Mixed Methods Approach for Secondary Data Using Survey Reports from an Exploration Industry Database

by

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ABSTRACT

The rich information acquired from incident and near miss reporting has been studied within high-risk industries and such industries have used statistics acquired from past incident reports to reveal trends to improve occupational health and safety. The proposed project aims to understand the specific nature of injury severity reports within Canada's mineral exploration field to enhance existing occupational health and safety. The proposed research is unique as the data arises from the entire mineral exploration industry in Canada, gathered by Prospectors and Developers Association of Canada (PDAC), to represent a group of companies, working across Canada. Data of this magnitude, over such a long time span, in this workforce, has never been conducted before. Much research in H&S in the mining field has focused on mine workers, not on mineral exploration, due to the difference in numbers. It is difficult to extrapolate knowledge from other fields to mineral exploration, because of its high specialization, creating unique H&S challenges. Although closely linked to production mining, Mineral Exploration requires a different health and safety approach. This workforce has unique health and safety needs that arise due to: the nature of the working environment; remote locations subject to extreme weather and terrain; difficulty recruiting skilled workers in times of economic booms due to production pressures or conflicts of interest between H&S superiors and trainees; lack of available resources in the field which vary and are dependent on financial capacities of each company ; and H&S efforts heavily influenced by a company's market capitalization meaning smaller companies often times not having one person specifically in charge of H&S or potentially be less obliged to follow or partake in H&S procedures, and in large companies it is more likely to have a whole group whose sole focus is H&S and the environment. Determining which factors influence health and safety within mineral exploration is therefore a crucial first step to better understand

the safety culture, safety consciousness, and the specific needs of this field. Given that the health and safety environment of mineral exploration is multidimensional, it is pertinent that research be conducted directly within this field to bridge gaps in prevention and practice. The expected outcome for this project was twofold: i) to highlight the health and safety trends in the industry; and ii) to determine common trends, areas of importance, critical issues, and actionable training suggestions, to mitigate risk for workers. This was done by taking survey data and showcasing points for industry and occupational health and safety advocates through knowledge transfer components, to provide a deeper understanding of various components that contribute to injuries and fatalities.

KEYWORDS: Mineral exploration; Health and safety; Occupational injury; Recordable injuries; Incident severity; Heinrich safety pyramid; Safety culture; Risk factors.

CO-AUTHORSHIP STATEMENT

This project was developed in consultation with Dr. Godwin, Dr. William Mercer and Mr. Jonathan Buchanan. Data was provided by the Prospectors and Developers Association of Canada (PDAC), and the Association for Mineral Exploration (AME). Data analyses were conducted by R. Bond with feedback provided by Dr. Pegararo and Dr. Godwin. The thesis document was completed by R. Bond, with feedback and editorial guidance provided by Dr. Godwin, Dr. Dorman, Dr. Mercer.

DEDICATION

This thesis is dedicated to my daughter, Iris Jean, who was the driving force to complete a project of this nature. I hope research such as this contributes to promoting a safer working environment, so when she joins the workforce, she comes home safe and healthy each day.

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GLOSSARY OF ABBREVIATIONS AND TERMINOLOGY

ABBREVIATIONS LONG FORM

AME	Association for Mineral Exploration (formerly AMEBC: Association for Mineral Exploration British Columbia)
CAQDAS	Computer Aided Qualitative Data Analysis
CDDA	Canadian Diamond Drilling Association
CROSH	Centre for Research in Occupational Safety and Health
FOOSH	Fall on Outstretched Hand
GPS	Global Positioning System
HFAC	Human Factor Analysis and Classification System
ICAM	Incident Cause Analysis Method
ICD	International Classification of Disease
IRS	Internal Responsibility System
LBP	Low Back Pain
MOI	Mechanism of Injury
MSK	Musculoskeletal
NOLS	National Outdoor Leadership School
OHS	Occupational Health and Safety
PDAC	Prospectors & Developers Association of Canada
PDA	Physical Demands Analysis
PPE	Personal Protective Equipment
SCM	Swiss Cheese Model
SPSS	Statistical Package for the Social Science
WCB	Workers Compensation Board/Commissions
WHO	World Health Organization

TERMINOLOGY & DEFINITIONS

'Seed words' in relation to Leximancer output: Words provided by the user or automatically extracted from the text which represent the starting point of a concept. Seed words make up the definitions of the concepts, with each concept representing one or more seed words (Version 5.0, 2021, Leximancer Pty Ltd., University of Queensland).

'Concept' in relation to Leximancer output: Individual words or terms that are grouped together with other associated terms in the text. Concepts can be word-like or name-like, and are derived from seed words (Version 5.0, 2021, Leximancer Pty Ltd., University of Queensland).

'Factors' and 'terms' in relation to Leximancer output: Two other expressions that are used to describe concepts.

'Theme' in relation to Leximancer output: A group of concepts that share some commonality through their close proximity on the concept map. Prevalence of each theme is determined by the number of concepts within the theme. Themes are displayed in circles on the concept map, with the size not determined by prevalence, but act solely as boundaries for the concepts within (Version 5.0, 2021, Leximancer Pty Ltd., University of Queensland).

‘Agency’ in relation to Swiss Cheese Model analysis: Otherwise known as hazards and refers to the specific source of which damage or harm was undue to either an individual or property.

Accident: An event, or sequence of events, that results in an injury (Avery (1995); An unplanned event that interrupts the completion of an activity, and that may (or may not) include injury or property damage (Government of Canada, C. C. for O. H. and S., 2023).

Incident: An occurrence, condition, or situation arising in the course of work that resulted in or could have resulted in injuries, illnesses, damage to health, or fatalities (Government of Canada, C. C. for O. H. and S., 2023).

Near Miss or Near Hit: An event that could have caused harm but did not (Government of Canada, C. C. for O. H. and S., 2023); An unplanned event that does not result in injury but has the potential to cause harm to personnel and/or damage to property or the environment under slightly different circumstances (Prospectors & Developers Association of Canada, 2010). It should be noted that some companies are now using the terminology near hit, rather than near miss.

Light Vehicle: Passenger vehicles such as trucks for the purpose of carrying small loads or a small number of passengers. Examples include pickup truck, ATV, UTV, and snowmobile.

CHAPTER 1

INTRODUCTION

This chapter will provide an introductory overview to Canada's mineral exploration field by highlighting the key characteristics within the industry.

1.1 MINERAL EXPLORATION DEFINED

Mineral exploration is the process of the active discovery of various mineral deposits within the earth's crust, which could potentially be extracted to generate profit by turning the location into an active mining site (Roonwal, 2018). The mineral exploration cycle generally consists of a few distinguishable processes that contribute to the discovery of mineral deposits. Each stage of the cycle presents unique challenges and risks, and requires the expertise of various skilled personnel and the use of specialized equipment. Once an area of land has been identified, prospecting and early exploration begins. In the early exploration stage, a multidisciplinary team works together, which can consist of personnel including geologists, geochemists, and geophysicists, and requires tools and equipment, such as topography, geophysical and geochemical maps, aircraft, satellites, and boats or canoes (Sabins, 1999; Roonwal, 2018). These prospecting and early exploration projects can take place on the ground, from the air, or from space, via satellites (AMEBC, n.d.). Once available mineral rights have been acquired and community engagement has been initiated, intermediate exploration is the next component of the cycle, which involves drilling and trenching. Following this stage, the cycle moves into advanced exploration, mineral development, restoration, and finally reclamation. It is evident that all stages of the cycle require diverse personnel and specialized equipment to successfully execute each phase in the mineral exploration process. As such, one exploration site may see many types of occupations: personnel representing various companies and operating specialized machinery; presenting a multitude of risks for the workers involved. For example, contract workers are hired to execute specific jobs such as drilling and geophysical drill hole logging, pilots are required to operate aircraft for the purpose of hauling materials, land mapping and zoning, and other personnel such as boat operators, miners and geologists are needed, amongst other occupations. Due to geological, technical, social, and economical risks, mineral exploration is categorized as a high-risk industry (Eggert, 2010). Further, mineral exploration is a multi-dimensional industry and presents diverse needs in every aspect of the operations, but most notably for this project, it has diverse occupational health and safety (OHS) needs.

