when a fatality occurred. Over the period 2000–2012, the study found that 62% of all fatalities in the Western Australia mining industry involved operator non-compliance with procedure. In 27% of cases, no procedures were in place and only in 11% of cases did fatalities occur when operators followed procedures. (Department of Mines and Petroleum, 2016b).

It was also observed during incident data analysis that positive communication interruptions occurred when drivers had not obtained authorization prior to the changeover. In addition, correct radio protocols were not used before overtaking. Priority rules were in place to give priority to the most important equipment. For example, water carts had to give way to transport trucks. The most common violations observed were trucks on trucks. The drivers were unsure of who had priority, hadn't observed the oncoming traffic or had forgotten to give way. Working graders had second priority to transport trucks. Another example was the U-turns of trucks on transport roads. U-turns were performed without assistance when the driver was lost or assigned to a new load source. Drivers were unsure of the process of blocking the road to prevent smaller equipment from moving on the truck path. Another study on equipment-related fatal accidents in U.S. mining operations established that less experienced workers appear to be more vulnerable to equipment-related mishaps and should therefore be at the center of intervention strategies for safe work with mobile plant equipment (Kecojevic et al., 2007)

A number of incidents, including fatalities, were related to vehicle over-edge and mainly the vehicles involved were haul truck, bulldozer, load-haul-dump (LHD) truck and surface/underground loaders. It was identified that absence of a bund or physical barrier, or appropriate hard barriers, allowed personnel inadvertent access to the void. Inconsistent (i.e., reliance on a second sign being in place that was not) signage procedure, insufficient detail in the procedure for working around an open hole and absence of appropriate warning devices to alert driver of approach to stop edge were the primary causes of these types of incidents in Western Australian mining industry.

There were many incidents related to vehicle rollover identified by the researcher during analysis of the notifiable incident database. Included was a fatal crane incident in which the belt splicer was struck by the boom of the mobile pick-and-carry crane. The crane toppled and boom trapped the belt splicer, who was not part of the work crew involved with the crane operations and this resulted in a fatal crush injury. Analysis as per Mines Safety and Inspection Regulations, 1995 revealed that irregularity in fatigue management protocols (e.g., rest breaks, sleep, diet, fitness patterns) was also one of the causes of these types of incidents.

1.3.1.1.2 Maintenance Procedure Deficiency

The mobile plant incidents analysis identified that a significant number of incidents occurred due to a maintenance procedure deficiency. This revealed that the Original Equipment Manual (OME), maintenance procedure was not always followed by workers.

It was found that one of the fatal accidents occurred when a maintenance worker was fatally injured by the uncontrolled release of stored energy when working in the field on a belly plate (also known as a bottom guard or under guard) fitted to a bulldozer. No energy isolation mechanism was installed between the belly plate and the ground during the work (Significant Incident Report 213, Department of Mines, Industry Regulation & Safety, 2017b). Accidents due to non-compliance of work procedure while working under suspended loads by the maintenance workers (heavy duty and light vehicles) was also observed while analyzing Resources Safety incident database and noted to be one of the major causes of mobile plant reported incidents.

A number of factors tabled in a study by Dhillon and Liu (2006) of around fifty participants related to human errors in equipment maintenance identified lack of skills, insufficient training, badly written operating manuals and maintenance procedures, poorly designed equipment, usage of unsuitable tools, insufficient work layout, limited lighting in the workspace and noise levels. On the other hand, various causal factors derived from Dhillon and Liu (2006) include the complexity of maintenance tasks, inadequately written maintenance procedures and obsolete maintenance manuals, the fatigue of the maintenance personnel, insufficient training and experience, under-designed work layout, inadequacy of equipment design, unsuitable tools for specified work, substandard work environment as the main factors causing incidents related to maintenance procedure deficiencies.

4.3.1.1.3 Machinery Movement Crush

Miners at the workplace have had substantial injuries including fatalities due to machinery movement crush as identified during the analysis of the data. Main vehicles involved in these types of injuries included forklifts, mobile processing units (MPU), elevated work platforms EWP) and cranes attached to a mobile vehicle. From the database, it was found that one of the fatalities occurred when a Mobile Processing Unit operator was crushed between the backs and the basket when he leaned on the controls. The Elevated Work Platform's basket was accidentally activated, moving upwards. There was also a crane incident in which the crane operator slipped on to the tilt-cylinder lever that activated the forklift post. The crane operator was crushed between the mast and the cab frame. In 2014 the Western Australia Department of Mining and Petroleum conducted an investigation into whether procedures were followed when a fatality occurred. In 27% of cases, no procedures were in place and only in 11% of cases did fatalities occur when operators followed procedures (Department of Mines and Petroleum , 2014).

Analysis has revealed that most of these types of incidents occurred due to the design of the machinery, non-compliance of machine maintenance procedure, not conducting full job hazard analysis (JHA) prior to commencing any *live work* on machinery by the workers and lack of updated information and/or defects from pre-starts in company maintenance system. In a study conducted by Virovac et al. (2017) about the casual factors resulting in incidents and fatalities identified communication, equipment design and fabrication, working environment, work complexity, knowledge, work organization, documentation (manuals and procedures), work planning, pressure, fatigue, insufficient personnel for work, personal problems, and distraction while doing work as major error causal factors resulting in accidents and fatalities.

4.3.1.1.4 Underground Rock-fall

Research findings identified that miners working in underground mines had many accidents. One of the major hazards which some encountered while performing work was a seismic event (rock-fall) either due to unsupported ground conditions (most of the cases) or due to a slab broken away from a hanging wall. These events mainly involved drill jumbo trucks and load haul trucks. These hazards contributed to underground mining accidents. For instance, one of the fatal incidents occurred when a load haul dump truck operator was struck and pinned by a large rock that exited the stope and rolled down the hill into the draw point. In another incident overhanging rock fell while air-leg miner was ahead of the ground support. According to Asteriou et al. (2012) rock fall events are a common hazard in open-pit mines, quarries, and slopes. The rock fall phenomenon usually constitutes two distinct stages, i.e., the initial–failure stage, which is described as the circumstances under which several blocks are detached from the parent rock, and the post failure stage, which is described as the motion of the detached rock blocks along the slope (Asteriou et. al, 2012).

During analysis of the database, there was one fatal incident reported in 2015 related to a rock fall in which a load-haul dump operator had just placed a rock bolt into the centralizer of a single-boom jumbo drill in preparation to install the bolt into the backs (ceiling) of the drive. The truck driver was preparing to lift the other end of the rock bolt into the jumbo slide when a piece of loose rock came off the face and hit the part of the rock bolt protruding from the front of the jumbo's centralizer, causing the bolt to cantilever upwards and strike the truck driver in the face. The truck driver lost consciousness and fell to the ground, hitting the back of her head on the pile of rock on the floor.

4.3.1.1.5 Tyres

In order to obtain a long life vehicle tyre and to promote road traffic safety, research has been conducted by several researchers and by some of the biggest tyre manufacturers, e.g., Michelin, Continental, Pirelli and Dunlop (David et al., 2011) to produce a means to sustain road traffic safety by improving vehicle control system and tyre-road interaction, e.g., tyre contact patch area and pressure distribution within it; that is an intelligent tyre (David et al., 2011). Introducing this intelligent tyre system in mobile plant vehicles may reduce the incidents related to mobile plant in mining industry. However, significant accidents in the Western Australian mining industry that occurred due to tyres were either due to inflation (under pressure) or tyre unloading. There were quite a few incidents identified due to tyres including fatal incidents that took place mainly during tyre unloading. For example, in one fatal incident the tyres landed on top of the truck driver who was unloading haul-truck tyres from a delivery truck (loaded in four groups of three, in a vertical and upright position).

4.3.1.2 Analysing Human Factors leading to mobile plant incidents

The evaluation of the Resources Safety notifiable incidents database has provided in-depth knowledge about the primary hazards associated with mobile plants and the significant contributory factors which resulted in mobile plant incidents. It was identified that the greatest threat that led to fatal and potentially dangerous incidents was human error, rather than technical or equipment malfunction. Therefore, when discussing the causes of mobile plant incidents, it is important to emphasize the fundamental causes of human errors.

Analysis of human factors is important. According to the Health and Safety Authority (2019) human factors refers to organisational, job, environmental, individual and human characteristics that influence behaviour at work in such a way as to affect health and safety. For the majority of industrial accidents there has been a causative chain of human errors and organisational conditions, with Reason (1990) suggesting that human factor causes can be responsible for 70–80% of accidents in hazardous industries. As detailed by Burrage, (1995, p. 235), "many of the failures that arise within systems and lead ultimately to disaster have their origins in decisions or actions taken by individual managers at some level within the system."

The high risk associated with mobile plant workers of the mining companies means that the consequences of a minor error can lead to catastrophic or life-threatening events. Non-compliance with maintenance procedure, fatigue and inadequately designed and integrated mine environment monitoring systems, flaws in prior risk assessment and information flow/record keeping, ineffective incident management and decision-making deficiencies during emergencies were the few casual factors identified that led to mobile plant incidents due to human error. Human factors research reveals that poor decisions made during an emergency situation have been a significant contributory factor in the occurrence and severity of major disasters (Flin et al., 2008).

The evidence suggests that humans are especially vulnerable to impaired decision making when tired, emotional and stressed (Canon-Bowers and Salas, 1998; Douglas and Flin, 1999; Kowalski-Trakofler et al., 2003; Paton, 2003; Schwarz, 2000). A mining emergency response can involve long work hours and reluctance to rest (Simpson et al., 2009). Unaccounted for miners (potentially killed or injured) are colleagues, friends and possibly even family of those executing the response to an incident (Royal Commission on the Pike River Coal Mine Tragedy, 2012).

The situation often involves incomplete information. The situation can be dynamic and the decisions that need to be made have the potential for catastrophic consequences, not only in terms of injury and loss of life but also legal ramifications for the individual with statutory responsibility for the mine (i.e., the mine manager). Some mines are trialing technological solutions (radio frequency identification tags), however, experience in their use indicates that there are significant operational issues to be resolved before they can be relied upon to identify where people are in an emergency (Pang & Zhang, 2011). Extensive research has been conducted in this field, and it has been found that human factors can be mitigated, although they can never be eliminated, and human risk management cannot be 100% effective (Health and Safety Authority, 2019).

To summarize, table 23 provides an understanding of the hierarchy of factors that influence major hazard risks and during data analysis the researcher observed the presence of these factors which led to mobile plant related injuries and fatalities.

Table 23

Human Factors that Influence Major Hazard Risks

Work practice	The complexity of the given task, how easy it is to make mistakes, best practice, normal practice, checklists and procedures, silent deviation and control activities.
Competence	Training, education, both general and specific courses, system knowledge.
Communication	Communication between stakeholders in the (PDCA) cycle of process of P lan, Do, Check and Act
Management	Labor management, supervision, dedication to safety, clear and precise delegation of responsibilities and roles, change management.
Documentation	Data-based support systems, accessibility and quality of technical information, work permits system, safety job analysis, procedures (quality and accessibility).
Work schedule	Time pressure, workload, stress, working environment, exhaustion (shift work), tools and spare parts, complexity of processes, human–machine interface, ergonomics.

Note. Adapted from "Quantitative Risk Analysis of Oil and Gas Drilling Using Deepwater Horizon as Case Study" by J. Skogadalen & J. Vinnem, 2012, *Journal of Reliability Engineering and System Safety, 100*(58-66), p.61 (https://www.sciencedirect.com/science/article/abs/pii/S0951832011002651).

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4.4. Chapter Summary

This chapter reports on a detailed analysis of notifiable incidents related to mobile plant in the Western Australian mining industry from 1/1/2006 to 31/3/2020 providing in-depth knowledge and understanding of the types of hazards involved in surface and underground mining. Significant incidents of 2018 to 2020 were also evaluated in order to obtain updated information regarding the causes leading to mobile plant injuries and fatalities.

Observations made while analyzing incidents related to mobile plant operators in Western Australian mining industry identified that mobile plant operators entering into the areas where ground is not supported by mesh and bolts, absence of physical indicators at ground level to mark the boundary between supported and unsupported ground, no written ground support management plan for all geotechnical domains and no proper system of geotechnical mapping and monitoring to ensure systematic process for mine plan and rock support design were the main causes of vehicle incidents in Western Australian mining industry.

It was identified that reporting managers and supervisors can play a vital role to minimize the recurrence of these types of incidents. For instance providing the workers detailed safe work instructions (SWIs) or safe work procedures (SWPs) that identify the hazards and controls for each job step, and the potential for hazards to be masked, ensuring practicable measures are available to reduce the exposure of workers to hazards (e.g. capacity to relocate maintenance tasks from the field to the workshop), ensuring workers are trained to recognize sources of stored energy, understand and have access to suitable energy control measures, report damaged equipment promptly so it may be assessed and repaired as necessary and returned to service in a safe condition are all important.

The other factors which would help significantly in reducing mobile plant incidents were recognised as having regular refresher training courses for the workers dealing with machinery, conduct risk assessments for design changes, specifically the addition of pull wire switches, strict guidance to workers to not to stand in the crush zone and provide clear labeling on working equipment.

One of the main risk control measures identified, after analyzing data, was the role of the Site Manager, either in the operations area or the maintenance area. Strict vigilance of Site Managers is required to ensure that where equipment and operators, and in particular manned loaders, are expected to work nearby open holes, proper completion of formal team-based risk assessments by the operators is conducted to determine adequate controls for the dangers associated with tasks to be performed. There is also a requirement for a critical examination of the workplace whenever the activity is planned near an open hole and conducting an evaluation of whether a manned loader is suitable for the purpose of the planned task, if alternative equipment or techniques are required, including the application of remote-controlled technology, to keep the operator away from the open hole, this should be considered by the Site Manager to significantly reduce the recurrence of mobile plant incidents in mining industry.

The next chapter is based on the researcher's observations and learnings in relation to mobile plant during visits to four mining companies' work sites in Western Australia.

5. OBSERVATION RESULTS AND DISCUSSION

5.1 Introduction

This chapter focuses on the researcher's analysis of what was observed in relation to mobile plant during visits to four mining companies' work sites in Western Australia. It includes observations on the types of mobile plant used for surface and for underground mining, hazards involved while driving heavy machinery, mobile plant safety practices and work procedures, to answer research objective two. This objective was to *observe mobile plant in use in mining workplaces to identify what strategies are in place to promote mobile plant safety and any safety barriers.* Each of the four mining companies assigned one of their staff to assist the researcher to arrange interviews, visit the operations and maintenance areas where there was mobile plant. Relevant documents and information were also provided to the researcher by the mining companies' employees.

5.2 Analysis and discussion of mobile plant data gathered during sites visits.

For the discussion and analysis, the researcher has given the names A, B, C and D to the respective mining companies visited to collect data in order to de-identify the companies. Company representatives at each site facilitated data collection. At all mining sites there were morning and night shifts so that business could continue for 24 hours. It was a difficult task for the respective companies' representative to co-ordinate with the operations and maintenance team supervisors to enable the researcher to conduct workshops and mobile plant operation areas visits. Safety standards and protocols followed at each mining site were of a high standard.

The analysis related to data collected at mining sites was divided into the following discussion points:

1. Types of mobile plant being used at mining sites
2. Hazard identification and risk assessment activies
3. Safety related to mobile plant

5.2.1 Types of mobile plants being used at mining sites

The visits to the mining sites provided comprehensive information about the criteria of vehicle classifications used in surface open cut and underground mines. Following is the summarization of the different types of machinery used at the visited mining companies' worksites.

1. Light Vehicles – mainly included sedans, utilities, light vans, four-wheel drives, small trucks.
2. Heavy Vehicles - mainly included explosives trucks, cranes, forklifts, fuel trucks, low loaders, buses carrying more than 12 people, service trucks, mobile workshops.
3. Surface Mining Equipment (SME) – mainly included dump trucks, water carts, scrapers, wheel dozers, loaders, carriers, graders, excavators, dozers, drills and rock breakers
4. Underground Mining Equipment (UME) – mainly included jumbo trucks, bogger and boomer. The last is different to surface mining equipment while the rest were similar.
5. Autonomous Haul Truck – Two of the visited mining companies were using vehicle automation.
6. Heavy Haul Units – mainly included dump trucks, water carts and scrapers.
7. Vehicles that Require Escort Procedures – mainly included Low loaders (floats), skidsteer (bobcat), forklifts, tele-handlers and elevated work platforms.
8. Emergency Vehicles that required sirens and emergency lights to be activated on emergency duty; otherwise they are classified as one of the above vehicles. Includes fire engines, ambulances, police vehicles and emergency response vehicles.

5.3 Hazard Identification and Risk Assessment activities at mine sites

Patrick (2016) concluded that workplace inspections identified hazards and if appropriate risk control measures were implemented. This was an important part of workplace safety management and it was observed that each mining company visited by the researcher had been using a systematic approach for the risk management. Each mining company followed a standard approach to risk management that allowed risks to be prioritized and ultimately allowed the companies to have effective application of risk control to maximize the value from operations and drive good business outcomes.

A key element of effective risk assessment is the selection of the appropriate approach and methodology to match the context, nature, scale, decision making and communication of the risks. There was different type of Risk Assessment methods being used for mobile plant at each company work site and methods used varied depending on the context of the assessment. However, the principles and the process of risk management remained the same. At each mine site different types of personal risk management processes were used by mobile plant workers to manage the day-to-day risks they face as individuals and as work groups. The researcher observed during toolbox talk in the morning the safety supervisor emphasized the importance of correctly filling in the pre-start risk assessment sheets by the operators. There were different pre-start risk assessment techniques being used by mining companies. For instance, it was observed that mining company A was using STAR assessment and Job Safety Analysis techniques, mining company B was using TAKE-5 and JSEA (Job Safety and Environmental Analysis) as a pre-start Risk assessment tool. Mining company C did not provide any documentation to the researcher due to privacy restrictions while for mining company D it was found that they also were using Take -5 and Job Hazard Analysis for their Risk assessment.

At each mine site the critical first step in managing risk in the workplace was to have people stop and think before they act. Take 5 and STAR (Situation or Task, Action, and Result) processes were observed as being used for personal risk management at companies. At all of the observed worksites it was mandatory that everyone took a few moments to consider the hazards to which they may be exposed, consider the risk these hazards pose, and identify the things they might do to keep themselves safe. The Take 5 and STAR process risk assessment was aided by a pocket notebook. This notebook provided prompts and some specific questions to assist in the completion of the process that must be completed before every new job or when the job changes in an operational area.

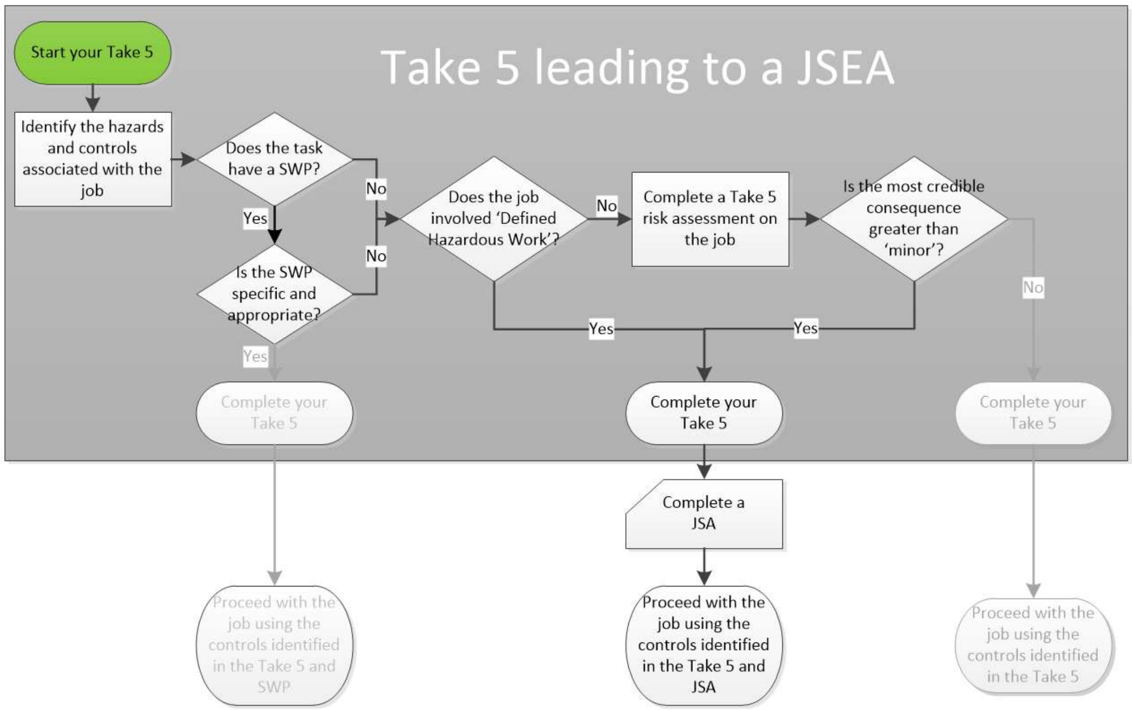
It was observed that this first step of risk assessment enabled the workers to identify the correct safe work procedures (SWP) and to decide whether to proceed with the job using the risk controls identified in the Take-5 or STAR notebook or to do further Job Safety and Environmental analysis. There were certain routine jobs which included normal operation of mobile equipment such as loading and unloading of dump trucks, spraying water using water carts and light vehicle patrolling sites which required only personal risk assessments (Take-5 or STAR) to be completed by the operator as these jobs have predefined safe work procedures. During the site visits, when the toolbox presentations were being conducted, it was observed that if any mobile plant operator was in doubt of the safe work procedure, then he or she immediately asked their supervisor for further information until they understood. Every operator was obliged to read their particular safe work procedure, understand what was required, and be competent to complete the described job steps and establish the hazard risk control measures. It was clearly instructed and written in the procedures for all mining companies visited that if any operator was in doubt of their ability to complete the work safely then he or she should not proceed with the work and must speak to their Job Supervisor.

If after completing the checks Take-5 or STAR notebook the jobs fall into the category of credible consequences work that includes any risk with a risk category of greater than *Very Low Risk* (hazardous jobs resulting in injury), then it was recommended at all mining sites that the supervisor was to be informed and the Job Safety and Environmental analysis completed systematically using either the MS excel Template or the hard copy Job Safety and Environmental analysis Template pad.

Following is the graphical representation of the instructions being used by Mining company B for the task which need further analysis after the pre-starts checks.

Figure 26

Take-5 leading to further Job Safety and Hazard Analysis



Note: From Mining company B document provided during site visit.

When completing a JSEA, the hazards to be considered in Mining company B documentation were: handling and working with tyres. Wheels and rims. Tyre fires, bursts and explosions when tyres are in service. Loss of control of vehicle due to tyre failure. Sudden release of stored pressure energy - leading to projectiles (e.g., rim components, rocks). Percussive shock Compressed air or other gases (e.g., nitrogen). Noise. Handling heavy objects. Working with or operating heavy equipment. Heat and fire. Fuels and chemicals and Pyrolysis or diffusion - leading to explosions.

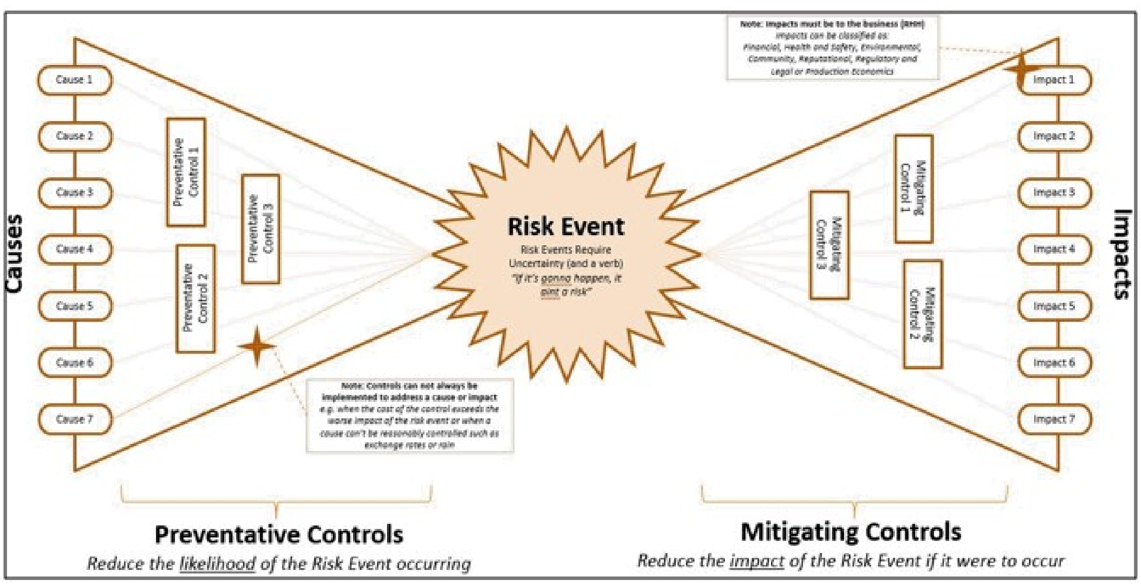
After completing the JSEA and getting it approved from the supervisor, it was instructed that those working on a job must read, understand and sign the JSEA prior to the job commencing. Specifically, they must complete the 'Sign-off Sheet' on the JSEA form.

Further any new personnel attending and working on the job after the commencement of the job must also read, understand and sign the JSEA prior to commencing work. It was stated in the documentation that the JSEA must be kept in close proximity to the area where the work is being completed.

All observed mining companies had established very good safety databases and employees were accountable for risk reporting. Risk Reporting was the communication of risks to those that are both accountable and in the best position to manage the risk. Reporting of risks to the appropriate level of management was defined at each company by the risk materiality, risk register or risk database. Mining company D used the Bowtie methodology to define risk, specifically focusing on causes, controls (preventative and mitigating) and impacts. It was stated by employees that this approach was beneficial when formulating an action plan to manage a risk as it enabled an understanding of the causal pathways and the applicable controls.

Figure 27

Bowtie Methodology



Note: From Mining company D document provided during site visit

It was also identified that mining companies were using risk rating matrix as well which is a combination of the impact and likelihood produces a risk rating score ranging from 0.5 to 300 as per the Risk Matrix (see Table 24). This score is initially used to prioritize the risks and support the decision as to whether further controls are required to be implemented to mitigate the risk.

Table 24

Risk Matrix

Risk Matrix (5 x 5)							
RHIO Risk Evaluation Matrix		MFL	Severity Level				
			Slight	Minor	Moderate	Major	Severe
			1	2	3	4	5
			Residual Risk Rating (RRR)				
		Factors	0.1	0.5	1	5	10
Likelihood Level	Almost certain	30	3	15	30	150	300
	Likely	20	2	10	20	100	200
	Possible	12	1.2	6	12	60	120
	Unlikely	7.5	0.75	3.75	7.5	37.5	75
	Rare	5	0.5	2.5	5	25	50

Note: From Mining company D documents provided during site visit

During documentation review, it was observed that Mining Company D used four key ratings that form the assessment of the risk:

1. **Maximum Foreseeable Loss (MFL)** is the worst plausible impact sustained by Mining Company D due to a risk event. MFL is assessed based on no mitigating controls being in place. All impact types (classes) in the severity table must be assessed.
2. **Residual Severity** is the impact to the business with consideration of mitigating controls being in place, working effectively as intended, to lower the severity of the risk event. All impact types (classes) in the severity table must be assessed.
3. **Likelihood** is the chance that the risk event will occur with the assessed residual severity, given preventative controls are in place and working effectively as intended.