1.2 CANADA'S ROLE IN MINERAL EXPLORATION

Canada is a globally recognized leader in mining, with vast mineral sectors consisting of exploration, mining, and related supporting activities (Government of Canada, 2021). Prior to the 1880's, most mineral deposits were discovered by chance amongst people not necessarily employed in exploration, and not necessarily prospectors. Exploration efforts slowly began to spread across provinces and territories within Canada, and by the early 1900's, designated prospectors actively searched for new mineral deposits, classifying this type of work as: mineral exploration. The realization made by prospectors was that Canada's land was rich with metals and minerals, which led to the development of companies, with the purpose of discovering new mineral deposits, which would lead to eventual mine development. Historically, the nature of prospector exploration changed with advancements in technology, including the development of float-equipped aircraft, helicopters, large geophysical survey equipment. Prospecting has also impacted by economic declines and the World Wars (Keeling & Sandlos, 2015). Until the 1950's, Canada's mineral exploration field was considered immature, due to a lack of sophisticated equipment and methodologies. However, it has since developed into one of the world's leading mining nations (Cranstone, 2004). To date, the provinces with the highest exploration and deposit appraisal expenditures are: Ontario, Quebec, and British Columbia. This is due to the geological richness of these provinces and the high economic mineral potential in these locations (Government of Canada, 2019b). However, mineral exploration efforts are carried out in all ten provinces and three territories, with prospecting and exploration ranging in scale between each. Simultaneously, mineral reserves within Canada are declining; while metal and mineral prices and demands continue to increase, causing exploration efforts to expand to locations previously deemed undesirable or economically unfeasible (Vingård & Elgstrand, 2013; Keeling & Sandlos, 2015). It is important to note that mineral exploration activity fluctuates depending on the availability of money to drive exploration efforts, mirroring metal and mineral prices. Maintaining the status of a top mining nation, as well as recognizing the significance of shrinking mineral reserves in key locations, have increased exploration sites and associated efforts in Canada.

1.3 FUNDING SECTORS

Within Canada, there are four groups that drive the mineral exploration field: junior exploration companies, midsize- to major-mining companies, government agencies, and non-classified companies. With respect to this thesis, the dataset includes health and safety reports from groups involved within all four of these divisions. Government agencies refers to provincial/territorial and federal governments, which have geological surveys conducting similar work to mineral exploration. Those health and safety reports are given to PDAC for the purpose of analysis. Similarly, non-classified companies, such as engineering and geoscience consulting firms, also report their health and safety data to PDAC to be analysed within the survey reports.

Junior, midsize, and major mining companies are at the forefront of total exploration and deposit appraisal expenditures in Canada, although each level of mining company brings diverse areas of interest and risk to the mineral exploration field. Government involvement is represented by either the federal or provincial government, where financial incentives are offered for mineral exploration and prospecting. At both levels, financial assistance can include tax incentives, grants, direct, and indirect financial assistance (*Compilation of Financial Incentives For Mineral Exploration In Canada,* 2019*)*. Non-classified companies consist of private individuals and financial institutions.

Since the beginning of Canada's mineral exploration field, junior companies have been at the forefront of prospecting. Initial projects were funded by local business personnel, small businesses and eventually company shares were sold to the public (Cranstone, 2004). Today, junior companies lead in financing mineral exploration: since 2004 they have funded a large and increasing proportion of Canada's exploration efforts, by outspending midsize and major companies, totalling just below 60% of the total share expenditures (Bouchard, 2017).

Junior companies can be poorly financed and specialize in higher-risk and early-stage exploration, relying on financing through issuance of shares and provisions of tax incentives (Klossek & Klossek, 2014). The focus of junior companies is to operate on low costs and acquire profits for the shareholders by, for example, takeover by larger mining companies and/or share price appreciation (Harwood, 2016). A few may go on to become mineral producers, or mining companies and grow from there. Mineral exploration and mining are seen as generally more capital intensive than other industries, simply due to the high costs associated with mine development. For the stages of a mine to succeed, large amounts of funding and intensive exploration are required; this is especially true for junior mining companies that rely solely on external funding (Rudenno, 2009).

Significant global developments in the 1990's, pushing for greater exploration and development around the world contributed to the expansion and merging of major mining companies. Canada's mineral exploration industry reflects these changes, with the merging and acquisitions of medium and large mining companies (Dashwood, 2014). Today, these companies are larger in scale, allowing them to have the necessary resources to bring a mine into production and still create a profit, while continuing to fund further exploration and deposit appraisal projects (Groves & Santosh, 2015; Government of Canada, 2019b). Major mining companies are generally subject to less volatility and perceived to be less risky compared to junior companies. Although different in nature, all company sectors fluctuate with economic trends, and as previously noted, today are aligned with increasing exploration efforts to aid Canada's.

CHAPTER 2

LITERATURE REVIEW

This chapter will provide an overview of relevant literature pertaining to OHS, theoretical frameworks and conceptual ideologies relating to the mineral exploration field.

2.1 INCIDENTS

For the purpose of this study, the term incident will be used to cover both 'accidents' and 'incidents'. The word accident can imply that the event was related to fate, otherwise known as an 'act of god'. Health and safety research has shown that determining the root causes of accidents reveal they are not related to fate or chance, but rather related to many events that could have been predicted or could have been prevented had the right actions been taken (Government of Canada, C. C. for O. H. and S., 2023).

Incidents within the workforce affect more than just the casualty; a ripple effect is seen throughout the organization with impacted mental health, reduced team morale, stigmas developing between workers and can result in financial burden for stakeholders (Hrymak et al., 2007). Within OHS, two main factors should be considered when evaluating incidents: individual and organizational factors (Oliver et al., 2002). Either factor alone, can result in the occurrence of an incident; however, in some circumstances, both individual and organizational factors interact, to create a more complex incident.

Incidents are multidimensional and can be initiated by a chain of events that can include factors such as technical issues, social constructs, the physical environment, and human failures (Bjerkan, 2010; Brown, Willis & Prussia, 2000; Clarke, 2006). Reason (1998) notes the distinguishable characteristics between individual and organizational factors lies within the nature of the agent and the injured worker and involves the levels of standards assigned for the barriers and safeguards that are intended to protect the people and stakeholders. He continues to define factors that separate the two categories. Individual incidents are more likely to occur compared to organizational incidents, and are categorized as low-frequency, rare events. The hazards involved in individual incidents are close to the worker who often has non-existent or limited defences in place, with limited scope of consequence, as the spread of the incidents is small. Whereas organizational incidents have widespread consequences, as generally whole systems are affected. The hazards present in organizational incidents are generally protected against, due to the involvement of complex systems that enforce ‘hard’ and ‘soft’ defenses. High-risk industries place greater emphasis on organizational incidents and factors, as organizational prevention practices have larger protective effects (Clarke, 1999). With this, the mineral exploration field is a relatively young industry and should develop a comprehensive organizational safety program, which should encompass prevention for both types of incidents.

2.1.1 INCIDENT CAUSATION

The literature presents various models regarding incidents etiology, each placing emphasis on different causation theory leading to incidents. These incident causation models have been used within organizational systems to assess the mechanisms in place that could lead to an incidents occurrence. These models attempt to explain how the factors involved in an incident can be traced back to determine the “root causes” of the incidents; and understanding the root causes should enhance incident prevention strategies (Sklet, 2004; Goh, Brown & Spickett, 2009). There are two main classifications of incidents causation models, single factors theory and multiple factors theory. The single factors theory of incidents causation is best described as the Domino Theory models. There are multiple models relating to the Domino Theory, however the most notable models were initially proposed by Heinrich in 1931, and later enhanced by Bird and Loftus in 1976 (Katsakiori, Sakellaropoulos & Manatakis, 2009; Toft, Dell & Hutton, 2012). Each variation of the Domino Theory model explains a different representation of the causes of incidents; however, all models follow the premise that incidents occur in three phases. These three phases are pre-contact phase, referring to the series of events leading up to the incident, contact phase which refers to the moment in time when the incident occurs, and post-contact phase, which refers to the implications of the incident (Toft, Dell & Hutton, 2012). The model premise revolves around the notion that removing one of the factors within the linear chain of events will reduce the likelihood of an incident. As this model was later tested, it was determined the weakness of this model lies in the unidirectional sequence of events; as the occurrence of incidents often involves multiple casualties relating to both human and organizational defenses (Katsakiori, Sakellaropoulos & Manatakis, 2009; Poor Sabet et al., 2013; Toft, Dell & Hutton 2012).