4. **Residual Risk Rating (RRR)** is the risk that remains with consideration of preventive and mitigating controls being in place to lower severity and likelihood of the occurrence. The RRR is calculated (by multiplying the Severity and Likelihood factors) as per the Risk Matrix.

It was observed that in each mining company there was ongoing monitoring and review of the risks captured in the risk management registers that was conducted on a regular basis to ensure that the risk information remained relevant and current in the context of the business of the company. In addition to ensuring the relevance of the recorded risk information, regular reviews also enabled:

5. New risks to be identified and considered as they arise;
6. New controls to be implemented according to the action plan schedule;
7. Check that existing controls are still in place and working effectively;
8. That information on risks is adequately communicated to appropriate parties, the relevant General Managers, where necessary, as well as being recorded in the risk management system where applicable.

During site visits it was identified that risk monitoring by the mining companies enabled them to identify any changes to the status of risks and controls, ensuring that the right levels of resources are focused in the right area at the right time.

The Risk Monitoring and Risk Review Table used by mining company D is an example to show how the mining companies were monitoring identified risks of hazards causing harm. This assisted with reducing the occurrence of injuries and fatalities.

Table 25

Risk Review Schedule

Context	Trigger	Risks	Timing	Notes
Strategic	Risk Review	Materials Risks	Monthly	Review key risks & actions at the Risk Review Committee & the Project & Operations Risk Review Meetings.
Operations Corporate Project	Operations Risk Review	All Risks	Quarterly	Review risk profile with key stakeholders as directed by the Delivery Owner.
	Corporate Risk Review	All Risks	Annually	Review risk profile with key stakeholders as directed by the Delivery Owner.
	Contracts (High or Medium rating)	All Risk	As Required	Conducted a facilitated risk assessment prior to tender.
	Mandated Legislative Risk Review	All Risks	As Required	Legislative risk assessment requirements deviate from this procedure, comply with the legislative requirements.

Note: From Mining Company D document provided during site visit

It was identified that each mining company provided clear instruction to every mobile plant operator that in the event a fault that presents a risk to the safe operation of a vehicle or item of mobile plant, that the equipment was to be tagged out and not operated until repaired and roadworthy. All mining companies had a pre-start check-book in which fault types were documented and each operator was required to tick the fault in the appropriate category. If the operator was unsure of the type of fault, then the operator was required to speak to their supervisor and the maintenance supervisor.

In summary, it was evaluated that mining companies had customized risk assessment, risk management and risk control standards as per site conditions, protocols, workplace safety management requirements and that regular audits were completed at each site to maintain legal and company requirement compliance and aim for a zero injury rate to make mobile plant equipment use safe for the employees.

5.4 Mining Industry Mobile Plant Safety Procedures

5.4.1 Mobile plant safety procedures in relation to notifiable incidents

Each mining company had a well-maintained database. Entry procedures were categorically related to each type of mobile equipment being used for either surface or underground mining. Strict laws had been made at every site in order to get 100% compliance to the instructions and guidelines to ensure the safe, efficient and productive operation of all vehicles and the safe interaction between all vehicles and personnel. According to the Safety and Health snapshot from July 2018 to June 2019 published by the Australian Mineral Sector of the Western Australian Department of Mines, Industry Regulation and Safety in March 2020, there were 1,324 injuries and 2,706 notifiable incidents during that time. Of these 422 injuries and 446 notifiable incidents were identified as injuries due to maintenance activities on mobile plants. Upon further analysis of the data 344 of the 422 injuries were classified as serious and 173 were lost time injuries LTI). Therefore, it is apparent that mining operations need to regularly maintain equipment and machinery to ensure they can be operated reliably and safely but they also are required to ensure that these maintenance activities are performed safely.

5.4.2 Mobile equipment pre-start checklist

It was observed that each mining company had a customized *Equipment Pre-start Checklist* to ensure all mobile equipment was in a good reliable condition. Common equipment pre-start checklist items included all mining companies start-up checks documents were a visual check of oil/coolant levels. Steering tubes/linkage pins. Hose, oil, fuel, coolant or any other possible leaks. Checking cylinders and security of pins. Checking outside and inside of tyres rims and nuts. Yellow wheel nut indicators check. Lights check including head, brake, hazard and indicators lights. Horn working. Fire systems check including extinguishers tagged and charged. Checking seating and seat belts

At all mining companies it was observed that it was the responsibility of the operator of the respective equipment to fill-in the pre-start checklist and signed it with their name.

There were some maintenance checks that operators performed with the mobile plant engine running. For example, in mining company B checking procedures included flashing light (if fitted), two-way radio working, reversing lights/alarms, service brakes/retarder, secondary/emergency brakes, primary/emergency steering and GET/hydraulics operational. At all mining companies, there were special instructions to the operator to report immediately to the supervisor if any fault was observed and then follow the supervisor's instruction.

5.4.3 Customised safe operating procedures for mobile plant.

Observations taken at mobile plant equipment workshops and information from the mobile plant workshop supervisors identified that there were separate safe operating procedures (SOP) for each type of mobile equipment used on the site. Safe operating procedures were used to provide guidelines to the operators for maintaining high and safe standards and safety in the operation of mobile plant equipment. These procedures were used by personnel who were deemed competent (had a licence) to operate the mobile machinery and who could understand safe operating procedures.

In mining Company B documenting the safe operating procedures to ensure safe working at site were mobile plant operators' responsibilities and included pre-start inspections. Testing and steering of braking systems. Gear selection for downhill hauling, gear selection for uphill hauling and use of braking systems. Windrows, loading, reversing, use of gates on the machinery deck at the ladder/stairway and parking instructions. There were clear instructions for not operating the vehicle that included not operating when there was smoke in the cab. Not reversing hard into windrows or working benches. Not allowing anyone to climb on or off a heavy vehicle whilst in motion and not opening the door or leaving the cab whilst the vehicle was being loaded. Each mining company had its own detailed safe operating procedures and the basic instructions were derived from Western Australian Mines Safety Inspection Act 1994 and Regulations 1995.

5.4.4 Measures for underground heavy mines vehicles safety

During the site visit at mining Company B, underground mining work was observed to identify the nature of hazards involved while operating heavy machinery underground. It was noted that working underground had different hazards compared to surface mining work. Sitting on mobile equipment for a 12-hour shift was a tough task requiring good mental health. Practical experience of the hazards involved while going underground at mining company B was obtained. Hazards identified included working in low light, rock falls and uneven ground surface that made it difficult for miners to maintain balance while walking on uneven surfaces wearing heavy personal protective equipment.

Through observation, talking to underground mobile plant equipment operators and reading mobile plant operation and maintenance manuals it was identified that there were certain mandatory requirements (built specifications) for all heavy mine vehicles (weighing more than 2 tonne) used underground. Heavy underground vehicles were required to have the power to run solenoid on the fuel pump. Lockable battery isolators that will independently shutdown the engine and isolate all electrical power. Lockable starter motor isolator to prevent inadvertent engine start-up during live electrical testing and troubleshooting. Dry powder fire extinguishers for manual use. A fail-safe brake system. Spring applied hydraulic release. A gauge that indicates residual braking pressure to be fitted inside the operator's cabin. Park brake indicator light in the cab. Brake lights on the rear and brake system residual pressure indicators or gauges in operator's cab. Tail lights that were illuminated at all times when the lockable battery isolator was on. In addition to a standard filler a Wiggins Fast Fill system. Decals to define all lights, gauges and controls. All hydraulic hosing in engine compartment was to be shrouded. Steel braided fuel lines to SAE 100R5 (Up to -12) AS 3791 – 1991. All fuel water separators to be made of a non-flammable material and no glass bowls. Standard Fuel Caps were to be non-ventilated fuel caps. Canvas seat covers or the equivalent. Reversing camera. Batteries to be dry cell type. Jump-start system. Two-way radio. One amber strobe light on an independent light circuit. Interlock to prevent tramming whilst high voltage was activated. Shielding, exhaust lagging or ceramic coating to cover all turbo charger and exhaust systems (LVs exempt) and the engine compartment should be effectively fire shielded from the driver's compartment. The above mentioned are some of the specific built-in features required for all underground machinery in order to maintain safety of the personnel working in hard underground mining conditions as mentioned in mining company B documentation related to working underground.

5.5 Mine Sites Visits Observations

5.5.1 Workplace Observations

In addition to the analysis and discussion of the mining sites safety management, safety work processes and type of mobile plant equipment following are some observations that the researcher has further noted with regards to:

1. Underground mining and the corresponding hazards.
2. Heavy Vehicle Automation.
3. Safety promotion at workplaces.
4. Workplace safety culture.

5.5.1.1 Underground mine sites and hazards identified

Compared to surface mining, underground mining has less impact on the environment but is far more dangerous for those who work in mining. In the underground mining sites observed the air was pre-rated for oxygen toxicity and there was an engine system and ventilation protocol to ensure safety at work. Underground rock-fall, fires, toxic atmospheric contaminants and explosions due to gas or dust were the most critical hazards associated with underground mining as discussed by one of the safety and health representatives at mining company B. Underground mining focuses on extracting minerals by excavating the land to obtain them (Ben-Awuah et.al., 2016). However, the conditions to which workers are exposed during working hours are not optimal and as a consequence of this work accidents and illnesses that affect the workers' quality of life can arise (Sanmiquel et al., 2015)

Observation identified that in underground mining the type of mobile equipment used was different to above ground equipment and was categorically designed for the underground work environment without unnecessary sophistications. Company B had an underground and special protocols and procedures were set at the site for this type of work. This mining company had specific documents considering the ground conditions, general requirement related to vehicles under-ground and records of the hazards involved while working under-ground at the mine site.

The risk of the type of accidents in mining depends on the nature of the mine. In underground mining the workers perform their activities in confined spaces, therefore they are exposed to a high number of elements that can affect their health, cause illness or death (Amirshenava & Osanloo, 2018; Duzgun & Einstein, 2004).Some of the most common causes of occupational diseases and accidents in underground mining are environmental risks, risks of physical and mental overload and risks derived from specific sources including mobile plant equipment (Ryan & De Souza, 2017)

At mine sites observed there were special bulletins and instructions related to outbreaks of fire as this is a serious hazard in underground mines. While visiting one of the underground mine sites, it was observed that working underground while driving heavy machinery, if a fire occurs, it is extremely dangerous due to the closed nature of excavation, potential amount of smoke and harmful fumes and limited opportunity for a quick evacuation from the mine. Therefore, strict measures were noted to have been taken by the mine site management to avoid any potential underground fire incident and a detailed document related to underground fire risk assessment was present at site with appropriate controls in place to manage the risks while doing work underground.

Discussion with employees identified that training had been provided to mine operators to prevent the outbreak of fires in underground mines including how to *minimise the effects of fire.* In the guidelines *Prevention of fire in underground mines* issued by the Department of Mines, Industry Regulation and Safety (2019c, p.18) it is documented that all mobile equipment fuel, lubrication and hydraulic systems are potential fuel sources for fires. Recommendations in the documentation of mining company B to prevent underground mining fires included that where practicable hydraulic systems should use steel lines. Where flexible hoses are used, they should meet the requirements of Australian

Standards AS 1180.10A and 10B and should be fire-resistant, or shield securely clamped away from hot surfaces, located so that impact damage is minimised and provided with bulkhead fittings where they pass through bulkheads.

It is recommended in the guidelines issued by Department of Mines, Industry Regulation and Safety, Resource Safety (2019c) that fuel and oil lines and hydraulics for underground machinery should be installed as required by the Original Equipment Manufacturer (OEM) specifications, and routed so that, in the event of a burst or leak, flammable liquid cannot contact a hot surface. Further it is also advised by the Department of Mines, Industry Regulation and Safety, Resource Safety, (2019c, p.12) that where routing away from hot surfaces is not possible, all lines should be securely clamped and shielded and should be kept separate from electrical cables and routed away from moving parts. This publication also recommended that plastic cable ties to secure fuel and oil lines in bundles to other fixtures or to electrical cable sheathing should not be used. All replacement hoses and components should meet OEM specifications. The fire risk for all vehicle fuel tanks and fuel containers should be assessed. Tanks and containers should be located so that flammable liquids from any overflow or venting cannot contact hot surfaces. Plastic and rubber fuel bladders in mobile equipment must be identified, maintained and inspected according to OEM recommendations. Foreign materials (e.g. cleaning cloths) left on hot surfaces are potential fuel sources that can be eliminated through a system of checks. Radiator coolant that boils off or evaporates can leave a flammable residue. This possibility should be identified during equipment inspections and eliminated (Department of Mines, Industry Regulation and Safety, 2019c).

Through observations while going underground at mining site B the importance of a proper ventilation system was noticed and how hazardous it could be if there was not adequate ventilation. For instance, during the data analysis of the significant incident database (significant incident number 232) there was a fatality of a jumbo drilling operator offsider observed in 2015 at a Western Australian mine site due to hot and humid mine conditions and improper ventilation while working 900m below ground. During this investigation it was concluded that the ventilation was not reliable, consistent or adequate and the Regulator imposed a penalty of $90,000 on the company for failing to provide a safe working environment and causing the death of an underground jumbo operator's offsider at a Gold Mine in the Pilbara region (Department of Mines, Industry Regulation and Safety, 2017b).

It was observed that when the human body is subjected to work related stress during mining activities the individual may be exposed to risks of physical and/or mental overload. Ergonomic and psychosocial risks fall under this category (Amponsah-Tawiah, et. al., 2013). Another category of observed factors that can affect workers in the mining work environment were mechanical and electrical hazard risks. Mechanical risks are caused by the use of machines that can cause entrapment, dismemberment, particle projection, falls, blows, etc. Electrical risks are caused by electrical installations or equipment, which can cause electric shocks, fires or explosions due to overloads or short circuits in conductors (Mahdevari et.al., 2014).

A further hazard observed that could occur in underground mining was rock falls that could be due to unsupported ground or due to a rock slab that broke away from a hanging wall. It was observed that there were clear documented instructions about the preventive measures possible to use to avoid incidents due to rock-falls at mine sites which included heavy machinery was not allowed to enter until the ground was supported by mesh and bolts, employees trained to always stand in a safe position and clearing of possible rock fall from a stope. It was noticed that physical indicators were in place at ground level to mark boundary between supported and unsupported ground and a safety bund was built across the width of the drive. It was identified during the analysis of the Resources Safety Notifiable Incidents Database that there were 10 incidents reported due to rock fall in the three years from 2017 to 2020. Out of these 10 incidents, five were related to surface mining and five were incidents in Western Australian underground mines.

5.5.1.2 Heavy vehicle automation in the WA mining industry

It was noticed while visiting mining company C and D that there were driverless haul trucks as mobile plant vehicles. No one behind the wheel: The new workforce driving

Australia's mines, (Gray, 2019, p. 2) recorded that “they were parked at a lookout, with sweeping views of the red and yellow Pilbara earth. It was impossible to miss: A fully-loaded haulage truck the size of a double-storey house on wheels, travelling at an estimated 60 kilometres an hour. What was unique about this truck was it didn't have a driver,”

It was observed from the mining site visits and in-depth analysis of observations at sites that mining automation technology in Australia is currently evolving from small underground applications to large scale surface mining. The researcher identified that automation technologies are being adopted in Australia because of the country’s supportive mining environment that includes a long mining history, a highly educated workforce and the community encouragement of entrepreneurial activity in the sector. The application of automation in mining haul trucks suggests that significant cost savings can be made and this will only further increase the uptake of mining automation by those companies that can afford the high upfront capital. Australian mining journey towards automation has been a long one, with autonomous trucks introduced to the Pilbara more than a decade ago (Gray, 2019).

Currently there are four big mining companies operating in the Pilbara region that are using autonomous haul trucks. Out of these four, the researcher visited two mining companies and physically witnessed the operation of these giant trucks at mining sites at mining company C and D. One visited mining company had more than 80 autonomous Komatsu trucks and operating. Driverless trucks have also proven to be more efficient than their manned counterparts, with autonomous vehicles operating 700 hours longer last year and with 15% lower unit costs (Jamasmie, 2018). Since beginning trial operations in 2008, there have been zero injuries attributed to haul trucks equipped with autonomous haulage system (AHS), which highlights the technology’s significant safety advantages (Jamasmie, 2018).

Haul trucks are a vital component of mining supply chain and in hazardous mining environments. The haul trucks can also have the potential to cause fatal incidents from unintended situations. According to the Department of Mines, Industry Regulation and Safety (2019b), there were ten fatal haul truck incidents in Western Australia between 1996 and 2020. Although the elimination of haul truck incidents is yet to be achieved, driverless technology is being introduced to remove human drivers in these vehicles. Automated haul trucks are monitored by humans through the use of computer technology with the employee doing this work sitting at a computer monitoring about 25 trucks and their operations at the one time for 12-hour work shifts. These employees need to be very vigilant and solve technology problems that can be unexpected and novel.

Automated systems have been proven to be effective in reducing significant incidents. This is largely due to the fact that permission-based control systems coordinates truck movements by permitting exclusive sections to the road (Hamada & Saito, 2018). Furthermore, manual equipment is provided with a system-based interface to manage haul truck interactions. Digital interfaces highlight the location of surrounding vehicles and sections of road occupied by the driverless vehicles. Despite the direct benefits of automation, new hazards and risks have emerged. These hazards and risks are unique to a driverless operation have played a role in the unconventional incident types involving driverless haul trucks (Department of Mines, Industry Regulation and Safety, 2015b).

The WA mining industry's risk transformation is being driven by the rapid introduction of artificial intelligence (Gray, 2019). According to recent reports, there are now more than 350 automated haul trucks in the Pilbara region (BHP, 2019; Fortescue Metals Group Limited, 2019; Jacques, 2019). Introducing automated systems, however, has already highlighted a number of important lessons (Department of Mines and Petroleum, 2014), particularly those that have already been learnt in Aviation, Maritime and Manufacturing (Dekker & Woods, 2002; Lee & Morgan, 1994; Woods, 2016). Yet, the same signs and symbols of human–machine breakdown appear to be repeating themselves—just simply in another industry context. Over the last six years, driverless haul trucks have been involved in a number of significant incidents (Jamasmie, 2019; Department of Mines and Petroleum, 2015b; McKinnon, 2019).

After observing that the driverless technology at two mining sites, that had introduced automation, had reduced the frequency of accidents it was noted that there was an increase in vehicle operating hours. As there was no human interaction involved while autonomous trucks were in operation at these sites this removal of human exposure in haulage process resulted in a reduction of accidents. For instance, during database analysis, results of which are recorded in the previous chapter, it was identified that there were large number of accidents due to vibrations, sudden seat hits and tray impacts. Truck automation has removed human exposure to these hazards.

Work site observations identified that there was a permission-based control system that was co-coordinating truck interactions resulting in increased accuracy and removed the need for associated infrastructure. It was also noticed that coordinating the movement of trucks has removed violations of priority rules and traffic management non-conformities. At each mine site there were specific programmed travel paths which were made to avoid contact with the material, refuelling and reversal in the crusher during the overturning.

Incidents with driverless trucks still occur, but they are usually a different type of incident to those that occur with manual haul trucks, with lane breaches being the most common reported incident. Lane breaches are caused mainly by wet or other road conditions or computer communication loss. After an autonomous truck crashed into a manned water cart Resources Safety, (2015) published a Code of Practice for 'Safe mobile autonomous mining in Western Australia.' More recently, the Global Mining Guidelines Group (2019) has published *Guidelines for the implementation of autonomous systems in mining* to provide guidelines for safe autonomous mining vehicle operations. At one mine site it was found that driverless operations reported 866 incidents per million hours worked which was less than manned trucks, where manually driven trucks recorded 968 incidents per million hours worked (Pascoe, 2019). Below are 432 reported incidents that occurred at a Western Australian mining workplace that involved autonomous haul trucks.

Table 26

Driverless truck incidents

Incident Type	Description	(#)	(%)
Lane breach	Truck had drifted outside of the assigned pathway	190	44.0
Proximity detection	Detection of potential pathway collision with machine	135	31.3
Truck damage	Truck has contacted or been contact by another machine	32	7.4
Process breach	System-based task did not comply with the procedure	31	7.2
Object detection	Identified object and stopped suddenly	14	3.2
Reversed into material	Truck reversed into a dump pile	7	1.6
Broken escort	Non-site aware vehicle became separated from escorts	4	0.9
Technician injury	Person was injured while attending to a truck	3	0.7
Production loss	Truck fleet down for extended period of time	3	0.7
Bogged truck	Caught in wet ground material	2	0.5
Uncontrolled movement	Rolling backwards or forwards uncontrollably	2	0.2
Windrow breach	Truck protruded through windrow on dump	2	0.2
Truck collision	Truck was had contact another truck	1	0.2
Ore tipped on waste	Ore material was tipped onto a waste dump	1	0.2
Rock breach bund	Rock tipped over a waste dump and breached bund	1	0.2
Procedural breach	A procedure was not followed in the execution of a task	1	0.2
Ore tipped on wrong pile	Incorrect material type was tipped on a stockpile	1	0.2
Failed truck assignment	Truck unable to execute given assignment	1	0.2
Crusher contact	Rock fell from tray and damaged the crusher	1	0.2
Total		432	100.0

Note. From *truck driver awareness to obstacle detection: A tiger never changes its stripes* (p. 8), by T. Pascoe (2019), 10th International Conference on Prevention of Accidents at Work. (http://visionzero.global/10th-international-conference-prevention-accidents-work-wos-2019). Copyright 2019 T. Pascoe.

Autonomous trucks still require humans to be involved in maintenance work. In one of the incidents referred to above during testing, a technician was injured when he put his hand into a rotating LiDAR when it appeared stationary. The above worksite observations related to the introduction of automated haul trucks in the Western Australian mining industry indicate that making full use of the automated technology is a way forward, although there is still a requirement for technology improvements.

5.5.1.3 Safety Promotion at workplaces

A safe workplace, safe equipment, safe work processes, and safe management practices are important and part of the safety management system (Brownlie, 2014). Observations at the mine sites provided an understanding of the day and night shift operations at site, camp life and the safety practices and processes at the site. It was observed that each mining company had full documentation related to safety practices and standards and had site-specific strategies used to promote safety at their workplace.

Having a personal focus on safety and good interpersonal skills were considered by all participating mining companies as one of the methods used to prevent employees having work related injuries, ill health and to manage fatigue at site. Fly In and Fly Out (FIFO) work rosters were used for employee employment at all mining sites. Employees interviewed stated that this was really tough and hard for the workers as some employees had to leave their children and family back home and this could cause mental distress and lack of concentration. Issues related to the workplace culture in a FIFO environment can have adverse impacts for FIFO employees and lead to higher workplace turnover and lower worker productivity (Beach et al., 2003). Families may also experience negative impacts associated with the workplace culture (Denniss & Baker, 2012).

Staying at the campsite made the researcher realize how difficult would it be for the FIFO workers to stay away from their families and on the other hand give 100% attention to their work on the site. Methods used by which workers cope with the FIFO lifestyle, and their willingness to seek help if difficulties arose, has been outlined in a number of studies

(Henry et al., 2013, p. 82). One participant in a mental health survey conducted by Lifeline WA noted:

"*Well it's really just a case of suck it up princess, you just do it*" (Henry et al., 2013, p. 82).

It was observed that many mobile plant operators were adopting this kind of lifestyle to cope up with the problems raised as part of the Fly-in Fly-out lifestyle. It was noted that each mining company had some entertainment activities planned at the roster change over day like a barbeque or musical event to refresh the workers.

Involving people and the relevant machine operators in the workplace in safety activities was also practiced by mining company B. There were site feedback forms available and all employees were welcome to write their recommendations with regards to any site issue or safety concern. This feedback was used in the development of site procedures, training materials and in field leadership (Creighton, 1983). Walters (1985, p.64) wrote that lack of access to information also hampers workers' efforts to organize around health and safety issues. Employers control workers' access to information as well as their participation in the collection of data in the workplace (Walters, 1985).

In the Western Australian mining workplaces visited it was noted that co-workers motivated their colleagues to raise workplace safety issues repeatedly to encourage management to solve them by implementing appropriate risk control measures. There was a culture of refresher courses being conducted at sites at regular intervals to promote safety at the workplace and to ensure that the workers attain a higher level of understanding to be able to perform their role competently. Past research findings agree with this and identified that trained safety and health workers showed more confidence and abilities, carried out a variety of workplace safety activities and were more ready to work with management and other employees to make their workplace safe and healthy (Garcia et al. 2007; Vanderkruk, 2003; Hillage et al, 2000).

Another point observed was that although all mining companies focused on providing a judgement free, safe space for their workers to discuss their concerns about safety, there was some disconnection found between those who have thinking jobs to those that have doing jobs. Perhaps this was due to infrequent interaction at site as one group was based in the field and the other at headquarters. It was for this reason that Lord Robens brought a general duty of care for workplace safety into the occupational safety and health legislation; so that the managers, who represented the employer, could meet with employees, who did the hands-on work, in the workplace safety and health committee meetings to discuss and resolve workplace safety and health concerns (Creighton, 1983).

5.5.1.4 Safety Culture

Safety culture is described as representing "an organisation's core values about the importance of safety and the underlying beliefs and assumptions that guide behaviour and decision making" (Casey et al. 2017, p. 344). During the literature review it was identified that internationally the Australian mining industry is renowned for the development of best safety practices and maintaining a good safety culture that ultimately supports a high level of worker safety and productivity at work. This was also observed while visiting each mining company in Western Australia. Mining companies were seen to maintain a good safety culture by adopting the Western Australian mining legislation which has been used as a tool in protecting mine workers and promoted safe mining operations. Western Australian Mines Safety Inspection Regulations (1995) requires the operator of a mine to adopt a general duty of care and to ensure the health and safety of workers, and other persons, is not at risk as a result of activities at the mine.

A positive safety culture can help prevent work-related injuries and major disasters (Frazier et al., 2013). With the goal of improving both occupational and process safety, various industries are exploring the approaches and means to create a positive safety culture. Some scholars who have considered that culture might be deemed necessary refer to the way employees approach their work, in which the creation of a positive safety culture ultimately means improving on-the-job behaviour (Geller, 2005; Krause et al., 1999). To effectively improve the prevention of injuries, each mining site had welcomed suggestions from the workers to create a positive safety culture. It was observed that mining companies were fully focussed on the implementation of safety commitment and enhancement of the role of functional departments, from both the inside and the outside the organisation. An important tactic that was observed at site for creating a positive safety culture was to enhance co-worker safety and promoting employee participation through incentives. Safety culture guides were in place to promote the development and implementation of the safety management system and to positively affect management activities to directly maintain a high standard of workplace safety (Fu et al., 2017, 2018).

To achieve safer work outcomes some effective approaches used by the mining companies were observed. This included to control the physical work environment in mines, using only competent people, using fit for-purpose plants and equipment and having safe work systems. A mature safety culture is regarded as an important means of ensuring good safety performance, particularly in reducing accidents (Foster & Hoult, 2013). As noted by Foster and Hoult (2013), mine sites at lower levels of safety culture maturity will require different strategies to those at the advanced levels, making the concept of a safety culture maturity model appropriate for the mining industry.

After visiting the mining sites it was recognised that each mining site had different maturity levels for different safety culture elements, suggesting that safety culture does not exert a consistent effect in all areas of a site's safety management system. It is therefore recommended that improvement strategies adopted by the mining companies must first target the weak areas and this can be done by regular audits, feedbacks and learning extracted from previous incidents.

5.6 Discussion - Mobile Plant Safety Promoters and Barriers

This chapter has reported on information discovered through visits to the worksites of four mining companies to achieve the second research objective that was to *observe mobile plant in use in mining workplaces to identify what strategies are in place to promote mobile plant safety and any safety barriers.*

In relation to the strategies in place to promote mobile plant safety it was determined that mining industries in Western Australia are adopting a variety of strategies and personal risk assessment techniques for incident prevention. One of the major safety promotion strategies identified with the mobile plant operators was the strict compliance with completion of the pre-start hazard checklist. Risk control was based on the structured identification of potential accident scenarios and the use of risk acceptance criteria to identify and sustain risk constraints, avoiding local errors or failures that could lead to major consequences (Stoop and Dekker, 2012). It was observed that each mining company had well-documented pre-start checklists and methods that must be followed by mobile plant operators. There was strict compliance to follow the procedures by the workers and safety officers were made responsible to keep a close check on compliance. Company incident records demonstrated that this resulted in a reduction in possible injuries.

A Permit to work (PTW) is a formal customized procedure which covers activities before, during and after a specific task, including risk identification, assessment and control, different levels of approval, communication among affected personnel, task steps and system safety reviews. It also has to cover, or be correlated to, procedures such as task preparation, isolation plans, system identification, safety reviews and personal protection (Iliffe et al., 1999).

Safety promotion incentives was a strategy used by mining company A and B to keep the workers vigilant and active during work. Hurst (1980) was among the first to discuss the use of rewards for promoting safe driving, hence trying to overcome the lack of intrinsic motivation by fostering extrinsic motivation. It was observed that there were certain awards for best safety performance of the operators in mining company B while mining company A was giving a cash award to the person nominated by their colleagues for excellence in following safe operating procedures and keeping safety as a top priority while being at work.

Another strategy that was used by Company C was the use of a Buddy System with a work peer in order to reduce stress and anxiety among the mobile plant workers. Other mining companies were using this as well. Peer mentoring refers to a network of support in which a more skilled, or experienced person, serves as a role model to a less skilled person to promote professional and personal development for the latter (Dorsey & Baker, 2004). A good peer mentor is characterized as someone who is confident, generous, competent and open to a collaborative relationship (Morse, 2006). In mining Company C all mobile plant workers were instructed to keep an eye on their colleagues and to ask if they are okay and with full presence of mind at work. If there are signs of mental stress or fatigue, which might be due to any reason, then the worker can discuss this with their colleagues at work. Supervisors were advised to spare some time away from their office work at the work site with the workers to have close interaction with them and increase their understanding of the workers and their tasks. Applying this peer mentoring strategy by mining company had reduced workers' anxiety and stress level resulting in a good quality of work with no safety issues or incidents.

Besides safety promotion strategies some safety barriers were observed. One barrier identified in relation to mobile plant safety was that in mining company B there was a need to review the roster for the fly-in fly-out mobile plant workers. Mining operations have increasingly become 24-hour operations. This, coupled with the increased use of FIFO workers, led to the common practice of rosters that combine a set number of days living on site and working up to 12-hour shifts with a set number of days spent at home on leave (Solomon et al., 2008). The types of FIFO roster arrangements that are put in place by mining operations vary according to the mine site, the employer and the job being undertaken (Sibbel, 2010). For example, machinery and plant operators, along with their direct supervisors, are more likely to have *shift* work, incorporating a number of *day shifts* followed by a number of *night shifts*. A common pattern was one week of night shift, followed by one week of day shift, followed by time on leave (Sibbel, 2010).

The proportion of time spent at home and at work depended on the symmetry of the work roster offered by the employer. Rosters can be symmetrical (e.g., 2 weeks on, 2 weeks off), asymmetrical (e.g., 2 weeks on, 1 week off), short (4/3 days) or long (6/1 days), and vary between staff and contractors, and between construction, operations and administrative personnel (Storey, 2009). Watts (2004) suggested that asymmetrical rosters are more commonly offered by land-based mining companies. There are, however, a number of variations of asymmetrical rosters in use, for example:

1. 6 weeks on, 1 week off (6/1);
2. 2 weeks on, 1 week off (2/1);
3. 9 days on, 5 days off (9/5);
4. 8 days on, 6 days off (8/6); and
5. 5 days on, 2 days off (5/2) (Clifford, 2009; Sibbel, 2010).

Highly compressed roster arrangements have been linked to lower levels of employee satisfaction. In particular, work-to-leave ratios greater than two combined with longer roster cycle times have been considered to be less satisfactory (Clifford, 2009). It was observed that at mining Company B, workers need to leave Perth by 12:00 midday in order to reach site in the evening and then worked a 12-hour night shift which meant around 20 hours of being awake. This caused fatigue and stress in these miners.

At mining companies A and B the size of the organisation may also impact company ability to provide a variety of recreational activities to the workers at site in order to engage them in different activities after work hours to ease their minds from the thinking of living away from family and to be able to focus more on work. This was an identified safety barrier. Large organisations were more likely to be able to provide access to the diverse range of resources needed to manage these challenges well, but smaller mining companies may lack the financial leverage to source the diverse range of recreational activities needed (Hutchins et al., 2011; Sibbel, 2010).

Recruitment of mobile plant operators with no previous background or experience in mining or mobile plant specific training was also identified as one of the safety barriers. In two of the mining companies visited the dump truck drivers were recruited either fresh, or with some other trade background (e. g prison guards, barbers), and they came directly to site for further training prior to driving the trucks. This has been a big challenge for the safety supervisors to get these workers trained and inducted for the site. The other two mine sites visited had autonomous haul trucks that did not require a truck driver.

5.7 Chapter Summary

This chapter has summarized the mine sites observations including the operation of driverless technology, hazards in underground mining, safety culture and workplace safety observations. The chapter identified safety promotion strategies and safety barriers to achieve objective two of the research. These findings and observations related to the pro-active approach of risk assessment. The researcher's practical exposure to hazards related to mobile plant in mining industries has helped to develop an outcome of this research which is the Triage Hazard Identification and Prevention (THIP) model. Some of the Risk Assessment techniques which were seen practically during the visits to mine sites have been used to write the steps in the Pro-active hazard identification focus and pro-active preventive focus columns of THIP model.

The next chapter includes the participants' interviews that the researcher conducted during mining sites visits, questions answers and their qualitative analysis results.

6. FOCUS GROUPS AND INTERVIEWS ANALYSIS RESULTS

6.1 Introduction

This chapter contains the results of the six focus group discussions with 17 participants and 27 individual interviews conducted by the researcher during the visit to four mining companies in Western Australia, the research participants' demographic information, participants' responses about their role as mobile plant operators, mobile plant supervisors and mobile plant maintenance workers. This chapter answers the third research objective which was to *conduct focus group interviews with mobile plant operators to identify their opinions on safety and risk control factors related to the use of mobile plant in their workplace.*

NVivo 12 software was used to create nodes, sub nodes, themes and word clouds to analyse the focus group and interview question answer results. Quotes from research participants were included to highlight important information related to the research findings. For some of the mining industry research participants English was not their first language, but all were able to communicate well with the researcher. To maintain confidentiality the participants' real names are not included. The chapter commences with a description and statement of the interview questions asked by the researcher to achieve objective three. Question answers were analysed using descriptive statistics and through Nvivo-12 data analysis.

6.2 Interviews with mining companies employees – Protocols and Procedures

Four mining companies were visited to conduct focus group discussions using the questions in Appendix-4 with participants at each mine site. Due to the busy work schedule of workers at 3 of the mine sites, it was too difficult for management to allow multiple employees to leave their work at one time for a focus group discussion, even though this had been agreed to with management prior to the researcher coming on site.

To enable research data collection from participants, if it was not possible to have a focus group, one to one interviews were conducted at the mine site with the workers available. This included interviewing mobile plant operators in their cabins, maintenance workers in their workshop and supervisors in their workplace. Interviews were conducted and included questions relevant to the participant's experience with mobile plant equipment and any hazardous situation that they met during this work.

6.3 Exploring the research questions – Participants' Interview Responses

In the following analysis, tables and participant quotes were provided to summarize the data, supporting the findings of the focus group discussion and the interviews to create a "thick description" of information related to the themes identified and to illustrate important aspects of each theme. Data gathered in this research is complex and densely laden because it describes personal experiences. To allow for emergent themes, the research questions in Appendix 4 are aligned in a broad manner because research questions have the ability to narrow or shift the scope to fully represent the codes that arose during the focus group discussions and during the interviews analysis. Question answers were advanced to emerging codes and the themes using NVivo-12 data analysis. As shown in tables below, the primary research questions are linked to create some secondary questions asked to get a more detailed response from the participants. Throughout the focus group discussions and the interview process, all participants discussed their experiences about the challenges faced, importance of safety, shared their work experiences, shared their opinions of dealing with stress and pressure and gave suggestions for improvements.

6.4 Participants Demographic Information

Initially it was planned to conduct focus group interviews at each mining site. However due to the unavailability of participants for focus group interview because of the need to keep the mine operating, one to one interviews were conducted at mining company A. At mining companies B and C data was collected through focus group interviews where possible by conducting one focus group interview at mining company B and two focus groups interviews at mining company C as well as one-to-one interviews if not possible due to work requirements. At mining company D three focus group interviews and four one-to-one interviews were conducted. Interviews were conducted with people whose work involved the use of mobile plant in mining and included operators, mobile equipment maintenance workers, safety personal and site supervisors.

Overall 6 focus group discussions and 27 individual interviews with employees were held at 4 visited mining companies. Results were included after transcribing and entering the answers into Nvivo-12 software. Data saturation was achieved with a total of 44 participants. Data collection constraints and limitations were reported in chapters 1 and 3.

The research participants were 15 mobile plant operators, 12 mobile plant maintenance workers, 8 operation and maintenance supervisors and 9 site safety professionals who worked for Western Australian mining companies.

Feelings, thoughts, intentions and previous behaviour is only known by the person so there is a reliability in people's verbal accounts and also body language to extract the feelings that they maintain regarding the problem under consideration. For this research, in-depth interviews and observations at mining sites were used to collect data for NVivo 12 analysis and research interpretation. Through purposeful statements from participants and in-depth interviews, rich descriptive data was gathered to analyse to identify participants' opinions on safety and risk control factors related to the use of mobile plant in their workplace.

The analysis of the data resulted in themed categories and clustered data applicable to the central research question and the initially outlined sub-research questions. Table 27 outlines the description of each group in a sample with a number of people interviewed from each mining company.

Table 27

Description of participants- One to one interviews

Description of participants			
Sr. No.	**Details**	**Description of one-to-one interviews**	**# Total interviewed**
1	Mining company A	Mining operators 3 Mining maintenance workers 4 Safety supervisors 3 Site supervisors 2	12
2	Mining company B	Mining operators 3 Mining maintenance workers 3 Safety supervisors 0 Site supervisors 0	6
3	Mining company C	Mining operators 0 Mining maintenance workers 2 Safety supervisors 2 Site supervisors 1	5
4	Mining company D	Mining operators 3 Mining maintenance workers 0 Safety supervisors 0 Site supervisors 1	4
Total			27

Table 27 shows the employment position of interview participants in each of the mining companies where interviews were conducted. Analysing the information in the Resources Safety notifiable incident database provided numbers of mobile plant incidents, while talking to workers enabled a more in depth understanding of the reasons for mobile plant accidents occurring and what workers perceived can be done to make the work processes, workplace and employees' actions safer in relation to mine site mobile plant use.

Table 28 outlines the description of each group in the sample with a number of focus group interviews conducted at each mining company.

Table 28

Description of Sample Size- Focus Group interviews

Sample Size			
Sr. No.	**Details**	**Description**	**Number of focus groups held**
1	Mining company A		0
2	Mining company B	Site Supervisor-focus group interview. Mobile plant operators and maintenance workers were not available for a focus group discussion.	1 with 2 participants
3	Mining company C	Mobile plant operators focus group. Supervisors at this site were not able to leave work to participate in a focus group.	2 with 3 participants each
4	Mining company D	Maintenance worker, site and safety supervisor. Mobile plant operators at this site were not able to leave work to participate in a focus group.	3 with 3 participants each
Total			6 focus groups 17 participants.

See Appendix 4 for the questions asked and discussed for supervisors, for mobile plant operators and for mobile plant maintenance workers. In mining company A due to the busy schedule of participants, no focus groups were able to be held so mobile plant operators, maintenance workers and supervisors were interviewed at their work location. The management co-operated well to gather the participants for the interview and interviews were held dependent on the availability of the workers.

For the interviews, both male and female mobile plant operators in mining were included so that their interview results could be compared and analysed with respect to the challenges faced by operators in mining industry. The responses of the participants were quantitatively analysed using the descriptive statistics of number and percent to determine their demographic profile. The first demographic factor considered was gender as shown in Table 29.

Table 29

Participants' Gender

Gender	Number	%
Male	40	90.5
Female	4	9.5
Total	44	100%

The mining industry is one of the largest and most dynamic industries in Australia, employing 1.8% (mostly male) of the Australian workforce (Australian Bureau Statistics, 2019). Mining has historically been a male-dominated workplace comprised mainly of men in blue-collar employment (Peetz & Murray, 2010). Thirty eight out of 42 participants were male and 4 were female which is a representative sample for the employees in mining companies, especially in FIFO (Fly-in Fly-out) roles. Employment within the mining industry typically includes FIFO employment and residential based employment or drive-in, drive out (DIDO). Mining employees working in a *residential* capacity live and work in the same region as the mine (Storey, 2001). Alternatively, FIFO is often defined as "all employment in which the work is so isolated from the workers' homes that food and accommodation are provided for them at the work site, and rosters are established whereby employees spend a fixed number of days at the site, followed by a fixed number of days at home." (Shrimpton & Storey, 2001, p.2). Employees themselves are showing a preference for FIFO as opposed to residential. Australia's population prefers to live in highly urbanised coastal areas, with over half of Australia's population living in five large cities located on the coast (Hogan & Berry, 2000).

The first three questions asked were related to the position of employees and the period of current employment along with the overall experience of employees in their relevant mining companies and these were the same in all the three questionnaires. The details of these answers are included in table 30 and 31.

The participants in this study had a minimum of 2.5 months and a maximum of 14 years' experience working in their role of mobile plant operator, maintenance worker, safety or site supervisor. Some participants were newly promoted to their current role while other participants in the focus group or interviewed were newly inducted trainees. However, as shown in Table 30, most of the research participants were experienced in their current role.

Table 30

Participants' Years of Experience in current roles

Number of years	Number	%
4 months to 2 years	10	24
3 - 5 years	13	31
6 – 8 years	5	12
9 – 10 years	7	16.7
> 10 years	9	16.7
Total	44	100%

Participants' total years of working experiences in the mining industry indicated that most of them were experienced in terms of operating, maintaining mobile plant. All site and safety supervisors were experienced in their work roles. Research participants' employment positions are documented in Table 31.

Table 31

Participants' Employment Position

Employment position	Number	%
Mobile plant operators	15	35.7
Mobile plant maintenance operators	12	31.6
Safety Supervisors	8	18
Site Supervisors	9	19
Total	44	100%

The most common employment title of the participants was mobile plants operators and the mobile plant maintenance workers. Fifteen (15) mobile plant operators and twelve (12) mobile plant maintenance workers were part of a focus group or interviewed before data saturation was achieved. A total of eight (8) Safety supervisors and nine (9) site supervisors were also part of a focus group or interviewed to obtain data saturation of information related to mobile plant related work on mine sites to provide an understanding of reasons why accidents related to mobile plant were occurring so that a model of risk control measures could be developed.

The response of the participants is divided into three groups for analysing the information taken from the participants.

1. Group A – Mobile Plant Operators
2. Group B – Mobile Plant Supervisors
3. Group C – Mobile plant maintenance workers

6.5 Group A – Mobile Plant Operators:

6.5.1 Types of mobile plant used

There were different types of mobile plant workers at each mining site. In mining company A the one-to-one interviews were taken from a bulldozer operator, excavator operator and a female water cart operator. Mining company B was an underground mine site and there the one-to-one interviews were conducted with a female bogger operator, tele-remote bogger operator and an underground truck operator who was interviewed at the underground work site. In mining company C two focus group interviews were conducted with dozer, excavator, truck and water-cart machine operators. There was also a one-to-one interview conducted with the emergency services co-ordinator who was previously a truck operator. There were three one-to-one interviews conducted with mobile plant operators in mining company D that included excavator, dozer and a female dump truck operator.

The machinery operated by male participants were bulldozers, excavators, water carts, bloggers, tele-remote boggers and trucks. Female research participants operated a water cart, bogger or dump truck.

6.5.2 Safety importance

Question 5, *How important is safety to you,* investigated the approach of research participants towards safety and the level of awareness of hazards in their work. Mobile plant operators from all mining companies were very clear about the importance of safety. In response to this question, one of mobile plant operators at mining company B stated:

> *Safety is paramount. Safety is everything in my eyes. I am a Safety Represenative. I am very good with procedures and their explaining of how to go about things. At the end of the day, we are humans and we try to minimize hazards as much as we can.*

Talking about the safety, one of the Bulldozer operators in mining company A stated:

> *Safety is very important. I have been in industry for long time and have seen unavoidable incidents, so please follow rules.*

In mining company C, while conducting focus group interviews with excavator and water cart operators, one of the participants shared his views and highlight the part of family and good company policies to keep the workers motivated towards safety, he stated:

> *Sure, safety is big things. I have a young family at home so need to go home safe. Safety is the reason I am here with mining company C.*

The following word cloud (see Figure 28) was developed by Word Frequency query to identify the most frequently used word in response of question asking about importance of safety for mobile plant operators.

Figure 28

Importance of Safety in view of Mobile plant operators

This word cloud identified that the most frequently used word when answering this question was *safety,* which was the focus of the question. Other frequently used words were *important, procedures* and *home* as these factors influenced the effectiveness of safe work. The word cloud provides validity for the participants question answers. As a summary, the codes derived after the Nvivo-12 analysis of transcribed response from mobile plant operators were: home, rules, procedures and incidents. Taking care of personal safety and reaching home safely were identified as the priority of participants during interviews.

6.5.3 Mobile Plant Operators Challenges

Question 6 was *What are the challenges you faced in your job as mobile plant operator*? One of the bulldozer operators in mining company A mentioned that weather could also be a big challenge for mobile plant operators as dry or wet weather could make it hard for them to operate the vehicle.

When talking to a female water cart operator in mining company A about the challenges of working in male dominant environment she said:

> *Yeah, am good. Everything and everyone is great; company site, policy and procedures makes it friendly, diverse and welcoming envirnonment so I do not feel like stranger. We are couple of female on each crew. Not so bad when you have company there and the environment as well.*

The mining company B was an underground mining company and most of the themes identified in response to the above question were related to the tedious nature of work, fatigue due to 12 hours working underground on either day or night shift and interaction with other vehicles.

Interviews were conducted with female operators to understand the challenges being faced when working in a male dominated environment. Mining has traditionally been the domain of men and thus, women working in mining are typically working in male dominated environments. Women are not only dealing with the challenges inherent in the mining lifestyle but also have to contend with a workplace that has been shown to be at times exclusionary of women (Eveline et al., 1988; Pattenden & Australasian Institute of Mining and Metallurgy, 1998; Steed & Sinclair, 2000; Yount, 1991).

A female bogger operator in mining company B stated that:

> *Being a female is being physical and being physical is to keep yourself strong and this is challenge while operating machine is okay as we got trained for fatigue and night shift work.*

In mining company B, an interview was conducted with a tele-remote bogger operator as well. He explained that the underground bogger was driven remotely by him and the main challenge was the laser beam while operating. Therefore, many safety precautions were in place for the laser not to break. Tele-remote bogger operator in mining company B mentioned that:

> *Challenges I face in my job are basically I am not big fan of video games. I found quite challenging to sit in front of computer screens for majority of time of day operating from remote. I more like to be hands on but at the same time I see it as a challenge and like to challenge myself all the time.*

An under-ground truck operator in mining company B while being interviewed stated:

> *I guess it's very tedious so stay away from fatigue is big challenge. Interaction with other vehicles. A week of nights and week a days. Long working hours. It is continous 12 hours undergound in day and night shifts. Pretty tideous. You can take breaks in between but none of us do. Normally we take breaks when waiting for your truck loading. Then you got 5 to 10 minutes. During loading you can have break and then get out, do some walk and then start work.*

In mining company C, interviews were conducted with graders, dozers, excavators and water cart operators and the themes identified were weather, dynamic risk environment, working away from home and learning new equipment. During the first focus group interview, one of the operators of mining company C stated:

> *Weather is big challenge, dusty and windy, soft material and sand.*

One of participant of mining company C, while being a participant in the second focus group interview, mentioned that:

> *It is always hard being away from home. Challenge in mine is learning new equipment and you always have opportunities to have improvement.*

Another participant stated:

> *Big challenge is family. You are not home for birthdays and it is hard.*

In mining companies one-to-one interviews were conducted with mobile plant operators and the themes identified in response to question 6 were weather, family and communicating with others regarding the things which were not clear. Identifying the challenges faced by mining workers, Gallegos wrote that the challenges created by the FIFO lifestyle included the effects of changing roles and responsibilities within the family unit and emotional distress due to separation (Gallegos, 2006).

The following word cloud (see Figure 29) showed what was identified as challenges being faced by mobile plant operators in their daily routine at mining sites. In this word cloud the biggest challenges were having day and night shift work.

Figure 29

Challenges for mobile plant operators

6.5.4 Hazardous Situation for Mobile Plant Operators

Question 7 asked *did you meet any hazardous situation during your job and how did you respond to it?* This question investigated the experiences of interviewees' when dealing with unsafe and hazardous situations while at work. A tele-remote bogger operator from mining company B shared his experience with regards to hazardous situations as:

> *With open holes and ground conditions, there is precautions and check list put in place to make sure all those are checked before starting the job and go through the system. However, machine failure is one of the challenges of my job because everything is remotely controlled and electronically as well. There is lot of problems rise with the wiring side of things. For example, laser not working. Lot of electronics involve inside and themasky can play up and challenging for 4 to 5 hours down time. I have done it couple of time and sometimes lot of dirt get stuck up in machine.*

A bulldozer operator from this mining company also spoke about his experience with regards to a hazardous situation as follows.

> *In Indonesia I was working in very dense jungle on a bull dozer. Dozer got started to get sinking in the sand and I had to jumped off the machine and climb my self and*

the dozer disapper and I think its still there. It was unforseen. We learnt some new appraoch after that incident. I also had a machine that catch fire.

A female water cart operator from mining company A shared her experience with regards to a hazardous situation as

I was pulling in windrows on the grader and the outside soft condition on the edge and it sink quite low and I called it up.

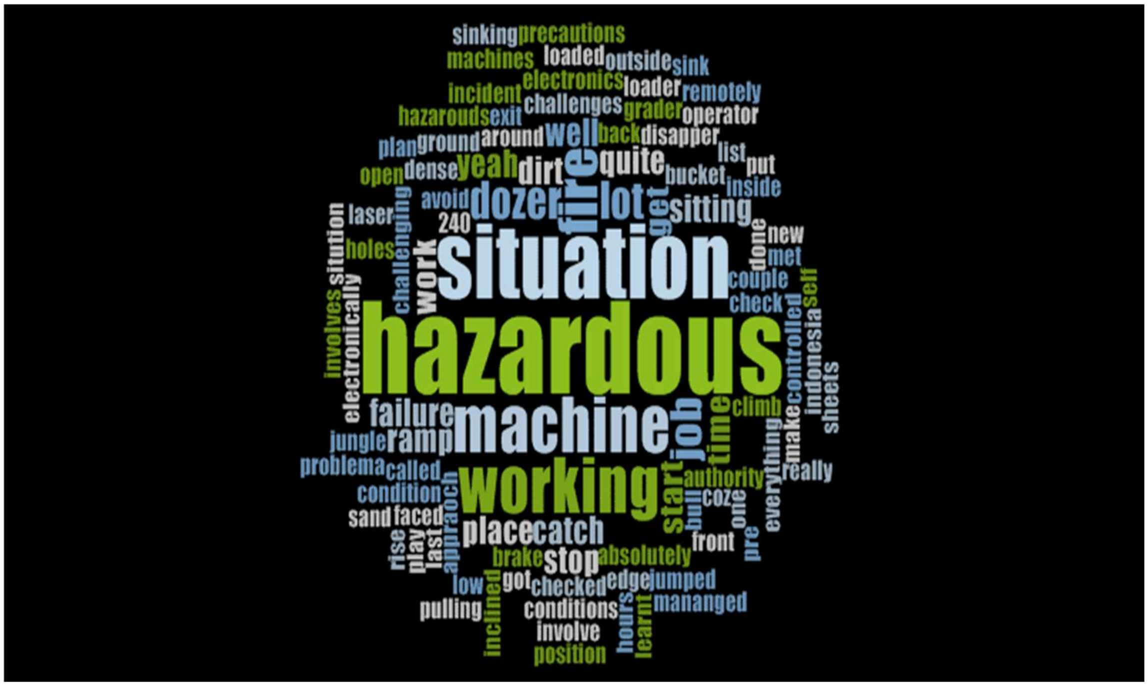
Some of the underground mining machinery workers had also shared their experience of underground fires due to faulty machinery, mainly Turbos. One of the research participants from mining company B shared his experience as:

Truck was loaded around 240 tons at the back inclined on the ramp and we had turbo fire hazardous involves were weight sitting on ramp, operator sitting on top, position of vehicle.

Using Word Frequency query key themes were created through the word cloud (see Figure 30) to identify the factors, which caused hazardous situation at while working on the mine site.

Figure 30

Hazardous situations faced by mobile plant operators



The Word Frequency query identified that the most frequent word used was hazardous. Other frequent words were situation, machine, working, fire and dozer. Most of participants mentioned that their experience of a hazardous situation was created by a breach of priority rules, faulty machinery, machine failure, ground conditions and lack of positive communication. There were several incidents identified due to human error and machine failure while analyzing the incidents related to mobile plants from Resources Significant Incident Database. The themes identified through the word cloud (Figure 30) provide validity to the participants' answers.

Participant responses indicated that, despite taking precautions and following rules, there are chances of incidents due to human error and these can only be minimized through proper training and positive communication between supervisors and workers at the start of the day. In a systematic review related to the effectiveness of occupational health and safety training conducted by Robson et al. in 2012, it was documented that the proper set up of training at the workplace is mandatory in order to keep the workers updated and refreshed about the safety protocols to be taken while at work. This applies both to their knowledge and their conduct (Robson et.al, 2012). These authors recommended that the training program should be adequately prepared both theoretically and practically. They wrote that the way the training is conducted is also important as it must be attractive enough and tailored to the level of the audience understanding to achieve the intended goals (Robson et.al, 2012).

6.5.5 Machine failure

Question 8 was *have you faced any machine failure during working*? In response the mining operators in company A replied that they never faced any machine failure that had caused an emergency. However, if they feel something is wrong then they pulled over their vehicle in order to avoid an emergency. Similarly, operators in mining company B replied that normal issues at site were a blown hose and, in this situation, they just pull the line, isolate it and call the fitter. In mining company C and D, operators did not face any machine failure while at work. Research participants' response in reply to this question indicated that they have faced machine failure while working and the only way to keep safe at the time of an emergency is not to rush, immediately call for help and follow guidelines.

An article in *The Financial Times Limited, UK* in 2018 about this BHP incident documented that BHP, the world's biggest miner, blamed human error and equipment failure for a *rollaway* train it was forced to derail after it travelled for almost 100km without a driver. It was reported by Edgar Basto, the head of BHP's iron ore assets in Western Australia, that correct procedures to ensure the train did not roll away had not been followed by the driver as he carried out an inspection. "Our initial findings show that the emergency air brake for the entire train was not engaged as required by the relevant operating procedure. In addition, the electric braking system that initially stopped the train, automatically released after one hour while the driver was still outside. Due to integration failure of the back-up braking system, it was not able to deploy successfully." (Hume, 2018, p 345).