The reality is that workplace incidents do not operate on a linear spectrum but are rather due to a combination of mutually interacting socio-technical variables (Toft, Dell & Hutton, 2012; Patriarca et al., 2020). Upon this realization, the second classification of incidents causation models were invented, known as multiple factors theory. There are various models that follow this ideology, such as the 4 M's theory invented by Brauer in 1990 (Brauer, 2006), the Systems Theory invented by Firenzie in 1978 (DeCamp & Herskovitz, 2015), and the Swiss Cheese Model (SCM), invented by Reason near the end of the 1980s (Reason, 1998; Larouzee & Le Coze, 2020). Of these, the SCM was chosen for the purpose of the paper. Critics have argued about the limitations of the SCM, including its simplistic vision of incidents and the degree of generality it holds by limiting usefulness in practice; however, many still consider that the SCM remains a relevant model, because of its foundations rooted in systemic macro visualisations of incidents and its sustained use in high-risk industries (Larouzee & Le Coze, 2020). The value within the SCM is found in its ability to create meaningful visual heuristics that can be conceptualized and utilized within high-risk industries. The discrepancies between the critiques and the support for the model underlines the need to keep imagining alternative theories that better explain accidents. The SCM model focuses on the interactions between latent and active failures, and how an incident can occur when these failures are perfectly aligned (Reason, 1998). Active failures are unsafe acts that directly relate to the incident, whereas latent failures are factors within a systemic organization that are otherwise undetected until revealed by either an incident or type of regulatory process such as an internal audit (DeCamp & Herskovitz, 2015; Reason, 1998; Toft, Dell & Hutton, 2012). Every layer within the model represents defences within an organization that are meant to protect against failures, whereas the holes in the layers represent active failures and latent failures. This model recognizes that incidents are not solely the result of an individual error but include factors that lay within organizational systems; this is important to note, because it demonstrates that a pro-active involvement from top management systems has the potential to reduce the prevalence of latent failures, thus reducing the likelihood of an incident (Katsakiori, Sakellaropoulos & Manatakis, 2009; Toft, Dell & Hutton, 2012; Lenné et al., 2011). The Swiss Cheese Model is the most applied model within organizational OHS systems as it reflects a positive shift within incident causation by promoting safety culture and a no-blame, systemic, latent failure approach that focuses on hazards and defences, rather than placing blame on the individual (Reason, 1998; Toft, Dell & Hutton., 2012).

Several frameworks have been applied to understand the specific factors that contribute to types of incidents in high-risk occupations. One of the most common frameworks for analysis of classification levels is the Human Factors Analysis and Classification System (HFACS) (Reason, Hollnagel, Paries, 2006; Shappell et al., 2017; Lenné et al., 2012). This model evaluates four levels of failures that contribute to incident occurrence: (1) unsafe acts, (2) preconditions for unsafe acts, (3) unsafe supervision, and (4) organisational influences (Madigan, Golightly & Madders, 2017; Reason, Hollnagel & Paries, 2006). Typically, HFACS is used retrospectively in incident analysis and reporting, relies on the four failures within Reason's Swiss Cheese Model, and serves as a tool for assessing human factors within incident causation (Shappell et al., 2017). The application of the HFACS model has been successfully used within similar contexts within various high-risk fields (Zhang et al., 2019; Lenne et al., 2012; Nwankwo et al., 2022; Patterson & Shappell, 2010). The results of such analyses have shown the HFACS model to be an effective method at determining systemic factors involved with incident causation. HFACS is a well-rounded model that incorporates all levels within a workforce that influence incident causation. Incorporating a model such as the HFACS can enhance existing reporting tools when evaluating incident occurrence.

All these models are relevant as they have shaped the perceptions of incident causation. These models are relevant regarding mineral exploration due to the multidimensional nature of this field, and the likelihood of both active and latent failures; understanding the different incident causation models, can help inform organization health and safety program development and management.

2.1.2 INCIDENT REDUCTION

Within OHS there are two important indicators to be evaluated when assessing incident causation: reduction and investigation. These two variables are commonly known as leading indicators and lagging indicators. Leading indicators are measures of actions taken to prevent an incident from occurring and can include proactive measures such as safety meetings, safety training, and safety audits. Lagging indicators are reactive measures taken to evaluate outcomes of events that have already happened, through the analysis of past performance and incident reports (Reiman & Pietikäinen, 2012; Sheehan et al., 2017; Manuele, 2009). Placing emphasis on both leading and lagging indicators has shown to be valuable within different work environments. The literature has stated there are benefits to organizational measurements that focus on both leading indicators and lagging indicators, as it is this dynamic interaction between the two variables that will provide the most information for incident prevention (Reiman & Pietikäinen, 2012). For high-risk industries, an organizational approach should be tailored to include both. Leading indicators limit the blame placed on the individual and allows for the identification of preventative measures, rather than being failure-focused and having safety measures that lay dormant until an event occurs (Clarke, 1990; Goh, Brown & Spickett, 2010). Lagging indicators provide information about failures present in the work environment and allow for reactive, measurable approaches to safety management (Sheehan et al., 2017). Of note, it can be difficult for organizations to place emphasis on leading indicators if they are unable to anticipate where failures or vulnerabilities lie, making it pertinent for OHS management systems to be stable and well defined, as well as have good risk analysis prior to work to aid in the identification of lagging indicators (Manuele, 2009).

2.1.3 INCIDENTS IN MINERAL EXPLORATION

There is limited research pertaining to incidents within the mineral exploration field. However, preliminary data suggests injuries and fatalities related to helicopters, boats, vehicles, and wild animals are the most prevalent within mineral exploration (Mercer, 2008). Some anecdotal analysis has been completed, yet questions remain regarding the specific practices and series of events that led to the documented fatalities in this industry. Given that limited research exists, a comparative analysis with a similar high-risk industry, specifically mining and construction, as well as high risk recreation activities such as remote adventure travel (canoeing, mountaineering, hiking) can be useful for the consideration of potential rates, trends, and outcomes in Mineral Exploration.

First, as noted in Chapter 1, mineral exploration is an industry that requires many different personnel, employed by various companies, to execute the demands of the field. Within the Mining and oil and gas industry, the hiring of contract workers to carry out niche tasks is common, and this group has historically higher rates of injury compared to company workers. The involvement of contract workers within these industries are at an increased risk for frequency and severity of injury, possibly due to: different working conditions, tasks assignment, and/or remote work; compared to those employed by the company (Blackley et al., 2014; Graham, 2010; Osmundsen; Blank et al., 1995). This is likely to be true in Mining Exploration as well.

Second, mining literature suggests discrepancies in injury/fatality data based on the age of workers. For example, Groves, Kecojevic & Komljenovic (2007) identified younger workers, with less than five years of experience, to be at a higher risk for injury; and older workers, with more than 55 years of experience, to be at an increased risk for of fatality occurrence. Carlisle and Parker (2014) state that younger workers are more likely to state higher levels of distress, both psychological and physiological. Conversely, Paul (2009) reported that older workers were at a higher risk of injury, due to their negative affectivity. Despite the current lack of clarity, age and experience are important considerations in mineral exploration; because within the field personnel ages/roles range from: student and assistant positions, likely younger, with less field experience; to senior personnel with many years of experience and training throughout the duration of their career. Understanding risk associated with these roles should guide a health and safety strategy. In addition, given changing demographics with a recent influx of new workers coming into the minerals workforce, and a projected increase in retirement of older, experienced workers, understanding the impact of age and training on injury rates and health and safety practices will continue to be a key area of study for prevention (Government of Canada, 2019c).

Third, like mining, mineral exploration uses heavy machinery. Numerous variables, associated with heavy machinery, increases a worker's risk of injury including; machinery egress and ingress, slips, trips and falls due to contaminants on equipment, reduced visibility, and the inability to identify and avoid unsafe ground conditions (Nasarwanji, Pollard & Porter, 2018; Ruff, Coleman & Martini, 2010). Research in mining operations has shown improved safety systems and reduced injury occurrence when workers receive increased safety training and education regarding machinery changes and usage, as well when personal protective equipment (PPE) is put to use (Nakua et al., 2019).

Lastly, in relation to the usage of heavy machinery, mineral exploration and mining have a higher prevalence of using highly specialized machinery such as: aircraft, boats, and equipment. Although occupational incidents as a whole view multiple fatality incidents as rare events (Bellamy, 2015), the occurrence of multiple fatality incidents within high-risk industries is more common. Also, multiple fatality incidents can impact total fatality counts and statistics. Industries that utilize aircrafts, show such usage is the single leading indicator of multiple fatality incidents (Pierce, 2016; Drudi & Zak, 2004). This is significant given that helicopter usage is a key component of mineral exploration and as such, should also be a focus area for an OHS prevention strategy.