6.5.6. Authority to stop a task if it is unsafe

The question *Do you have authority to stop a task if you feel it is unsafe* investigated the experiences of interviewees' about dealing with any unsafe situation at work and provided details about the level of confidence in decision-making that each mining company had given to their employees. This question was answered by all fifteen mobile plant operators of every mining company in a very confident manner that everyone at site has authority to stop and we had done that when needed at work. Similarly in the pilot study none of the participants stated that they did not have any power. A Stop work policy not only provides workers with the right and authority to discontinue work but also with the responsibility and obligation to follow such policy (Efendi, 2016; Ivensky, 2016; Walter, 2007).

An accident usually raises questions why stopping work when there was a safety risk did not occur, such as in the time leading up to the Deepwater Horizon rig explosion. Johnson, (2010) wrote that British Petroleum (BP) and Transocean ignored warning signs. Everyone aboard Deepwater Horizon had Stop Work Authority. Johnson (2010, p. 220) stated "the most damning thing we know about BP's safety culture is that nobody blew the whistle. Safety and health professionals should ask themselves whether they would raise hell to stop something that looked like a disaster waiting to happen and they should ask themselves what would happen if they missed it or were too cowed to blow the whistle: Would others at their operation raise hell anyway?". The below question is about handling stress and pressure by the mobile plant workers at the mining sites.

6.5.7 Mobile Plant Operators' Handling of Stress and Pressure

Question 10 was *how do you handle stress and pressure*? Theme answers identified after interviewing operators of mining company A were not to rush and having a good working atmosphere. One of the experienced excavators from mining company A replied that he does not stress out easily. One of the female water cart operators stated:

> *I just try not to take pressure one and to think of the more you rush the more chances of mistakes.*

A sense of community and a sense of belonging was identified by women employed in a

FIFO capacity as an advantage of the lifestyle (Pirotta, 2007; Steed & Sinclair, 2000).

One of the tele remote boggers in mining company B was very happy as his partner was truck driver in same company while the one of the truck operators in mining company B found driving truck much better than his previous employment working as a prison guard. Both said that feeling satisfied with work assisted with minimizing work-related stress.

Mobile plant operators in mining company C replied that they kept in touch with family and always called them at night to feel better. Another theme identified while talking to mining company C operators was the importance of good communication with peers. There is strong link between good social terms with peers and being able to handle stress and pressure. James et al (2018), highlighted that social, workplace and employment characteristics, (such as social connection and support, lack of financial strain, shift length and commitment to mental health from employers as components of a psychosocial safety climate), provide potentially modifiable factors which could guide interventions that aim to reduce the risk of mental health problems and improve health and safety from a mental health perspective.

During a focus group interview at mining company C one of the operators talked about the employment assistance program. He stated:

> *Employment assistance program with external company to assist employees to relief stress and anxiety and this program has getting positive feedbacks.*

In a study conducted carried out in 2018 related to psychological distress among workers in the mining industry in remote Australia, it was found that psychological distress in mining workers was higher than the average Australian day worker (James et.al., 2018).

Mining Company D employees did not share any information about how they handled stress and pressure. Mentioning the positive aspects of the FIFO lifestyle Gallegos (2006) included the financial benefits, the separation between work and home life, opportunities to change employers with minimum disruption to the family, large periods of time away from work to spend with family or pursue other interests, and greater access to educational and health facilities that are on offer in the larger cities for their families.

1. Mobile plant safety

The question *what is being done right at your workplace to make sure that the mobile plant that you use is safe for use* was asked to provide information about compliance of procedures and protocols in order to avoid accidents. Mobile plant operators at all four mining companies stated that they feel safe at their workplace and the primary reason was the good implementation of the rules and procedures. Operators follow the Standard Operating Procedures [SOP] and do the task risk assessment prior to using the machinery to avoid any unforeseen incident at site. The themes identified from the above question were compliance to rules and procedures. Studies of mining accidents have also highlighted the importance of procedural compliance and the need to follow rules to maintain safety standards.

2. Mobile Plant Operators Refresher Training

To the question *how often do you receive refresher training of procedures related to mobile plant safety and operation*s an experienced Bulldozer operator from mining company A stated:

> *I never do. You learn on the job when you go. Training comes with experience. The more time you spend on field, the more you learn.*

A female water cart operator at mining company A was not exactly sure of the refresher training time-period and she stated:

> *Every three years you get re-trained. It must be 2 or 3 years and daily we go through SOP's and all at begnining of shift.*

An experienced tele-remote bogger from mining company B said that for experienced vehicle operators there is no refresher training but the company put in lot of efforts into training the newcomers using experienced operators.

In mining company C, one of the machined operators stated that refresher training frequency is around one or two years and it depends on supervisors. The company has pushed the formal training to fifteen years, however yearly competency checks are performed. Fesak et al. (1996), Kecojevic et al., (2007) and Saperstein (2007) all reported that a reduction in accidents may be achieved through improved training for operators.

6.5.10 Mobile Plant Operators Improvement Suggestions

In answer to the question, *have you any suggestions for improvements to make operating mobile plant safer*, mobile plant operators provided some good suggestions with most of the suggestions related to overall improvement in terms of rosters, work hours breaks and opportunity to speak. For example an operator from mining company B mentioned that she does not have many safety issues at site. However, she proposed to have customized masks for everyone as the masks provided by her employer did not fit her due to her short physique. She brought her mask from her last site as at this site the masks were custom made for everyone. It was suggested that the company should ensure the people are wearing the right PPE that fits them.

In relation to hours of work one of the female water cart operators in mining company B stated:

> *My suggestion is to have continue night shift for two weeks rather than doing a shift change in between and it feel tired. This is not for me personally but for truck drivers. They work for 12 hours and not stop for break. I know when I was driving truck that was hardest time sitting in truck for long. They should have compulsary time to stop and move around. They don't take lunch breaks here, eating while sitting in a truck. I know they have option here but they don't take it but i think they should be made to take it to manage the fatigue but everyone should be given breaks thorughout the day. In my shift I got tired at 3 am and I have lot of friends in mining, they stop for 15 minutes at 3 am and even have park the machine and get out just like to have fatigue management thing for night shift.*

There were other suggestions provided by operators with regards to the role of good rosters and shift timings in order to reduce fatigue. FIFO/DIDO arrangements typically include a mix of 12-hour day and night shifts where workers reside on-site in temporary accommodation for the duration of their work period (between 1–4 weeks) and then return to their usual place of residency during their off-shift period (DeSilva et al., 2011). The operator from mining company B reported that people need to fly into the camp and then commence working the night shift straight away. For this, they needed to be at the airport at 12 midday to check in; they reached site at 3:45pm and then had a quick dinner before starting work for a 12-hour straight work shift. In the participant's view this can cause fatigue. Participants suggested to start the roster with a day shift on the following day to when they reach site. Regardless of the working arrangement, 12 hour shifts negatively impact on work-life balance, making the choice of FIFO less problematic than where the alternative is a 'normal' workday (Gibson, 1994).

Another suggestion provided by a mobile plant operator from Mining Company B was to be acknowledged for the work that he did. This participant stated that in his opinion the hardest challenge down the line in industry was for him to communicate his opinions and suggestions with the peace of mind that what he had to say would be welcomed positively. Similarly in mining company C, the suggestions from the mobile plant operators were that the opportunity to speak and get heard was not available. In response to the above question an operator from mining company C stated:

> *If someone make concern then make sure the concern is acknowledge and we will not gone to get penalised or in trouble about it.*

The operators from mining company C were happy with their rosters, however one of the participants suggested that there should be some events at site which allowed family to visit them. This response was also provided by the mobile plant, production and maintenance supervisors along with safety supervisors at all four mining sites.

2. Group B – Mobile Plant Supervisors

6.6.1 Importance of Safety to Supervisors

This question *how important is safety to you* was asked to mobile plant supervisors who included production and maintenance supervisors along with the safety supervisors' at all four mining sites.

In mining company A one supervisors stated:

Safety is critical and our logo is zero harm.

Similarly another supervisor mentioned that:

Safety is very important and we need to go home.

These two supervisors also replied that safety is number one and first talk of the morning before their crew commenced work. Research conducted by Xia et al in 2018 related to the importance of safety for the site supervisors highlighted that, despite being knowledgeable of safety rules or procedures, supervisors constantly adopt shortcuts in construction projects (Xia et al., 2018). Frontline supervisors often feel pressured to meet productivity demands onsite and are prone to bend safety procedures to complete jobs on time (Conchie et al., 2013). Therefore, it is extremely important for the site supervisors to keep safety as their priority in order to keep themselves and their team safe and they should have enough experience to be able to effectively deal with work pressure.

The importance of following rules and procedures to keep safe was also stated by many participants. One of the safety supervisors from mining company B said that:

> *Safety is very important. It's really pushed into forefront in last ten years as compared to past. I have been in industry for long time and have seen unavoidable incidents so please follow rules.*

A study by Galvin (2016) showed that in companies that have a Board of Directors the Board have the ultimate responsibility for workplace safety and health. He conducted research in the Australian mineral industries and concluded that:

> A Board needs to have a good understanding of the risks that it is charged with controlling and have policies and procedures in place that provide it with assurance that management has developed and implemented systems that are effective for managing these risks. (Galvin, 2016. p. 59)

Supervisors in all mining companies said that they undertake their responsibility keep the workers that they supervise safe. As an example, the supervisors from mining company D described safety as their everyday goal and number one priority. A supervisor from mining company C stated that:

> *Safety is everything for me. It's very important that all my people go home safely, so for me safety comes first. Safety is my value. If you get the safety right then rest of the things come fine.*

Using Word Frequency query on the view of mobile plant supervisors about the importance of safety the most frequent word was *safety* as extremely important. Other frequently used words were *passionate, home* and *people* and *critical.*

Figure 31

Importance of safety to Mobile plant Supervisors

Sinclair et al. (2010) in the United States of America conducted research that identified that the central stakeholders for workplace safety are top management, the immediate supervisors, the workers and their labour union; with the most important being top management and the workers' immediate supervisors as their actions and activities set the priorities regarding safety and health at the workplace. Leopold and Beaumont (1982); Beaumont et al. (1981), Walters and Nichols (2006) all wrote that managers who actively participated in occupational safety and health generally focused on their legal obligation for workplace safety and valued having a safe workplace, safe work procedures and worker's safety and health. Supervisors from mining company D said that safety was their everyday goal and number one priority and illustrated this with the example that supervisors develop pre-start safe operation procedures (SOP) with their employees related to the tasks coming up. Cho and Park's (2011) research results identified that employees' trust in their managers and supervisors enhanced overall safety at their workplace because honest communication about reporting incidents and hazards by safety and health representatives was more likely to occur.

This word cloud (Figure 31) provides validity for the mobile plant supervisors responses as it highlights the view about how important is for the supervisors to keep focus on safety and ensure the team is following rules and procedures to keep safe from any unforeseen injurious situations at work.

6.6.2 Supervisors Refresher Training

Question 5 asked supervisors *how often do you receive refresher training of procedures related to mobile plant safety and operation*? It was identified that there was different type of training regimes in all four mining companies that included online refresher training on computers and for some competencies, there was annual training. Most of the refresher training that supervisors reported was refresher training that they recommended for workers, or regular mobile plant worfokers refreshers training, and not refresher training that supervisors received. When talking about refresher training a supervisor from mining company C stated:

> *For operators, every 12 months they do quick assesment. We do not go full training on piece of equipment which they are operating daily.*

A maintenance supervisors in mining company C stated:

> *Machine training used to every year. Some one train for machine they observe every year.*

It was observed that supervisors in each mining company kept a close eye on the workers in order to achieve maximum safety. A workshop supervisor from mining company D stated that:

> *Our company policy is refresher course after 2 years but as supervisor if I see*

anyone not comfortable with anything I put him directly on the course.

According to the Mines Safety and Inspection Act 1994 of Western Australia, supervisors need access to workers' training and assessment records so that they can confirm a worker is competent before assigning tasks. The worker should be able to access their own training records at any time so that they know what they are deemed competent in as this forms part of a safe system of work. Records of all instructions, training, retraining, assessment or reassessment may be kept electronically and should be made available to the specific worker, their Supervisor and Regulators as required (Mines Safety and Inspection Act 1994, s 9). Maintaining records of training and assessment provided to workers and visitors is an essential element of an effective training system. Records should be kept confidential from other parties (Mines Safety and Inspection Act 1994, s 9).

Past research findings identified that trained safety and health supervisors showed more confidence and abilities, carried out a variety of workplace safety activities and were more ready to work with management and other employees to make their workplace safe and healthy (Garcia et al. 2007; Vanderkruk, 2003; Hillage et al, 2000).

6.6.3 Random Checks

Question 6 asked of Supervisors was *do you perform any random checks with the team to see if they are clear of hazards and risk of harm*? Supervisors from mining company A stated that they do variety of things daily with regards to checks on workers and that included daily tool box, prestart and safety meetings in the morning. Sinelnikov et al. (2015) identified that leadership commitment, support, engagement and a company-wide good communication system were required for successful workplace safety and health management.

A supervisor from mining company A stated:

Yeah, on a daily basis we observe a crew how to work. We do behavioural analysis occasionally and supervisor randomly select crew member and check document related to that.

In answer to the above question, behavioural analysis was one of the tools identified as used during interviews with supervisors in mining companies. Workers' participation in safe work practices can make a significant impact on the prevention of industrial accidents if it receives total support from the management as well. However, when the authorities have acted to implement legislation providing for workers' participation, the employer's first reaction according to Clarke (1982) has been to oppose it on the ground that workers' safety is a managerial prerogative and that any participation by workers in decision-making is an infringement of the prerogative.

There were also number of things identified in response of above question from the Development Superintendent of mining company C who stated:

> *Following things we have instructed our shift supervisors to do it everyday.*
> *1. Meant to go out and review a pre-task risk assessment.*
> *2.To do a safety interaction with team*
> *3. To do CCC (critical control coaching).*
> *We want them to do and implementing these as we have seen improvement in quality of Take-5. Talking to people and guys at the field has made the quality of risk assessment improved.*

Similarly, a study by Patrick (2016) in the health care environment and commercial construction industries was conducted to assess the well-being of employees. Using a workplace inspection instrument, the aim of the study was to identify workplace hazards and to reduce the risk of injury through risk control implementation. Patrick (2016) concluded that workplace inspections identified hazards and if appropriate risk control measures were implemented. This was an important part of workplace safety management in making the workplace safer for the employers and employees.

It was identified after interviewing supervisors regarding this question that there were different techniques being used by four mining companies. They included behavioral analysis, performing leadership in the field analysis that was focused on pre-task risk assessment randomly with any of the workers at site, and to review the filled Take-5 and JHA in order to check if all the columns are filled properly and risks were identified.

6.6.4 Supervisors Authority

Question 7, *do you have authority to stop a task if you feel it is unsafe* was answered by mobile plant supervisors of every mining company who said that everyone at site has authority to stop and we do that when needed at work. The mobile plant supervisors at all mining companies said that during random site visits, checks on initial risk assessment sheets were performed along with the visual checks about how the task is being performed by the operators in the field to check that the tasks were safe to perform. Any unsafe tasks were stopped. Supervisors control the day-to-day work in an area (Victorian WorkCover Authority, 2014). They normally allocate work tasks to be performed, ensure employee competency in performing work, provide information, instruction and training in performing the work safely and supervise the performance of the work and they have the authority to stop a task if they assess it as being unsafe (Victorian WorkCover Authority, 2014).

6.6.5 Supervisors' Challenges

In answer to question 8, *what are the challenges you faced in your job as mobile plant supervisor*, there were five mobile plant supervisors interviewed at mining site A and four of these supervisors responded that the biggest challenge is people management, getting the best out of people safely and to keep check on the workers to ensure that they are following the right procedure. One of the mobile plant supervisors in mining company A reported:

> *The most biggest challenge is getting good quality of people, maintain those people and maintain their motivation.*

Another mobile plant supervisor in mining company A identified the biggest challenge is the *Green Operator*. This is the term is used at mining sites for people new to mining. He said:

> *Green operators are new to mining and from background of hairdressing, labouring, and all of sudden want to jump in truck and previous history is not so good. We try to drive safety cultute as this site has history of incidents.*

Meeting deadlines is also of the challenge identified in response to the above question.

One of the Company B field supervisors stated:

> *Meeting production pressure and meeting targets is a big challenge. All mines say that they do not have production pressure, but there is pressure.*

In mining company C, a mobile plant supervisor said that the distance from the hospital, in the case of a significant incident, was their biggest challenge. He explained that the site has a good emergency management team, but for significant incidents they need to go to Newman by Flying Doctor Service. Working long hours continuously, either one-week mornings or one week nights, was identified by the supervisor from mining company C as a challenge. He mentioned that other sites have 4 days morning and 4 days night but that his company site has a continuous week where employees work 8 days morning or 8 nights. Another supervisor from mining company C identified keeping people focused as a big challenge. He stated that:

> *Big challenge is keeping people focus, I think. They are away 8 days from home and keeping family away so make their mind is to keep the focus. Obviously they are working on big equipment so if their mind is messed up they it will be hazardous.*

A mining company D Supervisor was fairly new to working at the site and the challenge identified by this workshop supervisor during his interview was to keep the team safe and getting the right person for right job. He stated:

> *Making the guys safe, give them right tools to complete the job safely so they return to their families and getting the right person for right job really, now we know everyone but in the start we do not know the still set of everyone so it was a bit challenge that time.*

Machine parts availability was also identified as a big challenge by one workshop supervisor from mining company D. He stated:

> *Parts are the biggest one especially the biggest part availability. We are 3000 km away from Perth so part delivery on time is a big challenge.*

To identify the most common words used by the participants in response of the challenges being faced by them in their role as mobile plant supervisors in the visited mining industry a word cloud was developed. The word cloud (refer to Figure 32) identified that the main challenge for the supervisors was to deal with people.

Figure 32

Importance of safety in view of Mobile plant Supervisors

Key themes were created through the running of *Word Frequency Query* in NVivo 12 software and this *word cloud* shows that *people* was the most frequently stated word by the participants, indicating that the main job of mobile plant supervisors is to train and keep people safe from incidents and ensure compliance of procedures and rules by the team. Supervisors are responsible for the day-to-day management of work in their area of responsibility. These first line managers may coach, mentor, and advocate for employees whose work they supervise (Authenticity Consulting, LLC, n.d.).

Other large key words identified were *job*, *work*, *training*, *truck, operator know*, *time*, *women,* and *right*, indicating that these were frequently used words when describing supervisor challenges. Sinclair et al. (2010) in the United States wrote that supervisors may worry about safety at their workplace because safety-related issues can affect subordinate staff, slow production and increase costs, particularly if work-related fatalities occur.

6.6.6 Unforeseen Circumstances

Question 9 asked *what do you do when your job schedule is upset by unforeseen circumstances*? In answer to this question almost all nine supervisors said that the team encountered situations which stopped their work regularly and these situations included equipment breaking down, uncertain engine failure, hose falling off and hydraulic hook. In these cases the maintenance and workshop team did the repairs with regards to the pre-set priority of equipment return to operation requirements.

6.6.7 How Supervisors Handle Stress and Pressure

In response to being asked *how do you handle stress and pressure?* the response from one of the mining company A supervisors was that this person reduced their stress and pressure by asking for support with office work as he worked with another supervisor so the work could be divided.

Other options described by the supervisors in mining company A were drinking, stay positive, enjoy the company of the people, love doing your work, keep a good attitude, fatigue management, ride a bike, play tennis and use a buddy support system. For example, one of the mining company A supervisors said that:

> *We can only achieve one thing at a time. Several machines break at same time and you do not have enough people to fix it so then it becomes a priority issue. Then we decide which machine will go first. Job is not stress free. Major failure put you under pressure but I stay positive, enjoy the company of the people, love doing my work and keep my attitude good*.

The answers derived from interviewing mobile plant supervisors from mining company B were that stress and pressures were reduced by prioritizing work, having good communication with family and colleagues at site and enjoying a proper sleep. One of the mining company B supervisors stated:

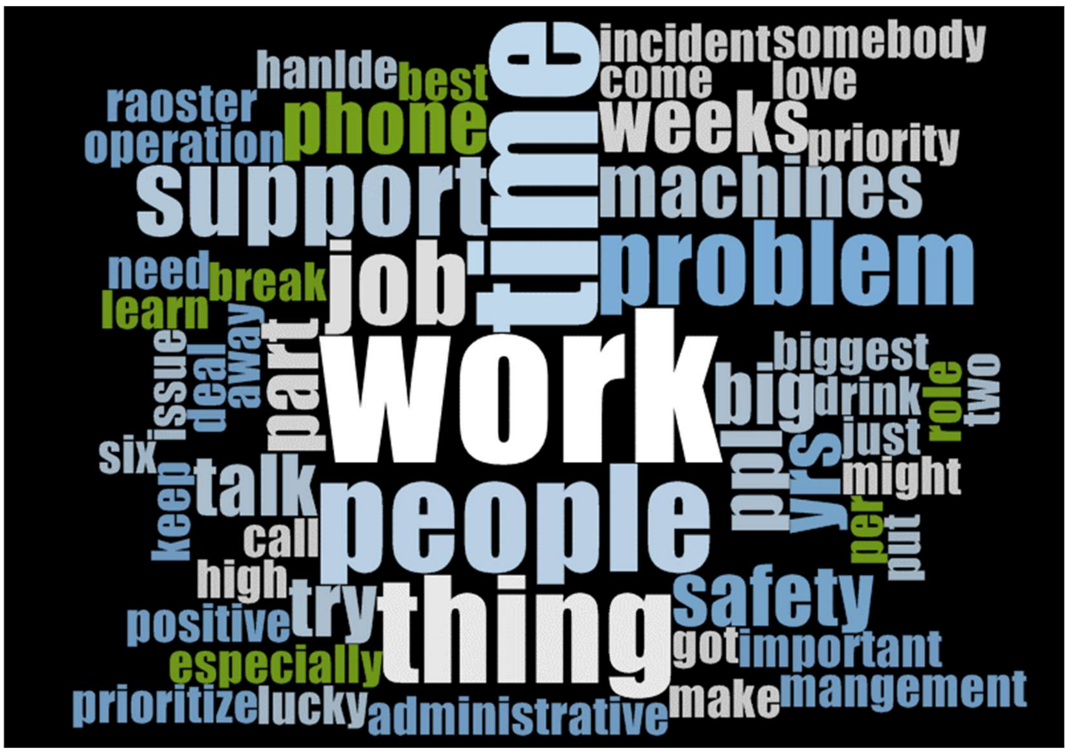
> *While I am at work, I try to get proper sleep. We have good support here. Some mine sites do not have good support but here is really good and we have lot of good people here. The next important thing is have a good laugh and get a bit of help and understanding what the important thing that colleagues understand.*

The stress causing factors identified for a workshop supervisor at mining company D were timely return of priority machines like loaders and water carts and he said that there was always a pressure as the workshop team supports the mining functions. The workshop supervisors in mining company D stated:

> *I do not worry about things which are not in control like if a machine breaks down then I do not stress and focus on safety and just prioritize what I do. That's how I handle stress and pressure.*

Figure 33

Word Cloud indicating the handling of stress and pressure



Key themes created through the running of *Word Frequency Query* in NVivo 12 software and *word cloud* shows that *work, time and people* were the most frequently stated words by the participants indicating that handling people and prioritizing work tasks are major stress causing factors for mobile plant supervisors.

6.6.8 Ensuring that the Mobile Plant is Safe for Use

When *asked what is being done right at your workplace to make sure that the mobile* *plant is safe for use*, the workshop supervisors from visited mining companies said that they have preventive maintenance regimes for every piece of mobile plant equipment and maintenance was being done as scheduled to keep the equipment safe for use. Prior to conducting a risk assessment for every task being done the team discuss any specific hazard related to work in the morning pre-start meeting as well. Supervisors also informed workers that in case of an accident or near miss, proper investigations have to be conducted to comply with Mines Safety Inspection Act 1994. According to the Mines Safety Inspection Act (1994, s. 53)

> in the event of an accident, a dangerous occurrence, or a risk of imminent and serious injury to, or imminent and serious harm to the health of, any person, immediately carry out an appropriate investigation in respect of the matter.

Further, in terms of corrective maintenance, the equipment had been divided into category A, B and C in which category A were the priority machines. This protocol had helped the workshop teams to prioritize tasks and divide the work between team members as per their skills in order to get the work done safely and on time every day.

6.6.9. Hazardous Situation During Work

Question 12 asked *have any of your team members met any hazardous situation during their work and how did they respond to the situation?* One of the supervisors from mining company A answered this question by saying that at work everyday their plans were upset and they had to come up with new plans. Training was described as being a huge part of enabling there to be workplace and work process safety. In company A they have a trainee dump truck operator inside the dikky seat in the excavator so that the new inductee at site can learn safe operating procedures and practically observe the hazards involved while driving heavy machinery at site.

A supervisor from mining company B identified that working near holes, work failures, fires underground due to faulty machinery, mainly in Turbos, and to rescue people from an incident location as the factors which had caused hazardous situation at mining sites.

In mining company C, there were a few incidents, not huge ones, but small incidents and near-misses when the vehicles were too close to the autonomous trucks and a tyre fire on the truck in which the truck completely burned out due to a suspected leak of oil or fuel in the engine. There were no equipment failures mentioned by Company C supervisors as causing hazardous situations.

The workshop supervisor at mining company D shared that in the workshop back strain and hand injuries are common because workers are twisting and turning when doing machinery servicing, repairs and maintenance. He described an incident at site which led to a hazardous situation:

> *Yeah, we had just last week truck slip off from the jacks, the back end of the truck and jacks same time. There was no person or equipment damage. Basically a very big learning from an incident or near miss incident. Now we realize we need to jack the machine at different place and put a stand underneath where we are jacking.*

Supervisors mentioned that support and engagement by them in the field also tends to reduce hazardous situations at sites. Holland et al. (2017) conducted a study with 1,039 Australian nurses. The aim of their study was to examine the relationship between supervisors' support and engagement of employees. This study examined "the direct voice mediated by trust in management" (Holland et al., 2017, p. 925). Data was collected through an online survey and concluded that "supervisor support and direct voice are positively associated with employee engagement, and these relationships are mediated by both supervisory and senior management trust" (Holland et al., 2017, p. 925).

Figure 34

Dealing with hazardous situation at site by mobile plant supervisors

Using Word Frequency query a word cloud was developed to identify the most frequent word query for the dealing with hazardous situations at mining sites. It appeared that the most frequent word was *incidents,* followed by *work, trucks, vehicles* and *risk*. This word cloud highlights the most frequent responses to the above research question. Brownlie (2014) recognised that dealing with hazardous situations, knowledge of hazard identification, risk management processes, ability to represent employees on safety and health issues, communication abilities and interpersonal skills was an expertise power. It was identified that supervisors from all mining companies were well trained to deal with hazardous situations at site.

6.6.10 Supervisors Improvement Suggestions

Question 13 asked *have you any suggestions for improvements to make operating mobile plant safer?* Some valuable suggestions were given by the mobile plant supervisors in response to the request for suggestions to make operating mobile plant safer. In mining company A, the supervisors suggested to improve the mobile plant reception at site as well as positive communication between line managers and workers. When working within the relatively close quarters of a mine site with a FIFO camp, the relationships that develop between co-workers have been reported as an important aspect of the FIFO experience (Beach, et al., 2003; Gillies, et al., 1997; Parmenter & Love, 2007; Watts, 2004).

In mining company B, the supervisor suggested that line managers should spend more time in the field because in her view:

> *If we do not spend time out of office and know the area where people are facing most of the hazards we cannot keep people safe.*

It was for this reason that Lord Robens brought a general duty of care for workplace safety into the occupational safety and health legislation; so that the managers, who represented the employer, could meet with employees, who did the hands-on work, in the workplace safety and health committee meetings to discuss and resolve workplace safety and health concerns (Creighton, 1983).

Increase in emotional intelligence was one of the suggestions given by a supervisor from mining company C to have safer operation of mobile plant. He suggested the introduction of more autonomous mobile plant equipment at site and to have less people at site. The Western Australian mining industry's risk transformation is being driven by the rapid introduction of artificial intelligence (Gray, 2019). According to 2019 reports, there are now more than 350 automated haul trucks in the Pilbara region (BHP, 2019; Fortescue Metals Group Limited, 2019; Jacques, 2019). Since the occurrence of a number of unconventional situations (Department of Mines and Petroluem, 2014), there are signs that the industry is starting to rethink how it approaches the expansion of driverless technology.

Another supervisor from mining company C emphasized the importance of positive communication with the workers down the line to increase mental health. He stated:

> *The role of supervisor is almost 50% psychologist. Especially on FIFO style people come and talk and discuss issues. We really encourage people to come down and discuss. You cannot help the person if you do not know about him. We become family away from home and we do look after people if they are not behaving well by asking questions are u okay? What's going on?*

In a report published by Safe Work Australia (2016b) it is documented that whilst the mining workforce has the highest median weekly earnings in the Australia working population, the roles come at a cost as they are often reported to be related to long, physically demanding shifts in isolated locations away from the workers' homes (Safe Work Australia, 2016b). FIFO/DIDO work arrangements can interfere with home and family life in a number of ways. The physical distance between work and home life can leave some workers feeling like they are displaced from family, friends, and social networks (James et al., 2018).

A fatigue management course for all the workers at site to learn about the effect of sleeping less was the suggestion provided by the supervisor of mining company D. Inadequate sleep (e.g., short sleep duration, poor sleep quality) is linked with adverse physical and psychological outcomes including cardiovascular disease, obesity, diabetes, memory impairment, and depression (Kecklund, 2016).

For fatigue management Safe Work Australia has issued a *Guide for Managing the risk of fatigue at work* (2013). According to these guidelines, when planning work schedules and rosters for specific work arrangements, including shift and night work, FIFO, DIDO, seasonal, on-call and emergency services work arrangements, consideration should be given to implementing additional specific control measures. According to Safe Work Australia (2013), specific control measures may include structuring shifts and designing work plans so work demands are highest towards the middle of the shift and decrease towards the end. Avoiding morning shifts starting before 6am where possible. Avoiding split shifts or if there is no alternative to split shifts consider their timing, for instance whether they are likely to disrupt sleep. Setting shift rosters ahead of time and avoiding last-minute changes, to allow workers to plan leisure time. Allocating shift and night workers' consecutive days off to allow for at least two full nights' sleep including some weekends. Aligning shift times with the availability of public transport or if required, provide alternative transport at the end of a long shift. Overlapping consecutive shifts to allow enough time for communication at shift handovers. Avoiding overtime allocation after afternoon or night shifts. Consider if night work is necessary and rearrange schedules so non-essential work is not carried out at night. Keeping sequential night shifts to a minimum and providing information to shift workers containing tips for them to prevent and manage the risk of fatigue (Safe Work Australia, 2013). In the mining industry it was not possible for management to follow all of these guidelines but following as many as possible would be helpful for worker fatigue management.

Overall suggestions identified were to have an increase in the use of artificial intelligence, more positive communication between peers, better sleep and fatigue management.

6.7 Group C – Mobile Plant Maintenance workers

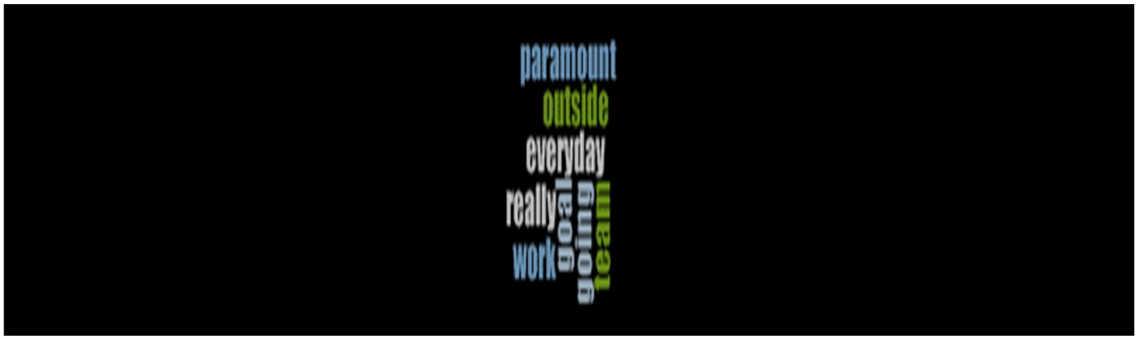
6.7.1 Importance of Safety to Mobile Plant Maintenance Workers

The response to the question *how important is safety to you* from the mobile plant maintenance workers was that their safety was not only important to them but also for their family back home. It was observed that the family back home of the majority participants was a driving factor to keep them safe at work. One of the participants from mining company B stated that:

> *Safety is everyday goal. It's my life and very important to me and I want to go home safe, If I don't feel safe in doing some job I don't do it.*

Figure 35

Mobile plant maintenance workers view of the importance of safety



Using the Word Frequency query on the view of mobile plant maintenance workers about the importance of safety; the most frequent word was *paramount*. Other frequently used words included *goal, every day, really* and *work.* Soehod (2008) undertook a study to assess workers' involvement in safety and health at their workplace. He concluded that workers' involvement was very important, but also important was support from management, training, legal support and trade union support to contribute to having a high standard of safety and health in the workplace (Soehod, 2008). This word cloud provides validity for the mobile plant maintenance participants' responses as it highlights the view of participants about safety as a key focus and the factors that influence their work when promoting safety.

6.7.2. Preventive Maintenance Frequency

In response to the question, *what is the preventive maintenance frequency of mobile plant machinery at your workplace,* the mobile plant maintenance workers from each mining company stated that for each piece of mobile plant equipment there is a set frequency of preventive maintenance (PM). The planning department is responsible for generating the work orders that are then circulated to all concerned departments. In mining company C one of the workers during the focus group interview said that the tentative time for preventative maintenance of trucks and dump trucks was every 500 hours. In mining company D, they make changes and conduct preventative maintenance after 2,000 hours. However, due to companies' privacy policies, detailed documentation of the preventive maintenance regimes for every piece of equipment could not be obtained for assessment. In this regard there is a guideline issued by Department of Mines, Industry Regulation and Safety, Resource Safety (2016e) with the name *Management of mobile equipment maintenance audit – guide*. This audit document included standards associated with the management of mobile plant equipment maintenance used in mining operations. The mobile equipment audit documents had four parts: traffic management, mining operations and equipment selection, surface and underground operations with site deliveries and management of mobile equipment maintenance (Department of Mines and Petroleum 2016b)

The fourth part of this guideline document covered the management of mobile plant equipment maintenance. This part had five elements and included a total of 52 individual standards. This audit document included reference to a wide range of powered mobile equipment including haul trucks, water tankers, industrial lift trucks (forklifts), integrated tool carriers, elevating work platforms, mobile cranes, earthmoving machinery, surface miners, aircraft tugs, light vehicles and other vehicles fitting the title. It included anything that can be driven or ridden on or in but excluded rail mounted equipment and equipment such as bridge and gantry cranes, stackers, reclaimers, ship loaders, locomotives, rolling stock and tethered mobile equipment (e.g. electric shovels, rope driven equipment) (Department of Mines and Petroleum, 2016b).

In part two of this guideline it was documented that there should be an effective routine preventative maintenance program for mobile equipment which is carried out at predetermined intervals of time or distance (Department of Mines and Petroleum, 2016b). The maintenance program is to be developed in accordance with the recommendations of the equipment manufacturer and the maintenance program should cover all the operating functions of the mobile equipment (Department of Mines and Petroleum, 2016b).

6.7.3 Equipment Fault and Failures

Question 6 was *what are the types of equipment fault/failures you deal with for corrective maintenance?* To perform corrective maintenance of heavy machinery in workshops is not an easy task and involved standards and procedures compliance prior to starting the repair work according to the maintenance workers interviewed. The hazards of working with heavy machinery included having to move heavy objects, potential for crushing, pinch points, drilling, uncontrolled equipment movement, working at heights, oil spills, disconnecting hoses, falling objects, energy sources, fixed platforms, isolation checking, isolation and secondary person checking isolation.

During analysis of the Resources Safety Significant Incident Database there were incidents identified in which the mobile plant maintenance workers were involved that show how critical it is for the workers in the workshop to be aware of the hazards involved while doing maintenance work with heavy machinery. For instance, in significant incident number 213, which was a fatal accident, a maintenance worker was pinned by the bulldozer belly plate. This was due to a stored energy hazard as the bulldozer was left uncontrolled with no support installed between the ground and the belly plate and the worker was beneath the belly plate when it fell. During investigations it was concluded there was non-compliance with approved safe system of work when performing any task. It was suggested that area managers should ensure a job hazard analysis or a job safety analysis is completed and risk control measures implemented as required, as well as maintenance workers being trained to recognise sources of stored energy and have access to suitable energy control measures (Department of Mines and Petroleum, 2015).

As communicated by workers during interviews corrective maintenance included maintenance for turbo fires, changing of tyres, hoses, fixing oil leaks etc. However there were also cases of equipment breakdown, mainly due to electrical faults in the machinery. A participant from mining company C said that this included air conditioning breakdowns and batteries not charging.

6.7.4 Mobile Plant Maintenance Workers Challengers

In response of the questions, *what are the challenges you faced in your job as a mobile plant maintenance worker,* participants explained how challenging it is to work on heavy machinery in their workshop. One of participant from mining company B said that while doing corrective work crush points can crush workers to death. Apart from that, working at heights, centre hitch points in the heavy machinery, propers locks, isolation, prior maintenance work, pinch points, lock and roll and set up write, were some of the challenges faced by workers in their workshop.

To have correct tools in place to avoid hazards was one of the challenges discussed by a participant from mining company C. To do repair work on heavy machinery when the air conditioner breakdowns was identified as another challenge by a mining company C participant. He stated:

> *We are in midlle of some job and air con break down. Its midlle of day on excavator, heat is 60 degree Celsius. It is probable the worst thing to do with last summer we had 20 breakdown when it quite hot. Downtime for job is from quick to a 2 or more day job.*

Working away from family, waiting for machines to show up in the workshop and availability of machine parts were challenges listed by participants of mining company D during a focus group interview. One participant from mining company D stated that the workshop team should have good communication with people around them and this included operators and supervisors. Parmenter and Love (2007) conducted a study with Indigenous employees looking into the impacts of the FIFO lifestyle. The study involved a survey of 89 indigenous participants followed by 54 semi-structured interviews. Participants in the study stressed the importance of a workplace culture that fosters relationships between colleagues. In particular, employees valued the opportunity to form new relationships that inevitably arose when working and living with the same individuals over a period of time.

The biggest challenge identified by most of the mobile plant maintenance workers was the proper isolation of machinery and to sign off the isolation procedure with all of the people concerned. For instance, during the data analysis of the significant incident database (significant incident number 243) there was a fatality of a jumbo drilling operator offsider observed when a drill fitter working on a blast-hole drill rig died after being crushed between the drill rod centraliser arm and drill head. The fitter was accessing the drill head when the centraliser arm closed unexpectedly while he was standing on the hydraulically operated break-out tool (HOBO). He sustained fatal crush injuries to the chest and upper abdomen when caught between the drill rod centraliser arm and the drill head. During investigation, the contributory causes of the accident found were that effective isolation had not been carried out prior to conducting the work. The uncontrolled movement of the rod centraliser arm had been identified on pre-start forms in the past but had not been actioned in the maintenance system. It was also found that no task-based risk assessment (e.g. Job Hazard Analysis) was performed for the task (Department of Mines and Petroleum, 2016e). Figure 36 is a word cloud developed from the frequency of the words used by the mobile plant maintenance workers.

Figure 36

Challenges faced by Mobile plant maintenance workers

Using Word Frequency query on the view of mobile plant maintenance workers about the challenges being faced at work, the most frequent word was *shift and night.* Other frequently used words were *big, job, remote, machine, time and female* indicating that that these were all challenges faced.

6.7.5 How Mobile Plant Maintenance Workers Handle Stress and Pressure

The response to question 8, *how do you handle stress and pressure* was much the same as given by mobile plant operators and supervisors that with time and experience people learn how to handle stress and pressure while working FIFO at mining sites. A participant from mining company B said that working in the mining industry is fun, we earn good money and we get used to stress and work pressure.

A participant from mining company C stated that instead of working under pressure they work step by step to perform the repair work with the first instructions being to do the work safely and correctly. He stated:

> *If there is priority and time limit, we load with people to complete it.*

Good communication skills and channels are important to maintaining and improving workplace safety (Espluga et al., 2014). From the literature reviewed, it was concluded that supervisors play a major role in prioritizing work, managing people's workloads, avoiding safety violations and in shaping the norms at work. For instance, Flin and Yule argued that supervisors or leaders have a direct effect on workers through their modelling of unsafe behaviours (Flin & Yule, 2004). Enforcement of safety rules and procedures describes the extent to which strict enforcement and frequent inspections are conducted by managers and safety personnel on the actual implementation of safety procedures and practices (Vinodkumar & Bhasi, 2010)

Participants from mining company D were happy with their rosters and one mentioned that:

> *Roster is very good 8:6 and only daytime working. It's really good. I enjoy being here and spending time here.*

Another participant from mining company D said that:

> *For fatigue managment I drink. I try to be in bed on time and have been in mining*

for 12 years so quite used to stress and pressure.

Figure 37

Handling stress and pressure by mobile plant maintenance workers

Using Word Frequency query on the view of mobile plant maintenance workers about the handling of stress and pressure at work, the most frequent word was *time.* It was identified that having enough time to do work safely was very important. Safety violations can be mainly categorized into routine and situational safety violations based on whether situational constraints (e.g., not having enough time, unavailable safety equipment or adverse environment) are the main causal factors. Specifically, situational safety violations are those provoked by situational constraints that make it impossible to follow safety rules (Reason, 1990).

Previous empirical research has shown that situational and routine safety violations involve different antecedents (Chmiel et al., 2017; Hansez and Chmiel, 2010). For instance, Hansez and Chmiel, 2010 found that routine safety violations are more related to job demands such as work overload (Hansez and Chmiel, 2010). Therefore, it is necessary for the mobile plant maintenance workers to raise the alarm if they feel over-loaded and stressed out with work in order to avoid safety violations while doing work on heavy mobile equipment.

6.7.6 Mobile Plant Safety

Question 9 asked *what is being done right at your workplace to make sure that the mobile plant is safe for use*? Answers included having proper isolation prior to the start of the repair job on heavy machinery in the workshop and this was identified by almost all participants associated with maintenance work in mining companies as being done right at their workplace to make sure that the mobile plant was safe for use. One of the participants from mining company B stated that for isolating equipment there were two tags put on the equipment for safety. One is total isolation and the other is a danger lock. Another participant from mining company C reported that the isolations were checked by two people to ensure the safety of personnel working on the equipment.

A company C participant stated that the release of stored energy was another of the steps being followed to make the equipment safe for working on. In mining company D, the participants stated that the permit to work (PTW) system played a vital role in ensuring safety. On the permit all hazards and necessary precautions are marked after doing physical checks and the permit to work was issued by the supervisors who made sure that the equipment was safe to work prior to issuing the permit. Mining organisations have a number of standardised institutional protections to keep employees safe (Bahn & Barratt-Pugh , 2012). Machine maintenance and repair and the operation of equipment, such as trucks and loaders, were the most dangerous activities. The study by Karra (2006) concluded that worker activities during maintenance and repair of machines should be a top priority in safety programmes.

6.7.7 Mobile Plant Maintenance Workers Safety and Health

Mobile plant maintenance workers' response to question 10, *what is currently being done to ensure the safety of mobile plant maintenance workers at your workplace* was the same as that of the mobile plant operators and supervisors. Traditionally, the responsibility to provide safety in an undertaking for the prevention of accidents lies in the hands of the employer (Blair & Geller, 2000). Walters (2000, 1998a, 1998b) and Versen (1983) asserted that the joint participation of employers and workers is said to be indispensable.

In response to the above question it was answered that there are pre-task risk assessments for every job in workshops that the executor needs to fill in prior to the task. There were daily morning meetings at sites as well conducted by the supervisors to emphasize the safety checks and precautions that need to be taken while working on the job. It is the duty of the employer to provide a safe workplace and safe work processes for workers as documented in the Western Australian Mines Safety and Inspection Regulations 1995. According to this Act, s. 6.2,

> the principal employer, and every other employer, at a mine must ensure that, in respect to any plant in the mine -
>
> (a) a system is implemented to identify any hazards associated with the plant, and assess the risks of an employee being exposed to those hazards; and
>
> (b) all practical measures are taken to reduce those risks.

Respondents did say that, despite risk assessments being conducted, occasionally accidents did occur. According to the Mines Safety and Inspection Act, 1994 (s. 77), the manager must cause to be kept at the mine a book of a type approved by the State Mining Engineer and call the accident logbook and must after the occurrence of any accident ensure a record of the accident is entered without delay in the book. This was reported as being done at all mine sites visited.

The Western Australian Mines Safety and Inspection Act, 1994 (s. 75) also documents that every employer at a mine must establish and maintain a system for the surveillance of the health of their employees in accordance with the regulations to check that miners' work did not adversely affect their health. In the Work Health and Safety Act, 2020 (WA) s.19 it is documented that health means physical and psychological health.

6.7.8. Maintenance Workers' Response to Hazardous Situations

In answer to question 11, *have any of your team members met any hazardous situation during their work and how did they respond to the situation* mining company B underground mine and the maintenance workers said that there are some are maintenance task that they do underground. One of them is changing tyres (front tyres most of the time). The challenge which they come across in this situation is to find a level surface underground for changing the tyre. One of the worker from mining company B stated:

> *If there is truck and it's loaded then you need to wait and see some level surface for changing the tyre, underground. Life is challenging and need experience too for maintenance. Majority maintenance done is above ground and if something is broken and need to bring above ground then it is done underground to bring back in.*

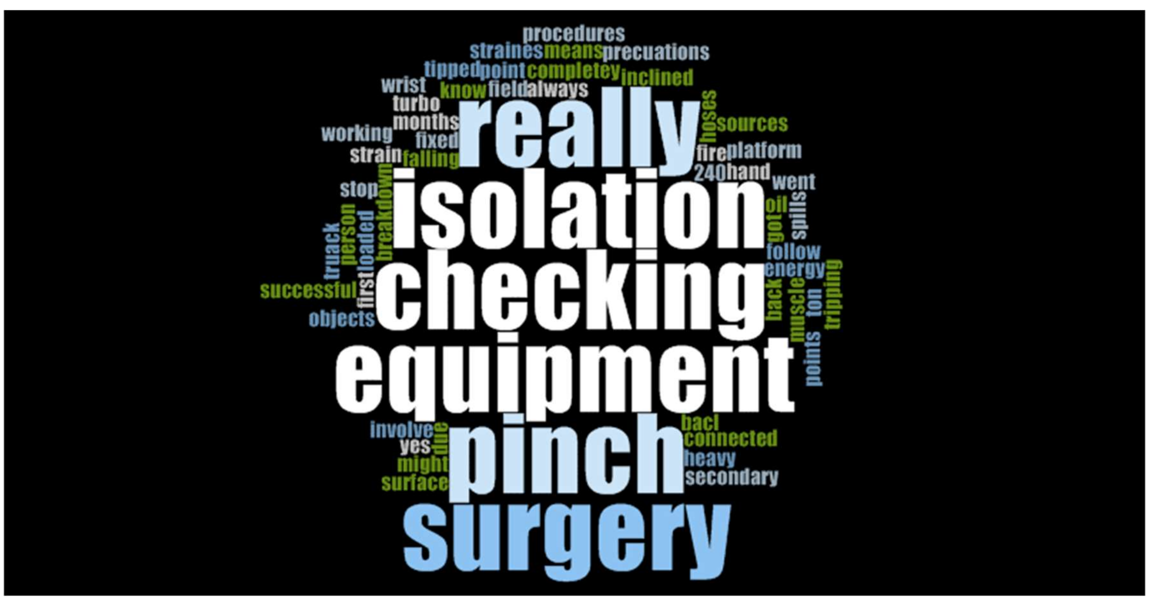
A situation that the maintenance workers dealt with was to bring back the machinery from site to the workshop in cases of a breakdown. One of the workers from mining company C stated:

> *"Most of the time you can drag the machine and sometime do it at site".*

A mobile plant worker from mining company D identified the issue of strains after working on heavy machinery. The majority of the workers responded that they didn't face any hazardous situation at site as they always followed procedures and if they found something dangerous, they reported it and talked to their supervisor.

Figure 38

Response of mobile plant maintenance workers to meeting hazardous situations at work



Using Word Frequency query on the view of mobile plant maintenance workers about meeting hazardous situations at work, the most frequent words were *really, isolation, checking, equipment, pinch a*nd *surgery.* From the word cloud, it is therefore depicted that having proper isolation of machinery prior to starting the job is vital in order to avoid hazardous situations at work as almost all interviewed workers mentioned that proper isolation procedures have been followed for the safety of people at work. In this regard there is a guideline issued by Department of Mines and Petroleum (2015d) with the name *Isolation of hazardous energies associated with plant in Western Australian mining operations.* This guideline was issued under the Mines Safety and Inspection Act 1994 and has been endorsed by the Mining Industry Advisory Committee (Department of Mines and Petroleum, 2015d).

According to this guideline, work performed by maintenance personnel generally requires more complex isolation, and consideration of stored energy sources, such as: accumulators, tensioners, hydraulics, pneumatics, batteries, inverters and solenoids, radiators, tyres. It is documented that where more than one person is performing the work, each person should apply their personal lock and danger tag as a minimum (Department of Mines and Petroleum, 2015d).

This word cloud provides validity for the mobile plant maintenance participants' responses as it highlights the view of participants about dealing with hazardous situations while doing maintenance work on mobile plant equipment in the workshop and in underground mines.

6.7.9 Troubleshooting and Maintenance Refresher Training

When asked *how often do you receive refresher training of procedures related to mobile plant maintenance and troubleshooting* the majority of the participants responded that, for an experienced maintenance worker, formal refresher training is not required as everyday they are working on the same machinery. One of the mining company B participants stated:

> *Guys are working with same piece of equipment all the time. They generally keeping their experience level up. Under the Act the requirment is to maintain competance because they are working with it all the time and not necessarily requirment for them to have formal updated training or refersher training.*

Another participant from mining company B reported that the formal refresher training is after every two years because lots of guys are doing the same type of work every day so they know the maintenance procedures. During a focus group interview with mining company C workers, one of the participants replied that they do not require a lot of training as they work performing the same tasks daily however, diagnosis training was provided when there was the need to learn about a new machine. For example, an auto electrician does not need training unless there is a new machine at site. Past research findings have identified that with regular training workers showed more confidence and abilities, carried out a variety of workplace safety activities and were more ready to work with management and other employees to make their workplace safe and healthy (Garcia et al. 2007; Vanderkruk, 2003; Hillage et al, 2000).

A participant from mining company D reported that most of the time it's not training, its discussion in the morning and a talk on the results of the pre-start risk assessment.

6.7.10 Maintenance Workers Improvement Suggestions

In response to question 13, *have you any suggestions for improvements to make mobile plant maintenance work safer*, a participant from company B reported that they were pretty happy and that everyone is going home safe at the end of their work shift which basically matters most. Suggestions were provided to improve work rosters as it was described as hard when, on the day that the worker comes to site they have to commence working a night shift after dinner. One of the jumbo maintenance workers from mining company B suggested increasing the number of fitters, he stated:

> *Would suggest few more people, fitters. One person doing certain job and for emergency we need to stop on it.*

Identifying the problem of fatigue while working at night, one of the participants of mining company C suggested:

> *I do not like night work and every swing rosters. The thing I would suggest definitly is the guys leaving the site early around 1 am, go back to camp, take shower and jump to bed and then wake up at 8 am, have breakfast and then at site.*

Improvement in food was also suggested by one of the participants of mining company D. He stated:

> *I do bring food for myself because you do not feel like eating same food all the time.*

Other participants from mining company D suggested to have more people on the job, opportunity to speak and get acknowledged, and the timely availability of frequently used parts in workshops.

6.8. Research Question Three

The above data was collected in order to seek to answer the third research question which was *to identify workers' opinions on safety and risk control factors related to the use of mobile plant in their workplace*. Through purposeful discussions and in-depth interviews, rich descriptive data was gathered to analyse the safety and risk control factors in order to prevent injuries in mining workers from mobile plant. In this section the analysis of the data results was through entering the responses derived from interviews related to importance of safety, challenges at workplace and handling stress and pressure at work into NVivo 12 to identify codes and themed categories. The answer to research question three is included in the answers to the questions and sub questions asked and documented in this research report.

6.8.1. Conclusions on the Importance of Safety

During interviews and in focus groups the question regarding the importance of safety was asked to all three groups of participants to investigate the approach of interviewees towards safety and their level of awareness with regards to the hazards involved in the job which they were employed to do at mining sites. This was measured though two sub-questions including:

Q.1 What are your views about safety while working with mobile plant equipment?

Q.2 Being a mobile plant operator at mining sites what is your perspective on safety?

Table 32 documents the codes and themes derived from the participants when they were asked the question *How important is safety to you?*

Table 32

Themes derived from codes related to Importance of Safety

Primary Question	**Secondary Question**	**Participants**	**Nature of Job**	**Direct Codes from interviews**	**Themes derived from codes**
How important is safety to you?	1-What are your views about safety while working with mobile plant equipment?	Mobile plant operators	Operating Bogger, Tele-remote bogger Underground truck Bull dozer, Excavator, Water Cart; Grader	Life Family Rules & Procedures Incidents	Safety is priority Goal of everyday
	2- Being working in mining company with lot of hazards involved, what is your perspective on safety?	Mobile plant Maintenance workers	Jumbo, Underground machinery, Bogger, Bull dozer, maintenance co-ordinator, service co-ordinator, inspection co-ordinator	Goal of everyday, Team, Life	
		Safety Supervisors	Safety & Training co-ordinator, Learning & Development Co-ordinator, Safety supervisor	Priority, Logo, Zero harm	

		Site Supervisors	Field supervisor, Operation supervisor, Maintenance supervisor	First & most, Number one, Critical	

The above table shows that most of the participants understood the importance of safety and how to keep themselves safe while working. The themes identified from question three were "Safety is priority" and "Goal for everyday" as most of the participants considered it vital and the first and important thing to consider at the start of their workday.

6.8.2 Dealing with Hazardous Situations at Work Conclusions

Practical exposure was gained with regards to hazards involved during the operation, maintenance and supervision of mobile plant equipment in four mining companies. Useful information was obtained when the participants were asked about dealing with hazardous situations during work. Answers to this question provided the researcher with in-depth awareness of the types of hazards involved while working with heavy machinery and how to react when an incident happened. The question related to hazardous situations were measured though two sub-questions including:

Q.1 What are the type of hazards you deal with every day as part of your job?

Q.2 Have you met any unsafe/injurious situation at work and how you deal with it?

The same question was asked differently to Safety and Site Supervisors as:

Q.3 Do you perform any random checks with the team to see if they are clear of hazards and risk of harm?

This was asked to understand the role of supervisors at mining sites.