2.2 THE SAFETY PYRAMID

Organizational health and safety systems are multidimensional and incorporate factors such as political, environmental, cultural, and philosophical determinants. In this section, a philosophical dimension of safety will be addressed. Dating back to 1931, organizations have followed a philosophical framework called the safety pyramid created by Heinrich, which assesses the ratio of unsafe acts, near misses, minor incidents, and fatal events (Marshall, Hirmas & Singer, 2018; Yorio & Moore, 2018). This theory suggests that one may predict the occurrence of fatal events based on the prevalence of lesser-scale injuries. More specifically, a ratio of 300 near misses to 29 minor injuries for every one major injury, 300:29:1, means the resulting incidents are the interaction between several factors accumulating over time to create a precise environment for incidents to occur (Moore et al., 2020; Jebb, 2015). Present day, there is scant literature to support the use of the safety pyramid in the prediction of fatalities. Most recent articles critique the safety pyramid scheme, as well as the feasibility to integrate such a framework into the modern-day work environment (Moore et al., 2020; Marshall, Hirmas & Singer, 2018). Rebbit (2014) questions the exact use of the safety pyramid model but suggests there could be benefits to following the pyramid structure by potentially reducing risks and promoting compliance with legislation and internal systems. Coinciding with the notion of workplaces adopting a generalized version of the safety pyramid, some theorists agree that the safety triangle model should solely serve as a guideline, as many factors contribute to the overall health and safety of an organization, including safety culture (Dunlap et al. 2019; Hudson, 2001). Furthermore, following the generalized implementation of the safety pyramid could satisfy the components within the Swiss Cheese Model in recognising that events are the result of complex factors stemming from organisational systems. One of the most notable trends from research revolving around the safety pyramid is the acknowledgement that delineating severity would be enhanced if industry specific ratios and prevention strategies existed, as opposed to the fixed rates suggested by the pyramid. Scholars agree that the best method to prevent injuries is to focus on incident prevention strategies that address all incidents, as opposed to only focusing on the resulting injury type (Collins, 2011). Review articles in this subject area suggest there are gaps in the literature relating to the mining industry and its application of Heinrich's model, and further examination reveals there is virtually no existing literature relating to mineral exploration (Yorio & Moore, 2018).

2.3 SAFETY CULTURE

Workplace safety culture within an organization places relevance and importance on the attitudes, beliefs, and values that employees collectively share in relation to health and safety risks within an organization (Reason, 1998; Cooper, 2000; Mearns, Whitaker & Flin, 2003; Guldenmund, 2018). One of the most notable models within safety culture is Reason's (2000) model, which highlights five aspects related to culture: informed culture, just culture, reporting culture, learning culture, and flexible culture. Reason (1998) describes the five components of culture: informed culture involves the knowledge of the individual, organisational, technical and environmental factors; just culture is the understanding of acceptable and unacceptable actions, violations and errors; reporting culture is the atmosphere in which individuals feel confident and trust in reporting incidents; learning culture places emphasis on an organisations competency regarding reporting systems; and lastly, flexible culture refers to the organisations ability to restructure systems if required to adapt to the changing needs. These aspects are built upon one another and the relationship between each is dynamic.

The revelation that safety cultures within organizations were important to investigate was sparked after the Chernobyl incident in 1986. This incident challenged the way previous systems operated by highlighting the notion that incident etiology can be attributed to the interactions between technical, social, and organizational failings, and that emphasis should be placed on systemic weaknesses within organizations (OECD Nuclear Agency, 1987; Pidgeon & O'Leary, 2000). Since then, safety culture has been increasingly studied, with literature sources stating the benefits safety culture has on organizational production, risk, and worker job satisfaction (Clarke, 2003; Clarke, 1999; Flin et al., 2000; Borys, 2012; Bjerkan, 2010; Brown, Willis & Prussia, 2000).

Safety culture is a subdivision within organizational culture and involves various dimensions yet does not follow a universally accepted model for safety culture components (Cooper, 2000; Guillaume et al., 2018). Although themes within safety culture vary, a few distinguishable dimensions of a strong safety culture have been determined: management, safety systems, risk, work pressure, competence and procedures, and rules (Flin et al., 2000; Cooper, 2018; Brown, Willis & Prussia, 2000; Borys, 2012; Zohar, 2010).

2.3.1 THEMES WITHIN SAFETY CULTURE

Management

Management and supervision are at the forefront of an effective safety culture because of the level of influence these positions hold (Clarke, 1999; Mearns, Whitaker & Flin, 2003; Ajith et al., 2011). The health and safety attitudes and behaviours of these higher positions ripple down the hierarchical chain within organizations and ultimately have a direct effect on the workforce. Managerial styles that are not supportive, nor respectful to safety practices, can lack control of worker performance and can foster a workforce that is not compliant (Flin et al., 2003; Clarke, 1999). It is crucial to have all managerial levels educated on the importance of a positive safety culture, and how incident causation is impacted by their beliefs and actions.

Safety systems

Safety systems within organizations are amongst the top themes to influence safety culture (Fernández-Muñiz, Montes-Peón, & Vázquez-Ordás, 2007; Robson et al., 2007; Ajith et al., 2011). These safety systems are dynamic elements that influence OHS rules, regulations, and objectives, and includes the means to achieve such desired objectives. Safety systems cover a spectrum of organizational aspects ranging from safety management systems, safety committees, effective communications, and training protocols (Vecchio-Sadua & Griffiths, 2003; Flin et al., 2003; Brown, Willis & Prussia, 2000). One safety system that predominates in mining in Canada is the Internal Responsibility System (IRS). The IRS is a system where everyone has direct responsibility for health and safety, as an essential part of their job. It does not matter who or where the person is in the organization, both workers and management are responsible for jointly reducing hazards (Fidler, 1985; Vingård & Elgstrand,

2013) to achieve health and safety in a way that suits the kind of work they do. It is one of the personal responsibilities of a company President to ensure that the entire system of direct responsibility for health and safety within a company is established, promoted, and improved over time. Successful implementation of the IRS should result in progressively longer intervals between incidents or work-related illnesses (MLTSD, 2022).

Analyzing fatality and risk levels can highlight areas of accountability at higher levels within a company, regardless of whether the workers are diligently obliging, or even made aware of the IRS. Professional geoscientists across Canada, like engineers, are responsible through the regulations for the profession, for safeguarding workers and the public from the point of view of health and safety, and the environment, showcasing a level of IRS that places diligence in all types of personnel, regardless of the seniority on site (Mercer, 2008).

Risk

Risk is an umbrella term that involves risk perception or appraisal, risk assessment, and risk controls (Cooper, 2018; Khanzode, Maiti, & Ray, 2012). Everyone subconsciously conducts their own risk assessment due to the subjective judgemental process involved with risk perception (Slovic, Fischhoff & Lichtenstein, 1982; Flin et al., 2003). These self-reported levels of risk and perceptions of hazards influence general attitudes towards safety. Workers generally have an accurate understanding of the levels of risk involved in the task at hand, however factors such as motivational levels, safety efficacy, and consequences involved in safety hazards and safety culture can influence risk-taking behaviour (Brown, Willis & Prussia, 2000; Scholz & Gray, 1990). Workers who feel personally responsible for the safety of themselves and the working environment will perceive risk levels differently, as to not jeopardize the health and safety environment, noted as the IRS (Flin et al., 2000; Cheyne et al., 1998). Borys (2012) identified key characteristics that are present in organizations that are safety focused, emphasizing traits related to risks: promoting an understanding of risk through a defined picture of risk; risk controlling and implementation of frameworks to support the control of risk; education tailored to workers to appreciate that work is complex and recognizes barriers individuals face in the workplace. Therefore, considering risks in terms of safety culture is particularly relevant to the mineral exploration field since it is classified as a high-risk industry. Understanding that risk is dynamic and subjective should allow organizations to think of all-encompassing ways to incorporate and enhance risk procedures into safety culture.

Work Pressure

Pressures associated with work are important when assessing factors that contribute to an organization's overall safety culture composition (Flin et al., 2000). Work pressures are any factors relating to workload that result in added stressors to the worker, including physical and psychological demands of the job (Cooper, 2018). These pressures can be induced by personal, managerial, or peers (Mearns, Whitaker & Flin, 2003). These factors can be explicitly stated or unspoken expectations that are built into the safety culture. One of the most common themes associated with work pressure is the pressure of time, which is a complex derived from economic demands and production goals (Mearns, Whitaker & Flin, 2003; Brown, Willis & Prussia, 2000; Brown, 1996). These pressures are generally placed upon workers from upper management levels where a production bonus is offered as a financial incentive (Mearns, Whitaker & Flin, 2003). Common still in mineral exploration are financial incentives to the drill crew for increased production when diamond core drilling. This may also occur in other production type work such as manual line cutting in the field. In situations such as this, workers may be less likely to adhere to safety codes of practice, have a greater likelihood of unsafe risk taking and take shortcuts or chances to get work done unless the financial incentives are counterbalanced by OHS incentives (Mearns, Whitaker & Flin, 2003). There are two forms of OHS incentives that do not involve monetary incentives; behaviour based, and injury and illness-based incentive programs (Goodrum & Gangwar, 2004; Jaafar et al., 2018). The motivation behind injury and illness-based incentive programs have been questioned as these incentives have the potential to not change safety behaviour, rather change the nature of incident reporting. Incentives with this motivation can encourage workers to not document all incidents so that they still receive such recognition and reward (Goodrum & Gangwar, 2004). Behaviour based is focused on praise and recognition and can be geared towards individual and group outcomes (Teo et al., 2005; Jaafar et al., 2018). This approach of rewarding safety behaviour through praise and recognition is seen to be the most effective incentive and has been shown to be a more effective approach than focusing solely on zero harm (Jaafar et al., 2018). At an individual level, the benefits of OHS incentives are more likely to occur if a positive relationship between the supervisor and worker exists. This enhances the worker's perception of organisational support and directly affects the reactions to safety incentives (Haines et al., 2001). The praise in turn is seen as a reward to the individual and can motivate workers to continue best practices. At a group level, safety incentives are more likely to be beneficial if other components of safety culture, such as group cohesiveness, safety standards, and task competence exist (Haines et al., 2001). In turn, the incentives are appealing to the group's collective goal and have an impact on production and adherence to safety protocols (Haines et al., 2001).