Table 33 includes the codes and themes derived from the participants when they were asked the question: *Did you meet any hazardous situation during your job and how did you respond to it?*

Table 33

Themes Related to Dealing with Hazardous Situations at Work

Primary Question	Secondary Question	Participants	Direct Codes from interviews	Themes derived from codes
Did you meet any hazardous situation during your job and how did you respond to it?	1-What are the type of hazards you deal with every day as part of your job?	Mobile plant operators	Ground conditions, brake failure, Absence of exit plan, Incidents, faulty machinery, Underground fire, sour neck, Soft tissues.	Faulty machinery
	2- Have you met any unsafe/ injurious situation at work and how you deal with it?	Mobile plant Maintenance workers	Crushes, pinch points, Uncontrolled movements, working at height, breakdowns,	Priority rules breaches Lack of positive communication Safety awards
	Do you perform any random checks with the team to see if they are clear of hazards and risk of harm?	Site Supervisors	Windrows, Changing tyres, Slippery surface, fire incidents working at height Roll overs, fall on site due to ramp, pririty rule breaches	

On enquiry about the hazardous situations at work, information was provided about the type of incidents which the participants met while working with heavy machinery and this information allowed a clearer insight of the hands-on injuries and accidents involved in performing the work for the researcher to further analyse and understand the answer to research questions three.

6.8.3 Conclusion on Handling Stress and Pressure at Work

During focus groups and interviews with the participants it was stated that employees learning to deal with stress and pressure at work comes with experience and time. Participants who had more than five years' experience in their job responded that they don't stress out easily and don't rush to handle pressure situations. The question related to dealing with stress and pressure was measured though two sub-questions including:

Q.1 Do you feel stressed while working rostered work hours and how you cope with it?

Q2- Is your job stressful and when do you feel pressure?

Table 34 documents the codes and themes derived from the participants when they were asked the question, *How do you handle stress and pressure?*

Table 34

Themes Related to Ways of Handling Stress and Pressure

Primary Question	Secondary Question	Participants	Direct Codes from interviews	Themes derived from codes
How do you handle stress and pressure?	1- Do you feel stressed while working rostered hours of work and how you cope if stressed?	Mobile plant operators	Experience, Do not rush out, Good working environment, Drink	Set priority and targets
		Mobile plant Maintenance workers	Prioritize work, Drink, Sleep well	Time is the best teacher Participate in recreational activities, good communication, good work sleep balance
		Site Supervisors	Drinking, Stay positive, Enjoy the company of the ppeople, Love doing your work, Keep attitude good, Do fatigue management, Ride a bike, Play tennis, Buddy system, Prioritize work, Good communication with family and colleagues at site and proper sleep	
Is your job stressful and when do you feel pressure?			*All of the answers above are related to how people handle stress and pressure. None are yes or no answers for stress. No answers describe when people feel pressure.*	

The themes derived from analysis of the data using Nvivo-12 were setting priority and targets, time is the best teacher, participate in recreational activities, good communication and good work sleep balance.

6.9 Challenges at Work

Interviews identified that operators, maintenance workers and supervisors have faced different challenges while performing daily tasks. The question related to challenges faced at work was also measured though two sub-questions:

Q.1 In your opinion what is the most challenging thing you face daily?

Q.2 Is dealing with heavy machinery a challenge for you?

The same question was asked differently to Safety and Site supervisors as:

Q.3 Do you perform any random checks with the team to see if they are clear of hazards and risk of harm?

These questions were asked to obtain an idea of the role of safety supervision in keeping the people safe at mining sites.

Table 35 documents the codes and themes derived from the participants when they were asked the question: *what are the challenges you faced in your job?*

Table 35

Themes Derived from Codes Related to Challenges faced at work

Primary Question	Secondary Question	Participants	Direct Codes from interviews	Themes derived from codes
What are the challenges you faced in your job?	1- In your opinion what is the most challenging thing you face daily?	Mobile plant operators	Weather, Family, Learning new equipment, Communicating with others regarding the thing which is not clear.	Dynamic risk environment, Working away from home, Speaking out
	2- Is dealing with heavy machinery a challenge for you?	Mobile plant Maintenance workers	Correct tools, Proper isolation, Family	Equipment isolation, Procedure signoff Lack of positive communication.
	Do you perform any random checks with the team to see if they are clear of hazards and risk of harm?	Site Supervisors	*Need a yes or no answer to performing random checks. Then need an introduction in this column to say that these were the hazards identified.* People, Fatigue, Rosters, Spare parts availability	People Management, Green operators, Fatigue management

For mobile plants operators the main challenges were working in a dynamic risk environment, working away from home and speaking out. However, for maintenance workers the challenges were obtaining proper equipment, isolation, procedure signoff and lack of positive communication. Similarly for supervisors the challenges were people management, green operators and fatigue management.

The four mining companies visited were each at a different location and had a different work atmosphere. Therefore, the challenges have also been further tabulated for each mining company to show each site individually.

Table 36

Challenges Identified-Mining Company A

Challenges Identified –Mining company A	Number	% of 12
Weather – Hard to operate the heavy vehicle in dry or wet weather	2	16.7
Working away from home -Family	1	8.3
Communicating with others regarding the thing which is not clear	1	8.3
To get good quality of people, maintain those people and maintain their motivation	1	8.3
Green Operators	2	16.7
People Management	3	25.0

As shown above, 6 challenges were identified by mining company A participants. The most common challenge was people management.

Table 37

Challenges Identified-Mining Company B

Challenges Identified –Mining company B	Number	% of 8
Fatigue due to tedious nature of work	2	25
To keep yourself physically strong being a female operator to deal with heavy machinery	1	12.5
To do corrective work on heavy machinery and challenges are crush points, heights, pinch points and proper isolations.	2	25
Meeting deadlines and meeting production pressure	1	12.5

Four challenges were identified by the participants of mining company B. The most common challenges were: fatigue due to tedious nature of work and to do corrective work on heavy machinery.

Table 38

Challenges Identified-Mining Company C

Challenges Identified –Mining company C	Number	% of 11
Dynamic Risk Environment	3	27
Learning new equipment	2	18
Operate heavy machinery in soft sand	2	18
Distance from the hospital in case of significant incident	1	9
To keep people focused on job	1	9
Continuous working for eight days in night shift	2	18
Working away from home-Family	2	18
Weather – Hard to operate vehicle in dusty and windy weather conditions	2	18
Correct tools for job in place to avoid hazard while doing repair work on heavy machinery	1	9

Nine challenges were identified by the participants of mining company C with the most common being having a dynamic risk environment.

Table 39

Challenges Identified-Mining company D

Challenges Identified –Mining company D	Number	% of 13
Getting the right person for right job to keep workers safe	2	15.4
Machine parts availability on time in workshop	1	7.7
Working away from home -Family	2	15.4
Waiting for machines in workshop to show up to perform specified task	2	15.4
To ensure the isolations are properly done and sign off isolation procedure with all concerned nominees prior any repair work on heavy machinery in workshop	2	15.4
To have good PR with all the relevant departments for smooth execution of work	1	7.7
Weather- Sun glare and dust while driving heavy machinery	2	15.4

Seven challenges were identified by the participants of mining company D with the most common (15.4% each) being getting the right person for the right job to keep workers safe, working away from home, waiting for machines in workshop to show up to perform specified task and the weather.

6.10 Summary of Suggestions for Improvements

Throughout the focus group interviews and one-to-one interview sessions with the participants, data was collected with regards to suggestions for improvement related to workplace, policies, facilities provided, mental health and fatigue management. Responses from the participants was to summarize to provide suggestions for each mining company. The following section summarises the main suggestions given by the participants of each mining company.

6.10.1 Mining Company A

The research participants of mining company A were asked to give the suggestions for overall improvement that they considered would be effective in promoting good mental health and preventing and preventing employee work-related injury and ill health in their workplace. Table 40 provides their answers:

Table 40

Suggestions for Improvement-Mining Company A

Suggestions –Mining company A	Number	% of 12
Improvement in Rosters	4	33
Increase in Artificial Intelligence	2	16.7
Mandatory work hour breaks	3	25
Opportunity to speak	5	42
Improvement in mobile plant reception at site	6	50
Positive communication between line managers and workers	3	25
Program in which family can visit and meet the onsite workers to increase motivation	1	8

Overall, seven suggestions were identified with the most common being improvement in mobile plant reception at site (50%) followed by opportunity to speak (42%).

6.10.2 Mining Company B

The research participants of mining company B were asked to give the suggestions for improvements that they considered would be effective in promoting good mental health and preventing employee work-related injury and ill health in their workplace. Table 41 provides their answers:

Table 41

Suggestions for Improvement-Mining Company B

Suggestions –Mining company B	Number	% of 8
Customized mask/PPE's for everyone	1	12.5
Opportunity to raise voice and being acknowledged	2	25
Improvement in rosters	3	37.5
Improvement in food	2	25
Start roster with day shift on next day for fatigue management	3	37.5
Line Managers to spend more time in field	2	25
Training for supervisors to reduce administrational burden in order to spend more time in field with team	1	12.5
Increase in number of workers in workshop	1	12.5

Eight suggestions were identified with the most common being to improve the rostered hours of work and to commence the roster with day shift work after workers returned to work from the time away from the work site.

6.10.3 Mining Company C

Similarly, the research participants of mining company C were asked to give the suggestions for overall improvement that they considered would be effective in promoting good mental health and preventing employee work-related injury and ill health in their workplace. Table 42 provides their answers:

Table 42

Suggestions for Improvement-Mining Company C

Suggestions –Mining company C	Number	% of 11
Increase in Artificial Intelligence to make more safer operation of mobile plant	2	18
No work in night shift to reduce fatigue	1	9
More communication between line manager and worker for good mental health	1	9
Job specific titles to be placed in workshop	1	9
Increase in number of workers in workshop	1	9
Family to visit and meet workers onsite to increase motivation	1	9
Opportunity to speak and get acknowledged and not get penalized or in trouble	2	18

Overall, seven suggestions were identified with the most common being to have an increase in artificial intelligence to make operation of mobile plant safer and for the opportunity for employees to speak and get acknowledged and not get penalized or in trouble for doing this when there were safety concerns.

6.10.4 Mining Company D

Table 43 provides the answers of research participants at mining company D when asked to give the suggestions for overall improvement that they considered would be effective in promoting good safety practices and preventing employee work-related injury and ill health in their workplace.

Table 43

Suggestions for Improvement-Mining company D

Suggestions –Mining company D	Number	% of 13
Availability of frequently used parts in workshop	1	7.7
Improvement in food	1	7.7
Increase in number of people in workshop	1	7.7
Standardize PS1 (pre-shift information) for all departments	1	7.7
Mentoring for newcomers at mining site	2	15.4
Confidence to speak with someone who will listen and jump around for help and to guide in right direction as well	1	7.7
More accountability and penalties towards repetition of similar incident by same people	1	7.7
Crew to keep signs/tags on roads of the sites in good condition	1	7.7
Increase in number of ancillary machinery like graders and dozers at site	1	7.7

Overall, nine suggestions were identified. The most common suggestion identified for mining company D was to mentor newcomers at their site to be able to provide education about the safety protocols and provide a friendly environment in order to assist new workers to adjust well to the new working conditions.

6.11 Chapter Summary

At all companies the need for good communication to improve workplace safety was identified. Good communication skills and channels are important to maintaining and improving workplace safety (Espluga et al., 2014). At companies A, B and C there was a need to revise and improve employees' hours of work, but this was not a suggestion for improvement at company D, where employees seemed to be more satisfied with their hours of work. It was observed that at mining company D most of the mobile plant operators, maintenance workers and supervisors were on 8:6 rosters. Apparently after meetings with them at mining company D in order to record their observations and experience, it can be concluded that people are much happier with 8:6 which is providing them a better work life balance and due to this they can concentrate better on their job tasks and requirements.

This chapter has provided information to answer the third research question which was to c*onduct focus group interviews with mobile plant operators to identify their opinions on safety and risk control factors related to the use of mobile plant in their workplace.*

In answering the third research question it was determined that all mobile plant workers had good awareness of safety and risk control factors to keep them and others safe while working at mining sites. However, after performing a detailed analysis of participants' responses, following are the findings summarized with recommendations which would be useful to improve the safety of mobile plant operators to reduce the number of fatalities and incidents related to mobile equipment at mining sites.

1. Shift rosters. Many participants found it hard to cope with the hours of work, especially if working four 12-hour night shifts followed by four 12-hour day shifts and made suggestions to improve rosters to reduce fatigue and mental health issues.
2. Green operators who are less experienced miners and new to mine sites need more site supervision and on the job training to prevent the likelihood of recordable injuries.
3. Customized personal protective equipment for mobile plant operators to keep them safe from hazards.
4. Provide opportunity for employees to speak and raise concerns and trust to be developed by top management and that any concern raised down the line would be acknowledged.
5. Improvement in infrastructure for good quality mobile reception at mining sites which would enable mobile plant operators to stay connected with family while working away from home.

After interviewing site supervisors, it was concluded that site supervisors played a vital role in preventing recurrence of fatal injuries and in creating a safe workplace for mobile plant operators. The biggest barrier preventing site supervisors from spending more time in the field was being preoccupied with the administrative responsibilities at work. One of the mining safety supervisors suggested having an employee trainee for supervisors, not only to help them with recording and other paper work and to reduce administrative responsibilities, but also to give practical exposure of the supervisor's role and responsibilities to new graduates. This will result in the supervisor having time for more focus on site safety issues, training new employees and allow supervisors to spend more time with people in the field for psychological counselling as required to improve the mental health of mobile plant operators. This would allow supervisors to do their field work more effectively and to assist with developing a strong positive safety culture.

This chapter has examined the views of the mobile plant workers at mining sites with regards to safety and risk control measures being followed in order to prevent accidents and hazardous situations at work. Improvement in mental health and psychological wellbeing were identified as one of the risk control factors required in order to improve the safety of mobile plant operators at mining sites.

The next chapter describes the research outcome, summarises the research findings and includes the research conclusions and recommendations.

7. TRIAGE HAZARD IDENTIFICATION AND PREVENTION MODEL

7.1 Introduction

This chapter focuses on the achievement of the fourth research objective which was to develop a "Triage Hazard Identification and Prevention Model" (THIP) to improve hazard awareness and control selection for prevention of workplace incidents associated with mobile plants to contribute to preventing low frequency severe consequence injuries related to mobile plants. It includes how the analysis of Resources Safety Database recorded incidents, mining sites visits, focus group interviews and comparison of risk assessment and prevention techniques have assisted the researcher to achieve this objective. The researcher has also explains how the different areas of the model co-relate to each other, how to use this model to prevent incidents, and how it can benefit mining companies.

7.2 Development of the Accident Prevention Model.

The "Accident Prevention Model" was developed through a journey which commenced when analysing published literature related to mobile plants risk assessments and prevention of incidents and when analysing the Resources Safety Notifiable Incident Database as part of the quantitative analysis for the research. This journey ended with the identification of strategies to promote mobile plant safety while visiting and observing participating mining industries workplaces to conduct focus group interviews, and the analysis of the respondents' answers as part of qualitative data analysis for the research. The diversity of methods of data collection has provided an effective background to identify the current gaps and the need of the developed Accident Prevention Model.

Firstly, in order to achieve the fourth objectives, a comprehensive literature review of published literature was conducted in order to analyse the techniques which could be used specifically in the mining industry for mobile plant operators and workers. Refer to Table-6 in the Literature Review chapter two, which describes the most commonly used techniques until now as the Event and causal factors (ECF) charting, Multilinear events sequencing (MES) and sequentially timed events plotting (STEP), The ‘why’ method, Causes tree method (CTM), Why-because analysis (WBA) and Fault tree method. However, these techniques were mostly related to Risk Assessments with limitations for mobile plant risk assessment and risk control and there was no focus on Accident Prevention.

Further analysis was conducted with regards to Risk Assessment Techniques frequently used in the Australian mining industry (Refer to table-7) and the publications from Baybutt, P. (2013), Elliott & Owen. (1968), Lawley. (1974), Yan & Xu (2019), Eun-Soo Hong et al. (2009), Zhang et al., (2014) and Tay & Lim, (2006) which were reviewed to conduct a comparative analysis of risk assessment techniques with regards to their strengths and limitations. It was concluded that the same techniques have been used, not only in Australia but internationally as well, for the last twenty years with no focus specifically on mobile plant operators. All the methods used had a focus on Risk Assessment rather than Accident Prevention and the assessment methods were lengthy as well. Nothing was found with regards to an overall model which could be used as a one stop shop for all mobile plant workers and their relevant team at site, mentioning all steps right from risk identification to risk prevention and control.

“Future of Risk Assessment” was also analysed in the literature review chapter and publications by Aven et al. (2014) Venkatasubramanian (2011); Pasman and Reniers (2014); Society for Risk Analysis (2015) , Khan et al. (2015), Flage and Aven (2015), Aven (2016), Dekker (2011) ,(Latimer 2015) and Zio (2018) were critically reviewed to recognize the gaps in current knowledge and to obtain ideas for the proposed future pathway of risk assessments. It was identified that although the new technology and latest techniques like autonomous vehicles and tele-remote equipment controlling have been introduced in mining companies, there a still a need for a properly understanding of the dangers and the associated new risks involved which could not be conducted in the form of the existing models or a systematic approach. An in-depth study and findings of the currently used risk assessment techniques has identified a gap and the urgent need to develop an “Accident Prevention Model” because no suitable technique was found which was primarily focussing on mobile plants risk management to prevent injuries and fatalities.

The Resources Safety database was analysed to identify the common cause of mobile plant accidents. In this regard, all notifiable incidents that occurred in the Western Australian mining industry between 2007 and 2020 were examined to perform a comprehensive analysis and graphical representation. The following results related to mobile plant incidents in Western Australian mining industry were extracted from the database that was further used by the researcher to perform an in-depth analysis and graphical representation of the analysis findings. These results were that:

- Total number of mobile plant incidents in the span of 14 years from 2007 to 2020 were 5,767.
- Out of 5,767 mobile plant incidents there were 5,100 surface mining incidents with 13 fatal incidents and 667 underground mining incidents with 3 fatal incidents.
- Highest number of injuries recorded were in the sub-category Truck/Mobile Equipment and that was 2,404.
- 16 fatalities were reported to Resource Safety in Western Australia due to mobile plant incidents between 1-1-2007 and 31-12-2020.

A further, comprehensive analysis (Refer Table-21) of the fatal incidents was also performed by the researcher to find the primary causes of these mobile plant incidents in the Western Australian Mining industry. It was identified that vehicle Collision, vehicle Over-edge, vehicle Rollover and Vehicle Runaway were the major causes of fatalities related to mobile plants and these contributed to 36% of overall incidents related to mobile plants in the Western Australian mining industry. This analysis of fatalities assisted the researcher to identify three major areas to include in an accident prevention model. These areas are proactive identification, prevention, and reactive focus which complement each other in the form of flow-chart in the “Accident Prevention Model”.

Thirdly, to identify what strategies are in place in Western Australian Mining Industry to promote mobile plant safety and specify safety barriers, the researcher visited four mining companies which provided ideas of different types of systematic approaches for the risk management as different methods were being used in different companies. It was observed that each mining company followed a standard approach to risk management that allowed risks to be prioritized and ultimately allowed the companies to have effective application of risk control to maximize the value from operations and drive good business outcomes. There were different pre-start risk assessment techniques being used by mining companies like STAR assessment, Job Safety Analysis techniques, TAKE-5 and JSEA (Job Safety and Environmental Analysis). From the analysis of data and techniques being used in mining companies, it was concluded that although mining companies had customized risk assessment, risk management and risk control standards as per site conditions, protocols, workplace safety management requirements the standards, controls and protocols were not consolidated in the form of single model for the relevant people at site to use.

Overall, the in depth analysis of the risk assessment techniques in the literature review section, analysis of mobile plant incidents for 14 years from the Resources Safety Database and the researcher's practical exposure to hazards related to mobile plant in mining industries when visiting mine sites, talking to mobile plant operators, maintenance workers, safety people and managers helped to develop the outcome model for this research which was the Triage Hazard Identification and Prevention (THIP) model. Some of the Risk Assessment techniques which were seen practically during the visits to mine sites have been used to write the steps in the Pro-active hazard identification focus and pro-active preventive focus columns of THIP model. The next section describes the model developed.

7.3 Triage Hazard Identification and Prevention Model and How to Use It

The term "triage" is derived from the French word "trier" meaning "to sort" and was initially used for sorting food products such as coffee. Its first known medical use was in World War I, when the French used it to apply to the sorting of casualties. Considering the meaning the Triage, this word is used in the proposed model name as well because the intent of the Triage Hazard Identification and Prevention (THIP) model is to provide the preliminarily guidelines to all the users in the mining companies regarding how to access, identify and prevent the hazards prior starting the routine jobs in daily work life.

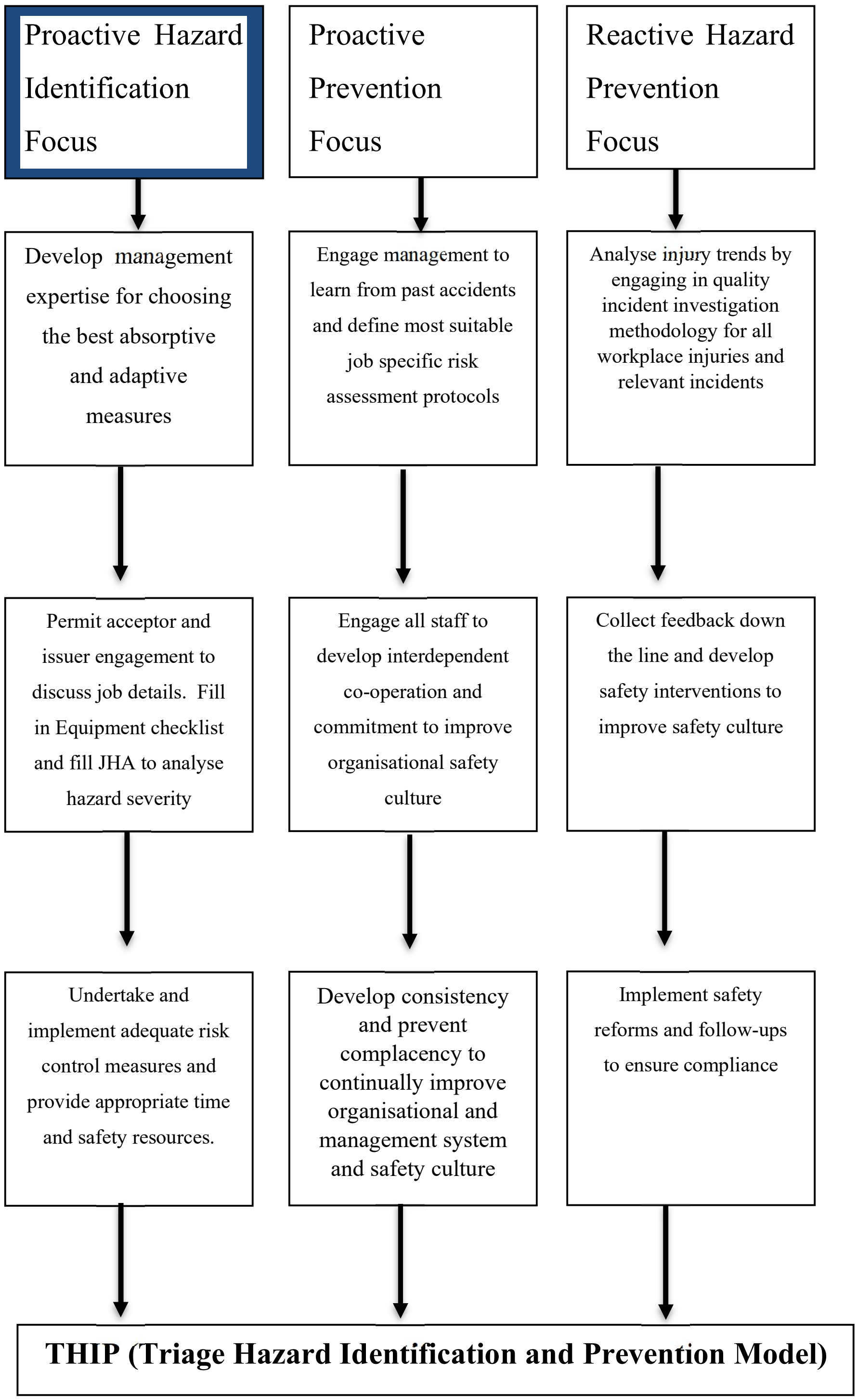
This Triage Hazard Identification and Prevention model was developed for use by the Western Australian mining industry with the intent of enabling the pro-active identification of hazards and preventing workplace injuries and fatalities and it works with the core idea of connecting proactive and reactive approaches. The Triage Hazard Identification and Prevention Model – THIP developed as an outcome of this research is innovative and can be a valuable tool for risk management at mining sites as it provides single platform to the user for performing all relevant checks required with regards to risk assessment and the process is explained simply in a flow chart format.

The model has been developed as a flow chart and is comprised of the following areas that are each complementary to one another:

1. Proactive Hazard Identification Focus.
2. Proactive Prevention Focus.
3. Reactive Hazard Prevention Focus.

Figure 39

Triage Hazard Identification and Prevention (THIP) Model



<u>7.3.1 Proactive Hazard Identification Focus</u>. The first component of the Triage Hazard Identification and Prevention model is to identify the potential hazards while performing the job.

7.3.1.1. First steps in using the model.

The first step of this component can be achieved by developing managers and supervisors' expertise to adopt and choose risk control measures that include a selection of skilled operators for driving the machinery, on-site supervision, and strict operational procedures to control the risks. These measures are primarily linked to companies' policies with regards to defining best suited protocols and procedures and are termed as absorptive capacity.

Zahra and George (2002, p. 185) describe absorptive capacity as the organisation's people's ability to create knowledge and use this knowledge to gain and sustain a competitive advantage for the business to increase profits. Absorptive capacity can be used to explore antecedents and their consequences. Absorptive capacity has four stages.

(1) Acquisition of knowledge.

(2) Assimilation of knowledge.

(3) Transformation of knowledge.

(4) Exploitation of knowledge and resources (Zahra and George, 2002, p. 189).

Using a business profit concept to improve workplace safety is a new use for the concept of absorptive capacity. Absorptive capacity is important for companies to apply the latest external knowledge through learning processes (Lane et al., 2006). Developing managers' and supervisors' knowledge and capabilities would significantly help in reducing mobile plant incidents. Absorptive capacity has also been defined as the capacity to learn and solve problems (Kim, 1997) and as the firm's ability to identify, assimilate and exploit outside knowledge (Cohen & Levinthal, 1990).

Adaptive capabilities and measures are required for identification and assessment of the best possible resources to use (Wang & Ahmed, 2007). This is a reason why selecting suitable adaptive measures would ensure that line managers adapt to the variable requirements, like having a focus on personnel training, not only to improve the operators' ability, but also to reduce the risk caused by operational and human errors, thus ultimately help in reducing the incidents related to mobile plant.

The second step of this component focuses on the importance of the Permit to work (PTW) system at mining sites and involves permit acceptor and issuer engagement to discuss job details, fill in equipment checklists and write a Job Hazard Analysis (JHA) to analyse all identified hazards' possible severity. These steps should assist in preventing the risk from evolving into reportable incidents.

The third and final step of the Proactive Hazard Identification Focus is for management to undertake and implement adequate risk control measures for the safety of mobile plant operators as well as dedicate appropriate time and safety resources considering the nature of identified hazards and risks.

7.3.2 Proactive Prevention Focus. The second component of the Triage Hazard Identification and Prevention model is to list the possible risk prevention methods for identified hazards related to specific jobs to be performed at the mining site.

7.3.2.1 Second steps in using this model.

The first step of this component is to engage line managers and supervisors to learn from past accidents and reportable incidents and define the most suitable job specific risk assessment protocols. Taking unidentified feedback and suggestions from the workers and operators would be significant in terms of identifying mistakes that lead to incidents and injuries. The second step of this component demands the engagement of all staff to develop interdependent co-operation and commitment to improve safety where opportunities are identified for improvement. The third step is most important in this component, and it is to develop consistency and fight complacency among the workers to continually improve organisational and management systems and safety culture.

7.3.3 Reactive Hazard Prevention Focus. The third component of the Triage Hazard Identification and Prevention model is the reactive strategy in case of accidents, incidents and injuries.

7.3.3.1 Third steps in using this model

In this step a quality incident investigation methodology would be applied for the reactive investigation of workplace incidents to analyse the causes of repetitive injuries and accidents. The second part of this would be to collect feedback down the line and develop safety interventions to improve safety culture. The final part of this component is to implement safety reforms and follow up the implementation of these reforms to ensure compliance. The implementation of these actions will impact positively on the prevention of workplace injuries and accidents in the mining sector.

7.4 Implementing the model

The proposed model can be practically implemented in the mining companies as a single platform for all Hazard identification and Prevention protocols and standards. Considering as there are three area that are each complementary to one another, the researcher proposed that companies can merge this with their current Hazard identification and Prevention plans and provide the links of the required procedures under each category. This plan would not only benefit job executers in the field but will significantly assist the supervisors and managers as well. For instance, it can be used as Preliminary assessment chart by all mobile plant's workers in the mining companies. It will benefit greatly if the relevant if all relevant information links are attached under each category of the model. This will allow the user to reach out to the document with the usage of single platform and to know the further steps or guidelines for safely executing the job.

The main idea of developing the Triage Hazard Identification and Prevention (THIP) model was to provide a comprehensive and consolidate platform for all data or protocols required for performing any specific task in the mining environment. It can used by company staff and contractors both as it was observed that lot of contractual or third-party companies were also involved along with company staff at the mining sites. The numbers of contractual staff significantly increased during the plant shutdowns and during equipment's overhauling and during this time extra precaution is required to perform jobs safely. The proposed model is suitable to be used by company staff and contractual as well as the mining companies have same standards and jobs protocols for both.

The first two areas of Triage Hazard Identification and Prevention (THIP) model are "Proactive Hazard Identification Focus" and "Proactive Prevention Focus" primarily focus on the pro-active approaches to be used with regards to Hazard Identification and prevention and these two really complement each other. The researcher's intent to add these two components at the start was to emphasize on the fact the choosing the right people for the job is the key to avoid potential incidents at sites. The first part of "Proactive Hazard Identification Focus" is to "Develop management expertise for choosing the best absorptive and adaptive measures" and it is proposed if the companies could link all their training and development plans specifically related to "Risk Control and Hazard Awareness " in this area and schedule regular meeting at the team leaders and supervisors level to brain storm and approve appropriate risk control measures required for ongoing or specialized jobs at the site. This part is very important as trained and well aware leaders would be able to delegate the best practices among the team and having all relevant links under one tab would help significantly the newcomers and existing team to know these are the practices and these are the protocols for a certain type of job.

The next part of this area is "Permit acceptor and issuer engagement to discuss job details. Fill in Equipment checklist and fill JHA to analyse hazard severity" and to have constructive engagement the researcher has proposed that every responsible individual should have the knowledge and easy access of company's "Hazard Identification and Risk Management "system. During mining companies' visits, it was observed that although all companies have their relevant documentation in place with regards to safety and risk management, however there was no centralized model or framework which is linked with documents specifically required either for operators, maintenance workers, contractors, and team leaders. Therefore, researcher felt the need for a framework which provides baselines for all relevant people at site and with a single click they can access the checklist and documents required for:

- To understand the context and initiating the risk process
- To identification hazard and risk scenarios for the task
- To evaluate risk and assigned ownership
- How to manage risks through implementation of existing and further controls
- Required documentation, communication and reporting of hazard and risk information; and
- Updating hazard and risk information on a periodic basis.

Triage Hazard Identification and Prevention (THIP) model can be therefore be used as a baseline model for the hazard identification and risk management process for a company. While reviewing the individual company's documentation related to safety, it was observed the most commonly use three level of assessments are being used in mining companies which are:

- Level 1 Pre-task hazard assessments, used by all personnel to identify hazards and suitable controls.
- Level 2 Qualitative risk analysis and use of the consequence and likelihood
- Level 3 Quantitative risk analysis

Company's documents related to risk level assessment and identification can be linked with the first area which is "Proactive Hazard Identification Focus" of the model.

Moving to the "Proactive Prevention Focus" area of the model, the first part of this area is "Engage management to learn from past accidents and define most suitable job specific risk assessment protocols" and in researcher's point of view learning from the past incidents would significantly help in the identification of the potential incidents. Fortnightly meetings both at the location and in house specifically with not only with the experienced personal but with the GREEN operators and workers by the supervisors and safety officers would benefit them to have awareness of the hazards and the risks involved in performing their regular tasks. It is proposed that companies should made attendance mandatory in these awareness sessions and to link some quarterly incentive for the mobile plant operators and workers who voluntarily took part in the physical demonstration of the potential and near miss incidents. All relevant documents related to Hazard Improvement and Awareness would be linked through this tab which would again provide the user a single platform for all required data.

The third area of the THIP model is “Reactive Hazard Prevention Focus” and in researcher’s point of view this area is the backbone and the source of developing relevant procedures and protocols for the remaining two areas. This area would actually be led by “Research and Development “ (R&D) teams in companies where the analytics perform regular analysis of injury trends not only in Western Australian mining but in Australia and internationally as well. This can be achieved by engaging the teams in quality incident investigation process on monthly basis and following are the proposed actions for the R& D team:

- It is proposed that the R&D team members can develop a schedule with all production teams at the start of the year and circulate that schedule at the start of year which would enable all teams to know when it is their time for the presentation and discussions. This would provide enough time to the teams to share the potential causes of injuries and incidents in their team and risk control measures used to prevent further incidents.
- It is then proposed that in order to raise awareness specially for the GREEN operators and workers, there is a need to start a special program by the R&D team for having communication sessions with them.
- Assigning the cross-team audits to the workers and leaders by the R&D team and the collection of regular feedback would also assist greatly in terms of gathering realistic feedbacks for the hazard preventions and improvements.
- Based on the injuries analysis, identification of potential hazards and risks by the site teams and from cross team audits, implementation of Safety Reforms and Improvement plan with regular follow ups from the relevant teams by the R&D team to ensure compliance would significantly help to improve the overall safety culture in an organisation.

It is also proposed to use THIP model as a single platform by the companies and to link their existing documentations and plans with the model would provide all users an overall view of the Hazard Awareness and Risk Improvement emphasis of the company.

7.5 Summary and Benefits of Model Use

This chapter has summarized the background working involved which has helped researcher to develop the "Triage Hazard Identification and Prevention (THIP)" as an innovative outcome of this research work. Some of the Risk Assessment techniques which were seen practically during the visits to mine sites have been used to write the steps in the Pro-active hazard identification focus and pro-active preventive focus columns of THIP model. Overall, the in depth analysis of the risk assessment techniques in the literature review section, analysis of mobile plant incidents from the Resources Safety Database and the researcher's practical exposure to hazards related to mobile plant in mining industries when visiting mine sites, talking to mobile plant operators, maintenance workers, safety people and managers helped to develop the outcome model for this research which was the Triage Hazard Identification and Prevention (THIP) model.

Using the framework developed through this research will enable mining companies to improve their safety culture by assessing hazards and risks of causing harm more precisely and in selecting appropriate risk control techniques for mobile plant equipment and operators. However, it is proposed that practical implementation will need to be individualised for each company as each company may have different employment roles and will individualise the documents that they use, but the principles in the model are the same for everyone to use to improve hazard awareness and control selection for prevention of workplace incidents associated with mobile plants to contribute to preventing low frequency severe consequence injuries related to mobile plant.

Implementation of individualised outcome will help companies to provide a single stop place for all documents related to hazard identification, risk control and prevention and most hazard-prone operations, which in turn will help to develop mitigation and improvement plans to treat and prevent unacceptable consequences timely and effectively.

With successful implementation of the most suitable approach, a safe and nearly zero-accident workplace can be developed, which will be a milestone in the history of safety for a company.

The next chapter describes the research outcome, summarises the research findings and includes the research conclusions and recommendations.

8. CONCLUSIONS AND RECOMMENDATIONS

8.1 Introduction

The aim of this research was to improve the safety performance of mobile plant operators in the Western Australia mining industry. To achieve this aim, a quantitative analysis of the Resources Safety Notifiable Incident Database was conducted to determine the causes of mobile plant accidents in Western Australian mining industry between 1/1/2007 and 31/3/2020. Four mining sites were visited to collect information for qualitative analysis and to observe mobile plant in use in mining workplaces to identify what strategies are in place to promote mobile plant safety and any safety barriers. Focus groups and one-to-one interviews were conducted with 44 participants at mining sites to identify their opinions on safety and risk control factors related to the use of mobile plant in their workplaces.

8.2 Conclusions related to the Research Objectives

8.2.1 Conclusions Related to Database Analysis

The first research objective was to *analyse the Resources Safety Notifiable Incidents Database to determine the causes of mobile plant accidents in Western Australian mining industry between 2007 and 2016.* Conclusions related to research objective one were derived after the quantitative analysis of Mines Safety Database. It was identified that the total number of incidents reported to Mines Safety for the 10 years between 2007 and 2016 were 23,405. Analysis identified 4,613 incidents related to mobile plant. Of the reported mobile plant, incidents there were 4,066 surface mining incidents with 8 fatal incidents and 547 underground mining incidents with 3 fatal incidents.

It was identified that 2,217 of the 4,613 incidents were related to vehicle collision, vehicle over-edge, vehicle rollover and vehicle runaway. The highest number of injuries recorded (1,867) was in the sub-category Truck/Mobile Equipment. Analysis in terms of the hazards revealed that the percentage of incidents in the sub-category "Truck- mobile Equipment-NOC" was the highest (41% of reportable incidents). "Truck-mobile collision" had the next highest number with 21%," Light-vehicle collision had 15% and

“Crane-incident” had 11%. The major causes of the 11 fatal accidents related to mobile plant incidents were: vehicle collision; vehicle over-edge; vehicle rollover and vehicle runaway; maintenance procedure deficiency; machinery movement – crush; underground (UG) rock fall; tyres; suspended load. In 2017 - 2018 there were 103,072 surface miners and 8,949 miners working underground (Department of Mines, Industry Regulation and Safety, 2018a).

Notifiable significant incidents were also analysed, as reported in 4.2.4, from 1/1/2017 to 31/3/2020 and similar causes were identified for mobile plant reportable incidents indicating that data saturation was achieved with the previous 10 years’ data analysis. During this time, there were a further five fatalities related to mobile plant use indicating that additional risk control measures were still required to prevent mobile plant fatalities in the Western Australian mining industry. Since this time in July 2020 there was a fatality where a mining contractor drove a loader over the edge of an open stope falling about 25 meters and dying; in December 2020 a worker was hit by a truck at Big Bell underground mine and died and another contractor was fatally injured in June 2021 at the Silver Lake Resources underground operations in Western Australia.

8.2.2 Observation Conclusions

The second research objective was to *observe mobile plant in use in mining workplaces to identify what strategies are in place to promote mobile plant safety and any safety barriers.* The major safety promotion strategies identified were:

1. Strict compliance with completion of the pre-start hazard checklist.
2. Promoting a positive safety culture.

It was concluded that pre-start checklists and safe working procedures for mobile plant equipment were well documented by the mining companies. Award and reward system introduced by the mining companies were observed to result in a reduction of possible accidents and near miss incidents. There were awards for best safety performance of the operators at mining company B, while mining company A gave a cash award to the person nominated by their colleagues for excellence in following safe operating procedures for keeping safety as a top priority while being at work.

Conclusions were that the major safety barriers identified were:

1. Recruitment of mobile plant operators with no previous background in mining or mobile plant specific training
2. Low focus on refresher training.
3. Fatigue due to FIFO rosters in some mining companies.

8.2.3 Interview Conclusions

The third research objective was to *conduct focus group interviews with mobile plant operators to identify their opinions on safety and risk control factors related to the use of mobile plant in their workplace.* Research objective three conclusions related to the use of mobile plant safety and risk control factors were that:

1. Younger age group (18-34 years), male gender, less experienced miners, long shift hours, job dissatisfaction and job stress were strong indicators of the likelihood of recordable injuries

1\. Shift rosters. Many participants found it hard to cope with the hours of work, especially if working four 12-hour night shifts followed by four 12-hour day shifts, and made suggestions to improve rosters to reduce fatigue and mental health issues

8.2.4 Triage Hazard Identification Model

Based on the research findings that included the review of published literature, Resources Safety Notifiable Incident Database analysis, mining sites visits, focus group and interviews analysis results, the Triage Hazard Identification and Prevention model was developed (see figure 39 in chapter seven) for use by the Western Australian mining industry with the intent of enabling the pro-active identification of hazards and preventing workplace injuries and fatalities. This achieved the fourth research objective.

8.3 Research Aim Conclusions

The aim of this research was *to improve the safety performance of mobile plant operators in the Western Australia mining industry*. Conclusions based on the research results are that this can be achieved by implementing the following recommendations.

8.4 Recommendation

Based on the research findings conclusions are that the safety of mobile plant operators while at work is a collaborative effort of not only site supervisors and maintenance teams, but management also plays a vital role in promoting a good positive safety culture at their workplace. Therefore, a safe workplace plays a significant role in sustainable development of the Western Australian mining industry. The following initiatives are recommended to improve the safety of mobile plant workers at the work site:

1. The major causes of the fatal accidents related to mobile plant incidents in the Western Australian mining industry were vehicle collision, vehicle over-edge, vehicle rollover and runaway, maintenance procedure deficiency, machinery movement, crush, underground (UG) rock fall, tyres and also suspended loads. In order to minimize these type of incidents, mine managers should review their site procedures for *spotting* haul trucks and other large vehicles. In general terms, a safe location should be selected for the spotter. This would commonly be a position on the ground, in direct line-of-sight of the driver where the spotter could not be trapped or run over.

1. Mining companies should have more focus on refresher training for mobile plant operators in order to identify and control hazards more effectively. Risk assessment tools that are specific to mobile equipment operations must be regularly updated and enforced to protect the workers at the work site.

2. Workplace managers must ensure that workers are properly trained and experienced enough to operate the equipment /machinery that they will use at the site. It is recommended that a special focus is required in order to train the green operators

to make them aware of the dangers and risks of operating machinery at the mining site. Green operators is the term used for new or trainee mobile operators at mining sites.

3. Customized personal protective equipment for mobile plant operators to keep them safe from hazard. Mobile plant operators should have personalized personal protective equipment such as helmets, gloves, long sleeved shirts and steel-cap boots according to their physique to mitigate or prevent the risk of injury to the upper and lower limbs and to all parts of the body, as required for risk control for the work that they perform.

4. Have a shift roster that can reduce the working hours of mobile plant operators for extended hours on the first day of their shift to reduce the risk of exertion and mental exhaustion while driving heavy machinery at night, if their first shift after returning from leave is working overnight.

5. Introduction of mandatory breaks during 12 hour shifts for mobile plant operators to reduce fatigue and stress since their job is labour-intensive and frequent breaks would allow them to restore their energy and to be able to focus more on their work.

6. More interaction and positive communication between top, lower, all levels of management and all levels of workers, to gain trust with regards to the resolution of problems. Management should welcome feedback and take immediate action to acknowledge and resolve concerns of site workers in order to develop trust and peace of mind at work for mobile plant operators.

7. Recommendations are made to reduce the workload of safety supervisors at mining sites to allow them to spend more time in the field with mobile plant operators and workers. This would allow safety supervisors more time to provide psychological counselling to workers as required in order to reduce their mental stress at work as well as for more vigilant monitoring of the risk assessment protocols being followed

by the workers. Safety trainees should work with the safety supervisors to provide support to supervisors in reducing administrative responsibilities and paper work. This will result in more time to focus on site safety issues and train new operators that would ultimately reduce the number of injuries and accidents due to mobile plant operations at mining sites.

Recommendations for further research are to extend this study and to use and test the Triage Hazard Identification and Prevention (THIP) Model in the mining companies. It is anticipated that implementation of the research findings, the THIP model and recommendations would be of significant benefit for the Regulator, the mining industry generally and that relevant companies could obtain maximum benefit by implementing the THIP model to reduce the occurrence of low frequency-high consequences injuries, improve mining industry workers' productivity and industry profits. The THIP model and the research findings can be used to provide investigators and risk assessment leads research-based information concerning known incidents and injuries related to mobile plant in the mining industry. If the mining companies follow an adequate implementation of the THIP plan, as discussed in chapter seven, then the mining companies should notice a reduction of safety incidents and can aim to achieve zero harm goals at work.

8.5 Summary

This research has been conducted through an analysis of 307 relevant publications, information related to the risk assessment techniques being used in the Western Australian mining industry and causes of mobile plant accidents in Western Australian mining industries. In the literature review, comparisons of Mining Legislative Framework in Australian States and Territories jurisdictions related to risk assessment, safety management system and principal hazard and management system have been included. A major gap identified that there were no specific regulations or a code of practice for mining industry mobile plant, with the exception of autonomous trucks, currently present in Australia.

Quantitative analysis was performed that analysed mobile plants incidents from the Resources Safety Significant Incident Database and identified the major causes of incidents and fatalities related to mobile plant in Western Australia. This research is the first comprehensive study which has investigated and explored the current causes of mobile plant operator injuries and fatalities of mobile plant operators in the Western Australian mining industry using both qualitative and quantitative research methods.

This research has identified safety promotion strategies and major safety barriers for mobile plant workers in the Western Australian mining industry through visiting a representative sample of mining companies and conducting qualitative interviews with managers and mobile plant workers. Findings have made a considerable, novel and significant contribution in helping the participating mining companies to identify the challenges being faced by mobile plant workers and suggestions for improvement at each mining site were made and provided to the mining companies.

The Triage Hazard Identification and Prevention Model (THIP) developed as an outcome of this research is new knowledge as it has combined existing accident prevention theories, and added to these theories through analysis of several thousand de-identified mobile plant incident reports in the Resources Safety Significant Incident Database, through workplace observations, work process observations and through interviews with mining industry employees who use, maintain, purchase, etc. mobile plant equipment. Thus, relevant information was collected related to the hazards involved with mobile plant operation and currently used risk control measures. Using the framework developed through this research would enable mining companies to improve their safety culture by assessing hazards and risks of causing harm more precisely and in selecting appropriate risk control techniques for mobile plant equipment and operators.

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9. APPENDIX

APPENDIX 1

Government of **Western Australia**
Department of **Mines and Petroleum**
Resources Safety

Your ref:
Our ref: A0460/201701
Enquiries: Su Ho - Ph: 9358 8154
Email: su.ho@dmp.wa.gov.au

Dr Janis Jansz
Senior Lecturer
Curtin University
GPO Box U1987
PERTH WA 6845

Dear Janis

PHD PROPOSAL FOR FAIZA MALIK

The Resources Safety Division will support Ms Malik's project on risk assessment as a tool for mobile plant operators by:

1. Providing de-identified data on mobile plant incidents between 2010 and 2016.
2. Keeping industry informed about the project's progress, including final outcomes. This will be done by inviting Curtin University to contribute articles to *Resources Safety Matters* magazine.

These actions will allow the project's learnings to be shared with industry and the promotion of good practices.

Yours sincerely

Su Ho

Su Ho | Acting Manager Support and Development
Licensing and Regulation, Resources Safety
15 March 2017

004753 Safety Corns
Release Classification: -

Level 2, 1 Adelaide Terrace East Perth Western Australia 6004
Postal address: Mineral House 100 Plain Street East Perth WA 6004
Telephone +61 8 9358 8001 Facsimile +61 8 9358 8000
ResourcesSafety@dmp.wa.gov.au www.dmp.wa.gov.au
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RioTinto

Iron Ore
152-158 St Georges Terrace
Perth 6000
Western Australia
T + 61 (8) 9327 2000

Private and confidential

Dr Janis Jansz
Senior Lecturer
Curtin University
GPO Box U1987
PERTH WA 6845

23 May 2017

Dear Janis

PhD Proposal for Faiza Malik

The Health & Safety division will support Ms Malik's project on risk assessment as a tool for mobile plant operators by:

1. Providing de-identified data on mobile plant incidents between 2010 and 2016.

2. Keeping industry informed about the project's progress, including final outcomes. This will be done by inviting Curtin University to contribute articles to *Resources Safety Matters* magazine.

These actions will allow the project's learnings to be shared with industry and the promotion of good practices.

We will provide flights and accommodation at Pilbara site/s as required.

Yours sincerely

SRetallack

Suzy Retallack
General Manager Health & Safety
Iron Ore

5 Whitham Road
PERTH AIRPORT
WA 6105

Locked Bag 42
WELSHPOOL DC WA 6986

Telephone: +61 (0)8 6242 1000
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Ref: PHD PROPOSAL FOR FAIZA OWAIS

11 May 2017

Dr Janis Jansz
Senior Lecturer
Curtin University
GPO Box U1987
PERTH WA 6845

Dear Dr Janis Jansz

Re: PHD Proposal For Faiza Owais

The Resources Safety Division will support Ms Owais's project on risk assessment as a tool for mobile plant operators by:

1. Providing incident data on mobile plant incidents between 2015 and 2017.
2. Supporting the project by covering the costs of Fazia's PPE, flights and accommodation to our operations whilst conducting infield trips to gather data as a part of the project.

These actions will allow the project's learnings to be shared with industry and the promotion of good practices.

Yours sincerely

Jamie Day
Manager Regional Health and Safety

REGIS RESOURCES LTD

Dr Janis Jansz
Senior Lecturer
Curtin University
GPO Box U1987
Perth WA 6845

26 May 2017

Dear Janis

PHD Proposal for Faiza Malik

Regis Resources will be supporting Ms Malik's research on risk assessment as a tool for mobile plant operators.
I understand this research will involve one on one discussion with mobile plant operators and maintenance personnel to determine the challenges and day to day issues with operating and maintaining the equipment.

Along with information and studies taken at other sites it would be expected that the risk of injury to personnel will be reduced through a better understanding of issues faced 'at the coal face'.

Regis Resources are happy to support this initiative and look forward to seeing the results of the study and looking at initiatives to continue to reduce incidents and injuries in the industry.

Regards

Alan Brown
OHS Superintendent
Garden Well Gold Project
PO Box 82, Laverton, WA 6440
[illegible]
[illegible]
[illegible]

Our Reference: IGO Reference

21/06/2017

Dr Janis Jansz
Senior Lecturer
Curtin University
GPO Box U1987
Perth WA 6845

Dear Janis

PHD PROPOSAL FOR FAIZA MALIK

I write to confirm IGO's conditional support of Ms Malik's PhD project entitled "Risk assessment as a tool for mobile plant operators for sustainable development: Lessons from the Western Australian Mining industry."

It is understood that that proposed objectives of the project are:

1. Performance of a statistical analysis of accidents and injuries related to mobile plant in Western Australian mining employees between 1996 and 2016 through analysing the de-identified data in the Resource Safety incident reports database.

2. Exploration of the reasons why injuries related to mobile plant have continued to have a sustained prominent impact on Western Australia mining industry.

3. Develop a "Triage Hazard Identification and Prevention Model" (THIP) to improve hazard awareness and control selection for prevention of work place incidents associated with mobile plant to contribute to preventing low frequency high consequences injuries related to mobile plants.

As per my email dated 27 April 2017, I would like to meet Faiza to discuss the objectives with the intention that they are broadened from mobile plant to include mine site traffic management more generally. Given agreement is reached, I would then like her to visit IGO's Nova mine to engage our on-site safety people. Again, given she wins the confidence of our on-site team, IGO will support her PhD project. This support will take the form of the cost of travel to and from our Nova operation, accommodation, and a grant of $20,000 subject to standard contractual terms.

Yours sincerely

Keith Ashby
Head of Governance & Risk
INDEPENDENCE GROUP NL

APPENDIX 2

Curtin University

Participant Information Sheet

Research Title: Risk assessment as a tool for mobile plant operators for sustainable development: lessons from the Western Australian Mining industry

.

Name of Investigator: Faiza Owais.
I am currently completing this research as part of my Doctor of Philosophy at Curtin University of Technology.

Aim of Research
This aim of this research is to improve the safety performance of mobile plant operators in the Western Australia mining industry

Your role
Your expertise in providing information related to the research topic would be used to assist and to identify the causes of injuries related to mobile plants and to identify the lessons to be learnt in order to avoid accidents.

Resources
For focus group interviews audio tape and printed questions will be provided and used by the researcher.

Consent to Participate
Your involvement in this research is entirely voluntary. You have the right to withdraw at any stage without it affecting your rights or responsibilities. Participants in this research will be asked to complete a Consent Form confirming their consent to participate. At no time will any of the details obtained, be provided or disclosed to a third party to this research. Should a participant wish to inspect their own personal information that is collected as part of this research, the researcher, Faiza Owais, can be contacted on phone number 0469606761 to provide you with access to the documentation. Any clarification regarding the privacy of information or further information related to this research can be obtained from Faiza Owais. The data analysis will take place after conducting focus group interviews.

Confidentiality
Names of research participants will not be recorded to maintain participants' confidentiality. Information obtained and collected from you in relation to this research will be stored and maintained confidentially, with the principal investigator and research supervisor only having access to the information. All electronic data will be stored on a computer and will be password protected with access by the principal investigator only.

All hard copy data will be stored on the Curtin University R-Drive, which is a secured password protected site.

Further Information

This research is conducted as part of my doctoral study through Curtin University. If you would like further information about the study, please feel free to contact me on the phone number 0469606761 or by email faiza.owais@postgrad.curtin.edu.au. Alternatively, you can contact my research supervisor, Dr Janis Jansz, on phone number (61 8) 9266 3006 or by email j.jansz@curtin.edu.au. Curtin University Human Research Ethics Committee (HREC) has approved this study (HREC number HRE2018-0046). Should you wish to discuss the study with someone not directly involved, in particular, any matters concerning the conduct of the study or your rights as a participant, or you wish to make a confidential complaint, you may contact the Ethics Officer on (08) 9266 9223 or the Manager, Research Integrity on (08) 9266 7093 or email hrec@curtin.edu.au.

APPENDIX 3

Curtin University

CONSENT FORM

HREC Project Number: HRE2018-0046

Project Title: Risk assessment as a tool for mobile plant operators for sustainable development: Lessons from the Western Australian Mining industry

Principal Investigator: Faiza Owais

Version Number: Version 1

Version Date: July 2017

1. I have read, the information statement version listed above and I understand its contents.
2. I believe I understand the purpose, extent and possible risks of my involvement in this project.
3. I voluntarily consent to take part in this research project.
4. I have had an opportunity to ask questions and I am satisfied with the answers I have received.
5. I understand that this project has been approved by Curtin University Human Research Ethics Committee and will be carried out in line with the National Statement on Ethical Conduct in Human Research (2007).
6. I understand I will receive a copy of this Information Statement and Consent Form.

Participant Name

Participant Signature

Date

Declaration by researcher: I have supplied an Information Letter and Consent Form to the participant who has signed above, and believe that they understand the purpose, extent and possible risks of their involvement in this project.