Although research has shown organizations are highly focused on production, the literature states that there is no direct correlation between the amount of production and safety performance, but rather that the methods of production are more influential (Ural & Demirkol, 2008). This enforces the idea that organizations need to have a better understanding of how influential safety systems are opposed to placing emphasis on production rates, to create a proper balance between production and safety standards. Work pressures and production rates directly correlate to ill perceptions of work: workers are more likely to experience mental and physical burnout and be less satisfied with work when faced with high work demands (Cooper, 2018). This issue can be rectified by promoting safety cultures that value workers and recognizes the limits of workload and expectations. Promoting a normative work environment can help to increase job satisfaction, positive affect, and reduce intentional job turnover (Masia & Pienaar, 2011; Mościcka-Teske, 2018; Balogun, Andel & Smith, 2020). An area that has not been studied in mineral exploration, but has been studied in the mining industry, is the effect of bonus pay and how this influences worker motivation. Financial incentives are seen as one of the most important factors that affect a worker's motivation (Sierpinska & Kustra, 2008). Bonus pay is a part of remuneration that is generally allocated based on production rates and could lead to two different outcomes in terms of work pressure. Production rates could lessen a worker's willingness to follow strict health and safety regulations, possibly contributing to higher rates of incidents (Hopkins, 1984). Comparatively, workers could feel more motivated to maintain their skillset, conform to corporate health and safety strategies, and be more consciously aware of surroundings to keep up with production demands, possibly reducing injury rates (Dansereau, 2006; Sierpinska & Kustra, 2008). These are relevant factors for industries such as mineral exploration, where the occupational requirements demand a higher physical capacity, and the workers are often subject to higher levels of burnout.

Competence

Competence within a workplace is related to the worker's perceived abilities, education, and qualifications towards work related tasks, training, and standards (Flin et al., 2000; Cooper, 2018). Competence is a changing perception that fluctuates with economic trends and is influenced by the availability of jobs of interest. A worker's competence level can vary for the same task depending on the working environment and support provided (Flin et al., 2000). Competent workers are those who feel capable to carry out the required duties of the job, safely and effectively. Such feelings can be attributed to acquiring the proper skillset and receiving periodic training or refresher training. Refresher training courses are offered to specialists in selected fields of work, with the purpose of maintaining existing knowledge and skillset, to address the deterioration of skills that occur over time (Malakis & Kontogiannis, 2012; Lane, 1987; Ruttenberg et al., 2020). Refresher training is diverse in nature and tailored to the demands of the work environment; training can be offered via simulations, in operational settings or at the organizational level (Malakis & Kontogiannis, 2012; Lane, 1987). Refresher training within mineral exploration varies depending on the occupational status, as each occupation is subject to their own levels of refresher training as mandated by the governing workplace. For example, individuals holding first aid certificates in Ontario must participate in a refresher course to renew their certification every three years at a minimum, unless otherwise stated by the workplace. There is currently no set interval for the occurrence of refresher training, as demands for skillset vary between industries and should be addressed at the policy level within each organization

(Lane, 1987). These refresher training programs can have benefits of enhancing existing skillset, strengthening teamwork and workers competence in protecting the wellbeing of their working environment through informed decision making (Ruttenberg et al., 2020; Lane, 1987). Offering resources such as refresher training is not always feasible, as Cooper (2018) states that in the modern workforce training is only offered until the task is carried out properly; there is generally not an option to repeatedly refresh skillsets, even though rehearsal of tasks has been proven to be beneficial to competency levels. Poor competency can result in a worker making poor decisions, failing to recognize hazards, unable to recognize early warning signals, incorrectly operate equipment, or improperly react to incidents (Cooper, 2018). Competency not only relates to workers but applies to higher level managerial positions as well. Managerial behaviours that lack competence in the realms of health and safety represents a poor safety culture. This supports the idea that competent leadership must become a fundamental managerial skill, as workers are influenced by the behaviours put forth by these positions (Cooper, 2018). Having competent workers within all hierarchical levels of an organization will foster commitment of OHS safety systems, and ultimately support a healthy safety climate (Bjerkan, 2010).

Procedures / Rules

Procedures and rules within an organization's safety culture can be seen as all-encompassing because they reflect every dimension that has been previously stated. Procedures and rules are identified as an individual's perceptions, attitudes and compliance to standards that have been determined within an organization (Flin et al., 2000). To start, the procedures and rules are reflected by a top-down approach. The attitudes and behaviours of upper-level management will heavily influence the perceptions of workplace safety (Brown, Willis & Prussia, 2000). Workers will be less likely to strictly follow procedures and rules if they are not supported or monitored by higher level staff. The supervisory safety climate will also affect how comfortable workers are for reporting unsafe working conditions or possible hazards (Brown, Willis & Prussia, 2000). Ultimately, all parties within the safety culture need to understand the way perceptions are mirrored and influenced. Secondly, safety systems need to be highlighted as an asset towards a healthy safety culture, as it is these systems that will educate and advocate for a safer working environment (Fernández-Muñiz, Montes-Peón, & Vázquez-Ordás, 2007; Ajith et al., 2011; Robson et al., 2007). Thirdly, risk and work pressures are related in terms of rule following. As previously noted, higher work pressure increases a worker's likelihood of reducing safety standards and compliance with procedures and rules (Mearns, Whitaker & Flin, 2003). Lastly, competency of both workers and management tie into rule following as greater levels of competence relates to greater levels of responsibly, which in turn relates to compliance of rules and procedures (Cooper, 2018).

Ultimately, the literature suggests that the negative impacts of factors such as poor job satisfaction, work stress, lack of hazard identification and risk control measures, poor management interaction and poor communication could all be improved with an enhanced safety culture and in turn enhance safety compliance. An enhanced safety culture could allow workers to place greater levels of value and respect in their occupation, all while becoming more compliant with safety rules and regulations

2.4 REPORTING CULTURE

The importance of incident and near miss reporting has been highlighted within high-risk industries and its prevalence has been shaped by higher-level political, social, and legislative concerns (Mahajan, 2010; Johnson, 2002; Jebb, 2015). Reporting culture is one of the five components that contribute to an organization's overall safety culture and holds the most influence as it is a foundational block that supports the other dimensions (Reason, 2000). In consideration of the IRS, the reporting culture is the environment within an organization that either deters or promotes workers to report near-misses and safety concerns (Reason, 2000; Reason, 1998; Johnson, 2003). Reported safety concerns can be human errors or at-risk behaviours, which range from reporting incidents to near misses and errors (Reason, 2002; Johnson, 2002; The Joint Commission, 2018). Reporting near misses and errors is as important as reporting incidents, as they provide information that can be used to avoid losses related to major incidents, and can be used for learning opportunities (Johnson, 2002; Jebb, 2015). Many factors such as psychological safety culture (Probst & Estrada, 2009), work pressures (Probst & Graso, 2013), managerial support and enforcement (Hopkins, 2002), and organizational resilience (Reason, 2000) contribute to the reporting culture of a workforce. The Joint Commission (2018) identifies four components that promote a healthy reporting culture: (1) establish trust through leadership and communication; (2) encourage reporting by using accessible and easy to use formats that provide clearly defined incidents, while also offering feedback to staff and to inform them once corrective actions have been taken; (3) eliminate the fear of punishment by ensuring protection for the workers to report incidents through coaching opportunities, as well as provide a standard of fairly disciplined consequences to all levels of workers regardless of their hierarchical position; and (4) examine all reported incidents big or small to obtain a cohesive and representative dataset that can be used to identify successes and weaknesses, and provide educational opportunities.

Fostering a reporting culture that gives workers the courage to report incidents is a continuous process and takes time and collaborative effort from all parties involved (Hopkins, 2002). Many organizations struggle with underreporting safety concerns. Underreporting is ultimately influenced by poor perceptions of safety climate, and lack of safety interest from supervisors (Probst & Estrada, 2010; Probst & Graso, 2013). Workers may feel less obligated to report incidents: if not supported by supervisors, if under high levels of work pressure, or if influenced by peers (Probst & Graso, 2013; Johnson, 2003; Hopkins, 2002). Determining those factors that relate to underreporting within an organization are key to promoting a healthy reporting culture.

Once reporting systems are implemented, the data obtained needs to be evaluated; this information is most powerful when analyzed properly and acted upon (Reason, 1998; Hopkins, 2002). Analyses can provide in-depth information to help determine, through the organizational hierarchy, which factors contribute the most to injury risk (Walters & Haines, 1988, Lander et al., 2010). Coleman & Kerkering (2007) note that it is crucial for organizations to maintain records of injury and illness data that are tailored specifically to health and safety research, as opposed to data that have been collected to satisfy regulatory, administrative, and legal requirements; reports such as these can then be used as a method of analysis to determine differences in incident outcomes.

2.5 INCIDENT REPORTING

As noted in section 2.3, organizations have become increasingly aware of the beneficial implications of effective health and safety systems. Extending the application of the Internal Responsibility System, Safework Associations perceive safety to be everyone's responsibility;

and safety practices should be shared to have the biggest impact. Notably, key organizations have banded together to create awareness on this topic: incident reporting. The Prospectors & Developers Association of Canada (PDAC), Association for Mineral Exploration (AME) and the Canadian Diamond Drilling Association (CDDA) have collaborated to create the 'Canadian Mineral Exploration: Environment, Health and Safety Survey;' which is a national survey that encourages all relevant companies, within the mineral exploration field, to complete a detailed report relating to health and safety incidents. The final product is an annual report that highlights leading indicators, promotes safety workshops and initiatives, and recognizes companies with outstanding contributions towards health and safety. Reports of this nature are valuable as they showcase statistics relating to lost workday incidents, which will foster a greater understanding of OHS, promote higher levels of compliance through awareness, and build strong safety culture through recognition for the top leading companies.

There are three main categories used within organisations for the purpose of incident reporting and documentation, which follow a hierarchical structure that classifies incidents broadly, then subsequently narrows down the incidents to provide more details. The top of the hierarchy is: incident classification; followed by a more targeted category, the mechanism of injury; down to the final classification that provides the most specific information regarding the incident, the nature of the injury. In this section, these three categories will be discussed.

2.5.1 INCIDENT CLASSIFICATIONS / INJURY SEVERITY

Incident classification is a structured approach to document any workplace incident that could jeopardize the health and safety of individuals. OHS institutions have adopted a framework to base these reporting protocols from; known as the Safety Pyramid or Accident Triangle. The

Safety Pyramid is a foundational model that led the way for academics and OHS institutions to better understand incident causation. The Safety Pyramid is used in incident reporting often with different organisations adapting the model to best fit the nature of their work environment (Pekney & Siddiqui, 2015; Collins, 2011; Collins, 2010; Yorio & Moore, 2018). The pyramid has tiers within, with each tier representing a classification of injury. Organisations classify the number of injury severities differently, depending on what is applicable to their industry; however, the injury severity matrix remains constant. There are five injury severity classifications, chronologically ordered from most severe to less severe as follows: 1) fatalities, 2) lost time injuries/serious, 3) minor injuries/reportable/first aid, 4) near misses and near hits, and 5) unsafe acts or hazardous conditions (Khazdone et al., 2010; Penkey & Siddiqui, 2015; Yorio & Moore, 2018; Rebbit, 2014). We define a lost time injury/serious injury is one which the worker requires a leave from work; minor injuries/reportable/first aid are smaller injuries such as a scrape or sprain that requires first aid attendance; a near miss is an incident that occurred but did not result in damage to an individual or property, however had the potential to; and an unsafe act is an act that could possibly lead to an injury occurring, whereas hazardous conditions is an incident where potential for an injury to occur due to unsafe working conditions. For organizations to understand the most appropriate structure to follow when classifying incidents, the Safety Pyramid is a theory of industrial incident prevention and it shows the relationship between serious incidents, minor incidents and near misses such that: (1) there are greater numbers of less serious incidents, compared to more serious incidents (and that if you reduce minor incidents there will be a corresponding fall in the number of serious incidents); (2) the accumulation of near misses predicts the likelihood of an incident with more serious consequences; and (3) all incidents represent failures of control and can be used as learning opportunities (Penkey & Siddiqui, 2015). Understanding and applying the five common injury severity classifications within the incident's triangle, along with these three core principles, can allow organisations to adjust their standard reporting protocols, while still using the fundamentals believed to be effective (Collins, 2010; Collins, 2011). Using this approach, safety performance can be classified as one organisational metric or individual metric for safety outcomes. Organisational metrics are outcomes from safety events such as incidents, injuries and near misses, whereas individual metrics are related to the psychosocial complex of safety related behaviours (Christian et al., 2009). Although the occurrence of incidents is dynamic, organisational, and individual metrics hold a conceptually distinct purpose in safety performance tracking, making it critical to distinguish between safety performance in relation to organisational and individual levels. For this section, organisational metrics related to safety outcomes is more relevant in terms of incident reporting.

2.5.2 MECHANISM OF INJURY

The Mechanism of Injury is the second category within the overall incident reporting scheme. The Mechanism of Injury refers to ways that damage to the skin, muscles, organs, and bones happened. Within Canada, there is no standard to follow regarding mechanisms of injury, however a general definition is provided by OHS Classifications (2020) as "the general action, exposure or event that best describes the circumstances that did or may have resulted in the most serious injury or disease." There are 27 classifications of overarching Mechanisms of Injury that cover all aspects regarding possible injury exposure, ranging from falls to vibration exposure (OHS Classifications, 2020); individual industries often tailor their incident reporting system to include the relevant mechanisms of injury, which can vary across industries. For example, common Mechanisms of Injury in mining are slips, trips and falls, muscular stress, tool/machinery related use and unintentionally struck/motor vehicle collisions (Kemmlert & Lundholm, 2001; Chang et al., 2016; Kia et al., 2019; Nakua et al., 2019; Ruff et al., 2011). Certain organisations will follow specific injury and illness characteristic coding that is mandatory and applies to industry wide organisations. This practice is best for allowing comparison between and amongst companies/industries. For industries that do not follow a mandated coding system, other relevant coding standards such as the International Classification of Diseases (ICD) should be adopted based on the nature of the working environment (Hedegaard et al., 2020). Coding standards such as this act as a baseline when comparing the presentation of injury statistics, nationally and internationally.

2.5.3 NATURE OF INJURY

The Nature of Injury is the last and most specific category within incident reporting schemes. The Nature of Injury identifies the primary physical/psychological characteristics of the injury, providing a description of the damage, relating to the body part affected because of the incident (OHS Classifications, 2020). The ICD is a great resource which also includes the nature of injury, and previously stated, can be used for a more cohesive systems approach to injury data collection if mineral exploration adapts components of these coding systems. Variables within mineral expiration such as diversity of occupations and working environments makes the codes needed for mineral exploration vast, therefore a combination of candidates such as the International Classification of Diseases (ICD), National Outdoor Leadership School (NOLS) and the Workers Compensation Board/Commissions (WCB) can be used to create classification codes that suit the nature of injuries within the field. Incorporating codes from the ICD would better allow for comparisons to be made between industries such as mining and mineral exploration, where as the addition of extra codes adapted from NOLS and WCB allow for a streamlined and cohesive documentation and analysing process that is specific to mineral exploration, yet comparable to high-risk industries.

2.6 PERSONNEL

Mineral exploration is an industry that requires the collaboration of various occupations, each faced with a varied set of workplace hazards. This section will address the key occupations within mineral exploration and the associated OHS hazards.

Contract Workers

Contract workers are an essential component to the mineral exploration field because they are a mobile workforce, which offers highly specialized individuals skilled across the cycles of exploration. Benefits to hiring contract workers are that they are economical for organisations compared to hiring full time permanent staff, they offer flexibility in skills and availability, and they can be brought on projects for short term employment. Contract workers also bring unique OHS risks that may not be present with a permanent employee. Contract workers alter the viability of the safety culture because it is difficult to integrate part-time individuals with diverse backgrounds and training into a cohesive safety team (Clarke, 2003). It is noted that the need for enforcing a shared understanding about the OHS culture is pressing with contract workers, as they may not have a collective and cohesive environment for guidance and/or may not have the same safety culture as the permanent team members (Lippel & Walters, 2019; NewsRX, 2019). Contract workers are also at an elevated risk for injury and fatality as they are generally younger in age, less experienced, and poorly trained compared to individuals working the same position within an established workforce (Gochfeld & Morh, 2007; Blackley et al., 2014; Graham, 2010; Osmundsen, Toft & Dragvik, 2006). However, some contract workers are highly experienced and can contribute strongly to work safety, but the company needs to empower them and stress their responsibility to them. Therefore, understanding the particularities involved with contractor risks can also allow organisations to make appropriate accommodations that will enhance existing OHS systems.