Researcher Name Faiza Owais

Researcher Signature

Date

APPENDIX 4

Questions to be asked of Mobile plant Operators:

1. What is your employment position?
2. How long have you performed this type of work?
3. How long have you worked for your present employer?
4. What is the name/type of mobile plant machinery on which you are working?
5. How important is safety to you?
6. What are the challenges you faced in your job as mobile plant operator?
7. Did you meet any hazardous situation during your job and how did you respond to it?
8. Have you faced any machine failure during working?
9. Do you have authority to stop a task if you feel is unsafe?
10. How do you handle stress and pressure?
11. What is being done right at your workplace to make sure that the mobile plant that you use is safe for use?
12. How often do you receive refresher training of procedures related to mobile plant safety and operation?
13. Have you any suggestions for improvements to make operating mobile plant safer?

Questions to be asked of Mobile plant Supervisors:

1- What is your employment position?
2- For how many years have you worked as a mobile plant supervisor?
3- How long have you worked for your present employer?
4- How important is safety to you?
5- How often do you receive refresher training of procedures related to mobile plant safety and operation?
6- Do you perform any random checks with the team to see if they are clear of hazards and risk of harm?
7- Do you have authority to stop a task if you feel it is unsafe?
8- What are the challenges you faced in your job as mobile plant supervisor?
9- What do you do when your job schedule is upset by unforeseen circumstances?
10- How do you handle stress and pressure?
11- What is being done right at your workplace to make sure that the mobile plant is safe for use?
12- Have any of your team members met any hazardous situation during their work and how did they respond to the situation?
13- Have you any suggestions for improvements to make operating mobile plant safer?

Questions to be asked of Mobile plant Maintenance worker:

1. What is your employment position?
2. For how many years have you worked doing mobile plant maintenance?
3. How long have you worked for your present employer?
4. How important is safety to you?

5. What is the preventive maintenance frequency of mobile plant machinery at your workplace?
6. What are the types of equipment fault/failures you deal with for corrective maintenance?
7. What are the challenges you faced in your job as mobile plant maintenance worker?
8. How do you handle stress and pressure?
9. What is being done right at your workplace to make sure that the mobile plant is safe for use?
10. What is currently being done to ensure the safety of mobile plant maintenance workers at your workplace?
11. Did you, or any of your team members, encounter any hazardous situation during your work and if so how did you and/or your team members respond?
12. How often do you receive refresher training of procedures related to mobile plant maintenance and troubleshooting?
13. Have you any suggestions for improvements to make mobile plant maintenance work safer?

APPENDIX 5

<u>Observations to be taken at plant:</u>

These observations would be taken on site over a 6 days period.

1- Types of Mobile plants and their usage at plant site.

2- Permit to Work System at plant site.

3- Hazardous Area Markings and Identification at plant site.

4- Rescue procedures to tackle any hazardous or emergency situation at plant site.

5- Preventive Maintenance, Corrective Maintenance and breakdown maintenance regimes for mobile plant and machinery at plant site.

6- Previous Learning Events related to mobile plants at plant site.

7- Safe system of work for mobile plants at site.

8- Risk Assessment procedures at site.

APPENDIX 6

Traffic Management Plan

Contents

PURPOSE

The purpose of this plan is to minimise or eliminate the risk of incidents or injuries resulting from traffic movements.

7. PRE-START TRAFFIC MANAGEMENT.

1. Identify Hazards

The first rule to minimise traffic hazards is to identify the risk of hazards causing harm. All vehicle drivers initially should identify potential hazards by keeping in mind the following points:

1. Observe the workplace to identify areas where pedestrians and vehicles interact. Check the floor plan of the workplace, if work is done close to public areas, when traffic volumes are higher, where potential blind spots are and check for other areas of poor visibility. Security footage may be useful if available.
2. Regularly report problems about traffic management encountered at your workplace so that the area manager can develop a generic list of hazards.
3. Review area incident and injury records including near misses.

To identify any traffic hazards complete the checklist in Appendix A prior to leaving the site.

1. Access Risks

For all hazards identified, record on the checklist in Appendix A the likelihood of somebody being harmed by this hazard and how serious the harm could be. The risk assessment is then used to determine what action you should take to control the risk and how urgently the action needs to be taken.

Most vehicle incidents at the workplace are from collisions between pedestrians and vehicles reversing, loading and unloading. People who work with, or near, vehicles are most at risk. Customers and visitors may also be at risk.

2. Control Risks

Record planned risk control measures on the Appendix A form and take action to control the risk. The first consideration is whether hazards can be completely removed from the workplace. For example, risks can be eliminated by physically separating pedestrian routes from vehicle areas. This can be done by conducting activities at times when pedestrians are not present, using physical barriers or overhead walkways.

3. Review Risk Control Measures

This action is primarily for management, to consider all possible control measures and decide the practicability for the workplace. Deciding what is reasonably practicable includes the availability and suitability of control measures, with a preference for using elimination, then considering substitution, followed by considering isolation or engineering controls to minimise risks (the upper levels of the Hierarchy of risk controls), before using administrative controls or PPE to minimize risks.

Management must check control measures regularly to ensure they are working as planned, to make sure they remain effective, taking into consideration any changes, the nature and duration of work and that the system is working as planned.

4. TRAFFIC MANAGEMENT

1. Induction and Training

Inductions at IGO site shall include, but not be limited to, the following topics:

1. Personal fitness requirements to operate vehicles.
2. Minimum vehicle safety requirements.
3. Specific site traffic rules.
4. Speed limits around the site.
5. Minimum clearance distances between vehicles.
6. Diagrams, images, descriptions of examples of blind spots of the various heavy vehicles used on site.
7. Training and competency process and requirements.
8. Pre-start check requirements and defect reporting.
9. Two-way radio type and communication protocols.
10. Give way and right of way rules.
11. Three points of contact requirement on accessing and exiting vehicles.
12. Overtaking rules.
13. Standard horn signals and locations/situations where they are to be used.
14. Parking requirements and designated locations for parking.
15. Procedure to be followed if road conditions deteriorate from optimal.
16. Personal protective equipment requirements in vehicles.
17. Isolation and tagging processes.
18. Emergency procedures related to vehicles and vehicle movement.

1. Fitness to Operate Vehicles

A pre-employment medical must be completed to ensure all personnel operating mobile equipment and light vehicles are deemed fit to do so. Factors included in the assessment of fitness to operate include:

1. Any physiological factors e.g. fatigue, illness, dehydration, affected by drugs/alcohol.
2. Any psychological factors e.g. personal problems, stress, depression.
3. Physical suitability to operate equipment e.g. size and weight versus capacity of vehicle.
4. Pre-existing medical conditions that may place an operator at risk whilst operating the equipment.

All employees, subcontractors and visitors shall be made aware of the requirement to be both physically and psychologically fit to be able to operate mobile equipment and light vehicles.

1. Vehicle & Mobile Plant 'Prestart' Checks and Fault Management

All vehicles/machines will have a full pre-start inspection completed by each operator prior to operating. Record of pre-start check shall be kept in all vehicles.

If any faults are found that present a risk to the safe operation of a vehicle or item of mobile plant, that equipment shall be tagged out. The vehicle shall not be operated until repaired and road worthy.

2. Light vehicle requirements

All light vehicles used underground must be operated in low range 4WD, and must be driven only in 1st, 2nd, or 3rd gears when moving forward, or in reverse gear.

Light vehicles are required to give way to loaded production vehicles (e.g. haul trucks), heavy mobile equipment (e.g. loaders or graders), pedestrians, vehicles carrying explosives, or vehicles towing other vehicles or equipment.

The driver of the vehicle that has right-of-way should exercise caution at all times and show consideration to other drivers.

5. ROAD MANAGMENT

1. Road Types

Road on the IGO Nova shall be managed by type. The road types on the IGO Nova operation are:

1. Site Access Roads.
2. Mine Internal Roads – this includes, but is not limited to the following:
1. Bore field and power line service roads
2. Other vehicle operating areas
3. Underground
4. Ore Processing
5. Tailing Storage Facilities
6. Core farm

1. Road Design and Construction

As a general principle, road design shall only be completed by competent and qualified personnel. This determination shall be made by IGO Management. The *Unsealed Roads Manual, Guideline to good practice*, March 2009 (ISBN 1876592 56 7) shall be adhered to during design and construction of roads.

The following key aspects of road design are to be addressed:

7. Type of road surface and materials used
8. Minimum road widths
9. Cambers
10. Ramp/decline gradients
11. Maximum speed limits
12. Speed and traffic control signs
13. Safety barriers
14. Delineator positioning
15. Adequate drainage
16. Flood crossings
17. Roadside marker guides and reflectors
18. Intersections
19. Mixed traffic, and
20. Vision and visibility

1. Road Signage

Roads shall be appropriately signposted with warning signage, traffic signage, and devices to control the speed and movement of traffic within all areas of the IGO Nova Operation.

1. All signs used to direct traffic safely shall be in accordance with Australian Standard specifications, (AS1742-2-2009 and AS1742-4-2008).
2. Personnel are to obey and adhere to all signs related to traffic movement.
3. Signs shall be kept clean and clearly visible as per their intended application.
4. Signs that are damaged, worn out or no longer applicable shall be removed immediately.
5. Designated pedestrian crossings shall have pedestrian crossing signs on either side of the roadway.

1. Road and Parking Area Lighting

Lighting shall be provided where required, as per Australian standards underground including:

6. Workshops
7. Fuel bays
8. Muster rooms
9. Substations
10. Other areas deemed necessary via risk assessment
11. A *Lighting Management Plan* shall be developed and implemented for all large earthmoving machinery parking areas.

1. Two-way Radio Channel

Vehicles shall be fitted with fixed two-way radios prior to operating in any operational area on site.

In cab AM/FM/music playing devices are to be turned down to a low level at all times whilst operating the vehicle so that radio transmissions can be heard clearly.

Pedestrians shall make positive communication with operators if working in close proximity.

Various radio channels are used on the IGO Nova Operation site as set out in the various area specific Traffic Management procedures. It is incumbent on the mobile equipment operator to know what the appropriate channel is for a given work area. If in doubt, speak to the work area supervisor.

2. Warning Signals

The following horn signals shall be used by heavy equipment to indicate that a vehicle is about to start up or about to move off:

12. Engine Start – Signal (sound the horn) once,
13. Moving Forward – Signal twice,
14. Reverse – Signal three times.

1. Parking

Vehicles shall park in accordance with the procedure specified in the site traffic management plan.

Generally, any vehicle may be placed in a fundamentally stable position by parking on flat ground, in a v-drain, against a bund on a gentle downhill slope, or by placing the rear wheels over purpose specific parking humps. Light vehicles can be made fundamentally stable by means of wheel chocking.

Vehicles shall not to be left unattended and running without an operator in the driver's seat.

As far practical, all vehicles must always be parked in a fundamentally stable position. The term "fundamentally stable" means that the vehicle or mobile equipment will not move when the transmission is in neutral and the handbrake is off.

All vehicles shall have designated parking areas for end of shift requirements.

Parking Near Heavy Mobile Equipment

Always exercise caution when there is a need to park a light vehicle in areas shared with heavy mobile equipment such as haul trucks and boggers.

1. There is a 50-metre buffer zone when approaching to park near an unattended or running heavy mobile equipment on the surface.

WARNING! Never Park immediately behind or in front of a haul truck, loader or other heavy vehicle.

1. Safe Distances

The minimum distances between travelling mobile equipment (including light vehicles) for both surface and underground operations is 50m or greater if environmental conditions deteriorate.

Overtaking and Passing on Mine Surface Roads of heavy mobile equipment is hazardous and may be prohibited where:

1. A water cart is operating with its sprays on.
2. The overtaking vehicle has to exceed the speed limit to do so.
3. There is insufficient clear visibility to allow safe overtaking.
4. The road is of single-lane width only or is otherwise not wide enough to allow two vehicles to pass safely.

Always call the driver of a heavy vehicle (e.g. a grader or dozer) to request permission, and obtain clearance, before overtaking.

It is important to:

1. Be aware of sections where overtaking is prohibited.
2. Overtake without hesitation once you have permission and the way ahead is clear.

1. Operating in Adverse Conditions

Driving on Wet Surfaces

Wet, slippery conditions reduce tyre traction. The following guidelines apply:

1. Ensure that the vehicle is in 4WD and that the free-wheeling hubs have been engaged.
2. Reduce speed.
3. Avoid sudden or severe application of either the brake or the accelerator, or any sudden movements of the steering wheel. Smooth driving is the key to safe driving.
4. When descending steep hills, use the same gear going down as you would when going up.
5. Increase your separation from other vehicles, especially heavy mobile equipment such as haul trucks.

Driving in Dusty Conditions

Dust may accumulate in some underground mine areas. The general rules for handling such conditions are:

1. Slow down, especially when visibility is reduced.
1. Keep a safe distance from the dust cloud of the traffic ahead.
2. Arrange for watering-down of dusty sections.

1. Right of Way

The vehicle right of way hierarchy is as follows.

1. Emergency vehicles in an emergency situation have right of way over all other vehicles.
2. Dump trucks have precedence over other mobile plant.
3. Other mobile plant has precedence over light vehicles.

1. Speed Limits

The following speed limits shall apply unless otherwise sign posted and specified in department traffic management plans.

1. Carparks	20km
2. Mine internal roads	40km
3. Mine access roads	60km
5. Decline and associated access road	30km

3.12 Restricted Access

Signage and barricades will be in place to restrict access to areas that may be potentially hazardous, such as damaged or hazardous roadways or work areas deemed to have inadequate ground support, explosives, inadequate ventilation, etc. Where practicable, a hard barrier should be in place so as to prevent inadvertent access.

An escort vehicle must be used if any vehicle is required to travel in an operational area that is not mine management approved.

3.13 Transportation of Personnel

Personnel being transported in any vehicle must:

1. Be seated in a proper seat while the vehicle is moving,
2. Wear a seat belt that is correctly adjusted,
3. Be able to readily communicate with the driver of the vehicle,
4. Travel shall not occur in a vehicle where seat belts are not fitted.

3.14 Windrows

Windrows shall be constructed on all ramps where there is a drop off.

Where roads are in the vicinity of infrastructure such as fixed plant, services, buildings and structures, they must be segregated from these structures by means of windrows, protection bollards or segregation barriers of a suitable type.

3.15 Clearance under Overhead Power lines

High voltage installations and overhead power line corridors shall be identified and installed to prevent inadvertent contact by vehicles and machinery.

At the point of crossing there shall be height limit signage and warning devices installed in such a manner as to provide adequate warning to approaching vehicles of the clearance height required.

No vehicle shall travel within the power line corridor access roads/tracks unless authorised by site's Area Specific Traffic Management Plan.

3.16 Pedestrian Requirements

Pedestrians shall be required to wear the site specified high visibility clothing on IGO sites in accordance with IGO ***GSS2-Personal Protective Equipment and Clothing.***

Pedestrians shall be instructed in, and confirm an understanding of, the standard horn signals used on site.

Pedestrians are required to adhere to all site procedures relating to movement on site by foot.

Pedestrians must give way to all vehicles and mobile plant, except on *Defined Pedestrian Walkways* or in such other circumstances as defined in an *Area Specific Traffic Management Plan.*

3.17 Vehicle Emergencies

The following procedures are used in the event of an on-board fire:

5. Stop the vehicle safely.
6. Apply the park brake.
7. Turn off the ignition.
8. Select first or reverse gear.
9. Use the emergency radio procedure to call for help.
10. Isolate the battery, if possible.
11. Leave the vehicle and remove the hand-held extinguisher.
12. Use the hand-held extinguisher to fight the fire only if trained and if it is safe to do so.
13. Fight the fire from the fresh-air side, making sure you have a safe line of retreat.
14. When the fire is extinguished, stand well clear of the vehicle but do not leave it.
15. Send someone else to report the fire.
16. Follow site emergency instructions.

17. Reference Documents

1. Company Documents and Guidelines

1. IGO GSS9 Traffic Management

2. CMS ST-03 Risk Management

3. IGO GSS3 - Personal Risk Management: ‘Take 5’ & JSEAs

4. IGO GSS41- Remote Area Road Travel

5. IGO GHS1 - Fitness for Work and Wellbeing

6. GO GSS21 - Mobile Plant and Equipment **External Statutes, Standards and Guidelines**

1. Mobile equipment on mines high impact function (HIF) audit, Part 1 – Traffic management 2011, August 2011.

2. WA Road Traffic Code 2000

3. AS2693 (2007) Vehicle jacks

4. AS2615 (2004) Hydraulic trolley jacks

5. AS2538 (2004) Vehicle support stands SAEJ348 (1990)

6. Design, manufacture, and testing criteria for wheel chocks NFPA 1901-03 Wheel chocks (US National Fire Protection Association)

7. IGOGHS1 - Fitness for Work and Wellbeing

8. IGO GSS21 - Mobile Plant and Equipment

9. ‘Unsealed Roads Manual, Guidelines to good practice’, 3rd edition, March 2009 (ISBN 1 876592 56 7)

10. AS1742-2-2009 Manual of uniform traffic control devices.

11. AS1742-2-2009 Manual of uniform traffic control devices for general use

12. AS 1742-4-2008 Manual of uniform traffic control devices - Speed controls.

18. APPENDIX

1. APPENDIX A – RISK MANAGEMENT CHECKLIST

1. How can people and vehicles intersection be minimized?

1. Use interlocking, chicaned or hinged gates that open towards the pedestrian—these methods create a stop or pause in the pedestrian's movement before entering a vehicle area.
2. Use boom gates and proximity devices which trigger boom gates.
3. Provide separate entries and exits for pedestrians and vehicles.
4. Create exclusion zones e.g. forklift-only areas in loading bays or pedestrian-only areas around tearooms, amenities and entrances.
5. Schedule work to prevent mobile plant and pedestrians being in the same area at the same time.
6. Have pedestrian routes which represent paths people would naturally follow to encourage pedestrians to stay on designated safe routes and avoid taking potentially hazardous shortcuts.
7. Remove or identify blind corners using bollards.
8. Use vision panels in pedestrian doors entering vehicle areas.
9. Use staging areas to facilitate alternative load shifting equipment.

10. How can vehicle routes be managed safely?

Provide vehicle routes that are:

1. one-way with enough passing space around stationary vehicles
2. wide and high enough for the largest vehicle using them including their load, taking into account turning circles, stopping distances and the need to reverse
3. flat or only have small slopes - steep gradients which cannot be avoided should be clearly signposted and guarded. Powered mobile plant like forklifts should operate on gradients only if the manufacturer specifies they are able to do so
4. avoid sharp or blind corners

5. well drained, maintained and lit, and free from obstructions, grease, and surface damage
6. Manage queuing vehicles with enough space so queues do not impact on other traffic or block emergency exits. Workplaces with a large number of trucks should consider a queuing time slot system.
7. Use a gatehouse to control traffic time slots.
8. Provide separate areas for tarping, load restraint, load splitting, maintenance and cleaning down.
9. Provide separate entry and exit points for large vehicles.

10. How to keep people safe from powered mobile plant.

1. Use signs to give advance warning to pedestrians and plant operators and to indicate who must give way.
2. Isolate pallet racking aisles.
3. Implement procedures setting out when and how mobile plant operators must give way to pedestrians.
4. Implement systems of work to prevent forward carrying of loads if they obstruct the operator's view.
5. Minimise the number of mobile plant working at one time.
6. Use speed-limiting devices and implement speed limits.
7. Use a combination of audio and visual warning devices like alarms, horns and flashing lights and ensure these are working when the plant is operating.
8. Provide high-visibility or reflective clothing for workers and plant operators and high-visibility markings for mobile plant.

9. How can parking areas be managed safely?

1. Set out parking areas so they are easy to drive in, out of and around in e.g. try to avoid the need for reversing and consider how large vehicles will be able to use the space safely.
2. Use devices like speed humps to slow vehicles down.
3. Prevent parked vehicles from rolling by parking them on level ground, preferably in a designated parking area with the brake firmly applied.
4. Where this is not possible consider installing wheel humps in parking areas to prevent vehicles rolling away.

5. Turn the wheels of the vehicle towards a safe stopping place like a curb or a wall so the vehicle or equipment does not accidently roll away.
6. Chock the wheels of parked mobile plant.
7. Avoid parking smaller vehicles behind large ones or in areas where the driver does not have clear visibility of the vehicle.

10. How to keep people safe from reversing vehicles.

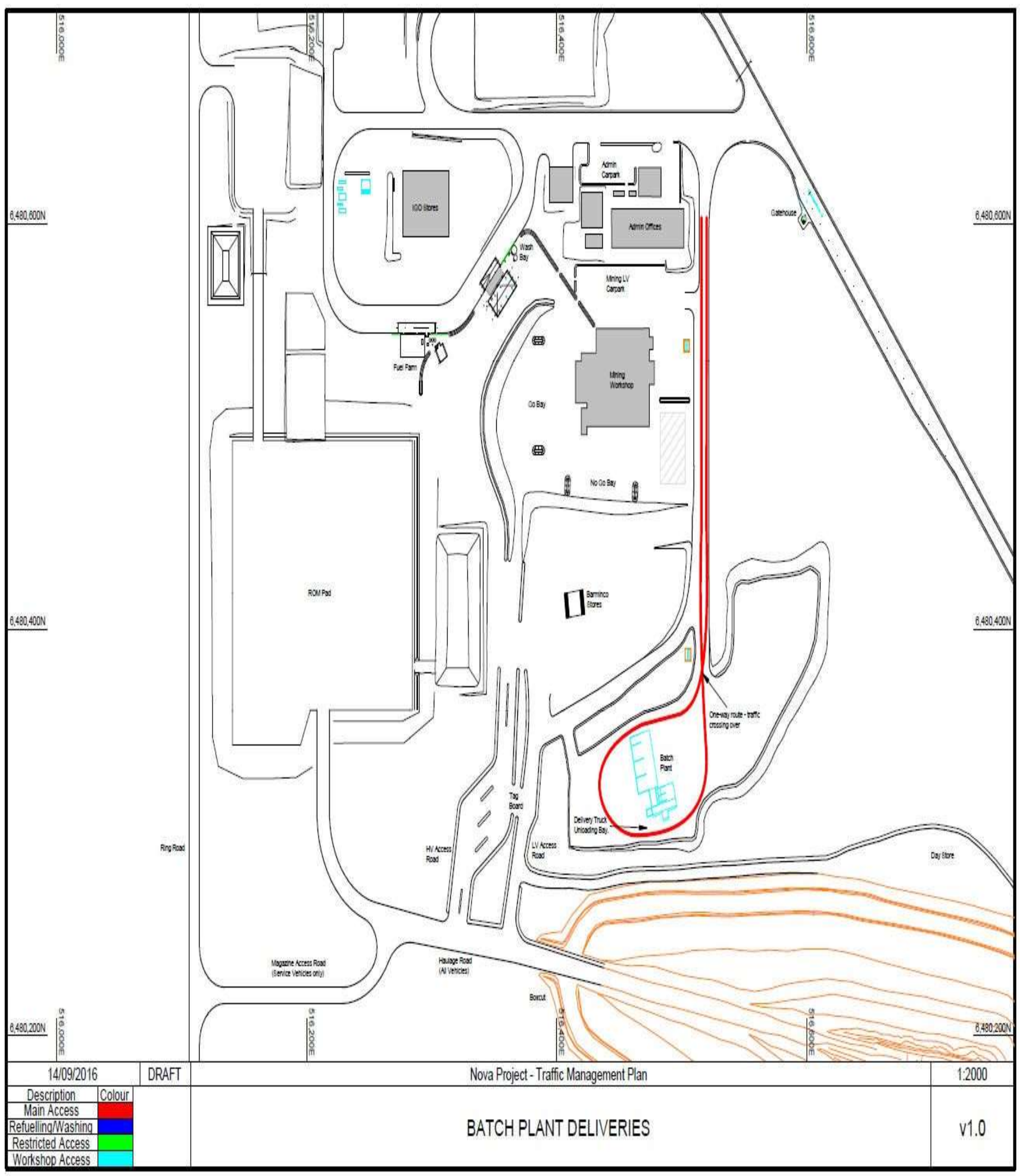
1. Ensure reversing sensors, reversing cameras, rear vision mirrors, fixed safety mirrors and windscreens are kept clean and in working order.
2. Use radios and other communication systems. Fix mirrors at blind corners e.g. convex mirrors.
3. Fit refractive lenses on rear windows to help drivers see ‘blind spots’.

11. What to do to make sure vehicles are safe.

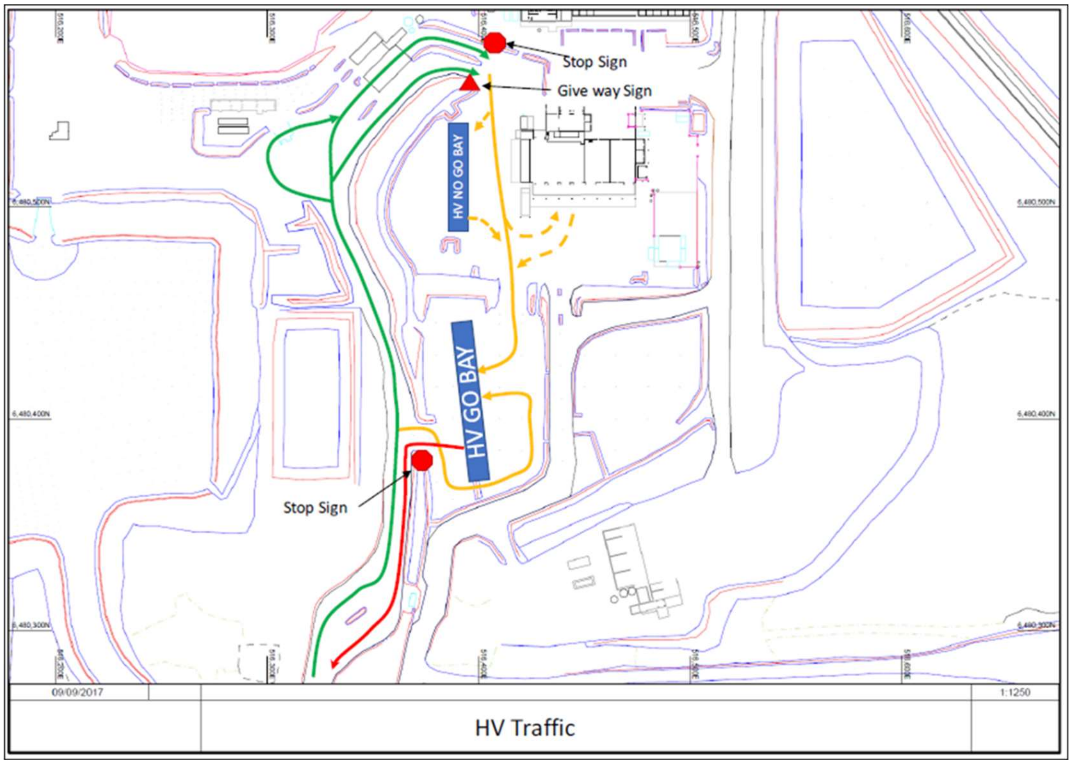
1. Ensure all vehicles are constructed to a company-specified build list.
2. Prior to approval for use onsite a general condition report is conducted to ensure compliance.
3. Maintain the vehicle maintenance schedule as a minimum to the Original Equipment Manufacture specifications.
4. Report faults on all vehicles and powered mobile plant.

5. APPENDIX B – MAP AND OVERVIEW OF TRAFFIC REQUIREMENTS

5.2.1 BATCH PLANT TRAFFIC FLOW (RESPONSIBLE MANAGER – UNDERGROUND MANAGER)



5.2.2 HEAVY VEHICLE TRAFFIC ROUTE (RESPONSIBLE MANAGER – UNDERGROUND MANAGER)



5.2.3 LIGHT VEHICLE TRAFFIC ROUTE