Drillers & Drill Helpers

Within the field of mineral exploration, drilling[1] is one of the most crucial techniques that aids in discovering economic mineralization locations (Marjoribanks, 1997). Drilling is arguably one of the most expensive components of mineral exploration; but it serves many purposes, such as allowing organizations to test theories and ideas that have been formulated in the early prospecting stages and confirms locations and tests grades of minerals for plausible mining (Marjoribanks, 1997). To advance a mineral project, the mineral resource must be defined, which is accomplished through drilling and analysing the resulting drill samples.

Individuals who lead the operation of drills are usually called “Drillers” in Canada and are certified and trained in all aspects of operating, moving, and dismantling drilling rigs. The drill crew during a work shift often has two members – the senior member called “Driller” or “Drill Foreman” and the junior member(s) referred to as “Drill Helper,” “Helper,” “Drill assistant,” and other terminologies. It should be noted that not all drilling companies use the words “Drill Helper” but some may use these alternative terminologies. Drilling is usually a 24/7

[1] “Drilling” is used here to refer to all forms of mechanical drilling into the ground, including diamond core drilling, reverse circulation drilling, percussion, and sonic drilling.

operation and thus unique amongst other mineral exploration activities, which normally occur only during daylight. This means that usually one drill will have two crews working shifts. The training and certification of Drillers is government regulated in some provinces including the Ontario highly structured mining “Common Core” system. Within mineral exploration, Drillers and helpers are considered to be at a higher level of risk for OHS incidents, due to the involvement of: hazardous materials, heavy equipment operation, manual labour, shift work and night shift, and subjective and varying environmental conditions (Staletovic, Kovacevic & Kovacevic, 2014). Drill Helpers specifically are at an increased risk for incident occurrence, associated with their experience (Groves et al., 2007; Alessa et al., 2020, Kecojevic et al., 2006). Less experience equates to greater need for resources and guidance to reduce incident occurrence (Hermanus, 2007). However, Drillers and Drill Helpers when working together as a cohesive unit can reduce the risk of incident occurrence by increasing risk perception. This happens when attention to risks and hazards is highlighted by the members of the team, by spotting risks which might otherwise have been overlooked (Gürcanli, Beradan & Uzun, 2015; McCann, 2006). This concept is known as team situational awareness, where individuals within a team hold a collective understanding of the situation at one point in time (Stanton et al., 2017; Salas et al., 2015). The individuals involved within the team work towards a common goal under their assigned roles (Salas et al., 2015). Having a well-educated team that understands the core elements of drilling is important for reducing incident causation and severity within OHS system.

Field Assistants and Students

Field assistants and students are imperative to the success of mineral exploration as these personnel are the future of the industry. These workers are hired for the purpose of educational experiences and they conduct experiential learning under the supervision of a qualified individual; usually be a Professional Geologist (common abbreviation in Canada is "P.Geo"). It is often up to the discretion of the supervisor that the understudy is properly educated and compliant with the health and safety practices of the workplace, including competence in their abilities to safely complete desired tasks. There are a variety of possible backgrounds covered under the title "Field Assistant". Some examples include but are not limited to: inexperienced geoscientist such as a first or second year Bachelor of Science student working during the summer months, or an individual doing a Mining Diploma in a collage, or an individual hired to help the Geologist with field work such as carrying rocks. Geology students working as Field Assistants often have little to no safety training provided through university, as the education is tailored more towards science and not practical field applications. Students and assistants are often younger in age, and are less experienced (Margolis, 2010). The literature has stated that both these factors elevate the risk for fatality and injury: they are less experienced in identifying hazards; may not properly follow safety procedures and protocols; and they may also lack confidence in reporting mistakes, incident and near misses (Groves, Kecojevic & Komljenovic, 2007; Bahn, 2013). For these reasons, organisations need to be mindful when assigning students and assistantships to work in the field and educate them accordingly.

Geologists/Geoscientists

Geologists are highly specialized individuals who incorporate all aspects of the scientific disciplines into the field of practice, such as: data collection and observation, analysis, formulation of theories, and interpretation (Nolan, 1962). The situation of geoscientists changed dramatically at the turn of the century when professional status became legally established in provinces and territories leading to professional legal obligations, including health and safety and the environment responsibilities. With this, Geoscience is a regulated profession where everyone must adhere to a code of ethics, be registered, and be held individually accountable for their actions (Geoscientists Canada, 2023). In eleven of the provinces and territories, Geoscience is legally self-regulated; this means the governing rules within each legislation are best managed by the community of practicing professionals, like other professions such as medicine and engineering (Geoscientists Canada, 2023). Whether an employee or contract worker, the professional geoscientist (P.Geo) has the same professional legal responsibilities. Geologists are active members within various industries, including mineral exploration, and offer advisory and consultative contributions, amongst other duties such as solving geological problems, producing geological maps, and working with other members of the team to maximise the effectiveness of mineral prospecting (Nolan 1962; Cranstone, 2004). Geologists are often the most senior member of the field organisational teams, due to their qualifications, mandatory levels of field experience, and educational background, bringing about more experience and familiarity with the work environment (Marjoribanks, 1997; Nolan, 1962; Bahn, 2013; Margolis, 2010). As a result, the day-to-day management of an exploration project in the field is often the senior geologist of the team and consequently the senior geologist is responsible for OHS oversight and authority on a project in the field. Geologists often work in the field, in remote locations, and are exposed to adverse conditions; thus, geologists are exposed to various OHS hazards.

Heavy and Mobile Equipment Operator

The operation of heavy equipment is common within advanced mineral exploration. The machinery varies from smaller scale vehicles, such as the use of multi-terrain vehicles (UTV, ATV), to large pieces of equipment designed specifically for the purposes of mineral exploration, including back-hoes, excavators, and bulldozers. More specifically, such machinery is needed for assisting mapping efforts in open cuts by digging shallow scrapes or trenches to expose identifiable rock, for digging pits or trenches, and to dig and remove rock (Marjoribanks, 1997). There are many variables within this occupation that consider heavy equipment operators to be vulnerable to an increased elevation of OHS hazards, including machinery egress and ingress, slips, trips and falls, reduced visibility, and unsafe ground conditions (Nasarwanji, Pollard & Porter, 2018; Ruff, Coleman & Martini, 2010). Heavy equipment use in Canada's mineral exploration field is unique, because of the varying seasons and associated weather conditions. The winter months in particular pose a greater risk to heavy equipment operators, since travelling over ice and snow creates risks of breakthrough, including through water. The operation of heavy machinery not only requires precise skills to successfully maneuver the equipment but requires the knowledge of external safety concerns to ensure the safety of themselves and surrounding personnel. Reviewing the components that contribute to the high levels of risk for heavy machine operators will allow OHS systems to better understand the specific nature of incident causation.

Pilots (Helicopter and Fixed Wing)

Pilots are an important member of the mineral exploration team because aircraft involvement is often needed in various aspects of exploration in remote areas of Canada; helicopters are needed for the transportation of personnel, supplies and equipment, slinging of heavy equipment and drill rigs, and geological, geochemical, and geophysical mapping surveys (Marjoribanks, 1997, Air Greenland, 2021). Helicopters are the preferred aircraft for exploration because of their ability to access remote and otherwise hard to access locations, in addition to their ability to provide an aerial perspective, which is elemental for prospecting (Marjoribanks, 1997; Cranstone, 2004). Fixed wing aircraft, including especially float planes, are often used for camp supply and similar activities because they are less expensive to operate than helicopters, in Canada, access to adequate bodies of water are common and they can carry heavy bulky loads at low cost compared to helicopters.

Pilots and associated personnel are at a higher risk for injuries and fatalities because of the multi-dimensional factors and unpredictable events associated with flying. Preliminary research has concluded that one of the leading indicators for incidents and fatalities within the mineral exploration field is helicopter use (Mercer, 2008). There are special conditions associated with helicopter use in mineral exploration, such as the use of smaller single engine helicopters with one pilot, which may also increase propensity for incidents.

It has also been noted that industries that use aircraft prove to be the single leading indicator of multiple fatality incidents, that by their nature increase the severity of incidents (Pierce, 2016; Drudi & Zak, 2004) and make an outsized contribution to fatality counts and statistics. In addition, factors related to aircraft operation such as varying instrument conditions increased the risk of a fatal event (Yang et al., 2021). Therefore, appreciating the risk severity involved with pilots can help OHS systems mitigate risk within the field.

CHAPTER 3

3.0 THESIS OUTLINE

The purpose of this thesis is to analyze 6588 reported workplace incidents, comprised of 15 individual categories, cumulating 105,408 data entries that occurred between the years 2005 to 2019, amongst Mining Exploration Companies in Canadian provinces and territories, as collected by the Canadian Mineral Exploration: Environment, Health and Safety Survey. Survey reports included the incident data provided by industry partners and is theorised to be a good representation of health and safety incidents within the mineral exploration field of Canada due to the diversity of companies involved. Additionally, PDAC, AME and CDDA estimate that the companies responding to the survey represent on average about 60% of the mineral exploration expenditures in Canada each year (Buchanan, 2023 Personal Communication).

3.1 RESEARCH PURPOSE

This research will be conducted to understand the specific Nature of Injury survey reports, within Canada's mineral exploration field by analyzing a representative data set and following a mixed methods approach. Since analysing this database will not provide adequate information from which to draw conclusions and recommendations, theoretical safety methodologies and conceptual frameworks will also be applied to enhance the standard reporting tools. It is the combination of health and safety factors within mineral exploration that result in an unique and multidimensional environment, making it pertinent that research be facilitated within this field to bridge gaps in prevention and practice. The outcome of this research project is to provide a comprehensive analysis of trends, critical issues, and actionable training suggestions to mitigate risk in the field.

3.2 OBJECTIVES

The expected outcomes of this thesis will be to present incident summaries and key findings relating to health and safety within the mineral exploration field. This will be accomplished by the following objectives: i) to examine the specific factors that are associated with and influence injuries, ii) to identify what factors contribute to a higher risk of injury, iii) to examine the relationship between personnel and prevalence of injury, and iv) to identify how safety methodologies and conceptual frameworks can be applied to this industry.

CHAPTER 4

4.0 METHODOLOGY

The proposed research will follow a mixed methods approach by using qualitative analysis and will be carried out in three stages. The proposed research is innovative as the underlying data is from the mineral exploration industry represented by a group of companies, working across Canada, as opposed to analysing specific subsections or individual companies within the field. Data analysis of this magnitude, in this workforce, has never been conducted before.

4.0.1 STAGE ONE: DATA EXPLORATION

Primary data exploration was conducted to gain insight into the dataset. This included unstructured and generalized exploration of the dataset to reveal potential trends, points of importance and characteristics.

4.0.2 STAGE TWO: CODE CATALOGUE

Firstly, we created a code catalogue to provide a list of coding classifications, to systematically categorize the data and to be provided for use by the industry moving forward to create consistent sorting of incidents (Appendix A); this should enhance our ability to accurately monitoring injuries over time within the field. The code catalogue was then translated into the Excel file that is sent to participating companies (Appendix B). Creating the catalogue was achieved by incorporating coding schemes created by the International Classification of Diseases (ICD), The Workers Compensation Board/Commissions (WCB), and The National Outdoor Leadership School (NOLS). Along with the codes that previously existed within the survey, these three resources helped aid the creation of the code catalogue, and are detailed below.

The International Classification of Diseases

The ICD is the first organization that influenced the coding catalogue (World Health Organization, 2019), and was selected for this analysis because of the global scope the classification system used and because it is a global standard within the healthcare field, provides a comprehensive database of human diseases and deaths, providing knowledge on the extent, causes and consequences of these events. The ICD is a cumbersome classification system, with over 68,000 codes for the purpose of diagnostic coding and is used around the world in 117 countries and translated into 43 languages (World Health Organization, n.d.).

Within the ICD, diagnostic codes are provided to classify details such as symptoms, social circumstances, and external causes of injury, to name a few (World Health Organization, n.d.). Notably, this classification system is the basis for comparable statistics on morbidity cases and is thought to be the gold standard when it comes to using a classification system that is both reliable and valid, over varying periods of time and location (Harrison et al., 2021). These code assignments have been created to cover virtually any injury or disease sustained that may present in a clinical setting. For this study, the ICD was used for injury codes relevant to mineral exploration.

The Workers Compensation Board/Commissions (WCB)

Within Canada, each province and territory follow a specific WCB tailored for that region; to provide liability insurance coverage for workplaces. Through WCB programs, employers have access to industry specific health and safety information. This information includes detailed classification systems accounting for all injuries and near misses. The WCB's have three main categories to record injuries: injury event, injury source, and nature of the injury. For this study, all province and territory WCB's codes were considered. Together, these WCB codes cover a diverse range of industries such as: health care, social services, construction, manufacturing, and transportation (AWCBC, n.d.). A main reason why the WCB was chosen for this study is due to the diverse occupations and varying working environments. This is relatable to the mineral exploration field as it has been previously mentioned that this field is diverse in terms of personnel and nature of the working environment. It was thought that including coding systems from all provinces and territories would allow for the most accurate depiction of the events that were sustained within the mineral exploration field. Injury codes from the ICD were reinforced by the occurrence of the same codes within the WCB systems. Other components were adapted such as injury event and nature of injury.

The National Outdoor Leadership School (NOLS)

NOLS is an internationally renowned educational system that teaches wilderness skills, leadership, and medical training to over 3000 students annually, accumulating a total of 150 000 field days of multi-week wilderness expeditions (Leemon & Schimelpfenig, 2003). NOLS was included because of the nature of their recorded incidents, injuries, medical situations and near misses. The NOLS incident database has been utilized for over 35 years, and with that, includes a diverse selection of backcountry entries (Appendix C). These entries include incidents involving adverse weather conditions, snow related events, camping incidents, and hiking related events (Leemon, 2008). The resources from NOLS were not only used to reinforce the previously chosen codes from the IDC and WCBs, but also brought attention to factors outside of specific nature of injuries, such as non-medical classifications, anatomical location and incident types. This backcountry database, used in conjunction with the ICD and WCB's database allows for an extensive and well-rounded basis for the creation of the code catalogue.

4.0.2.1 STAGE TWO: CLEANING DATA

The second component within stage two was cleaning the data. The process of cleaning the data involved going through all entries to fix incorrectly spelt and formatted, duplicated or incomplete data within the dataset. In some instances, cleaning and coding happened relatively simultaneously, as blank or 'unknown' entries were left blank during the cleaning stage and modified during the coding stage. This allowed for increased efficiency as the entries were filled out with the proper codes pertaining to the code catalogue, rather than filling out based on the original survey data codes.

4.0.2.2 STAGE TWO: CODING DATA

The final step within stage two was coding the data. Coding was the process of checking and changing, if needed, all 105,408 entries within the dataset, to suit the appropriate categories as per the code catalogue for the purpose of analysis (Appendix A; Appendix B). To do this, each column with the Excel file was analysed individually. The filter feature within Excel was used to see the entries that existed and was compared to those of the code catalogue. For example, the dataset contained over 250 different entries pertaining to location, under the column 'Location'. The code catalogue outlines 29 locations for companies to select from, therefore, all location entries had to be changed to appropriately fit into the 29 locations. For example, the catalogue outlines three locations pertaining to drill: Drill Machine, Drill Pump and/or Shack, and Drill Site (outside Drill Machine). The original data had various entries relating to drilling activities (Appendix D); of these, all entries had to be changed to suit the three locations as specified by the code catalogue.

4.0.3 STAGE THREE: DATA ANALYSIS

This chapter will explore the qualitative methods used for data analysis. The methods proposed for analysis follow a metadata approach, whereas no traditional descriptive statistics were followed. The metadata approach varies from traditional descriptives as it does not output:

frequencies, means or standard deviations; but instead relies on statistical processing of textual bodies to output the extraction of dominant and co-occurring concepts.

4.0.3.1 QUALITATIVE ANALYSIS

Leximancer Analysis

Computer Aided Qualitative Data Analysis (CAQDAS) has been increasingly popular within the last few decades due to its ability to manage high volumes of data statistically and rapidly (Bringer; Johnston & Brackenridge, 2004; Dalkin et al., 2020; Harwood, Gapp & Stewart, 2015). CAQDAS are broken into two categories, one of which analyses the statistical properties within the text (Jones & Diment, 2010; Sotiriadou, Brouwers & Le, 2014). Leximancer is an example of one kind of CAQDAS and is one of the most used software choices for qualitative analysis, as it satisfies three important evaluation criteria: face validity, stability, and reproducibility (Cretchley, Rooney & Gallois, 2010; Harwood, 2015; Smith & Humphreys, 2006; Sotiriadou, 2014). For this reason, Leximancer (Version 5.0, 2021, Leximancer Pty Ltd., University of Queensland) was used for this thesis. Leximancer automatically and statistically transforms written or visual text into semantic patterns called content analysis, based on the properties, word frequency and co-occurrence within the text (Indulska & Recker, 2008; Jones & Diment, 2010; Leximancer, 2021; Smith & Humphreys, 2006). Within this, there are two stages of information extraction, semantic and relational, where thesaurus-based concepts are generated (Smith & Humphreys, 2006). Leximancer is particularly favourable due to the fact the machine learning technique goes beyond basic keyword extraction, it removes the need to revise the thesaurus as the vocabulary evolves, it increases the automation of the analyses and is cost effective (Smith, 2003; Smith & Humphreys, 2006).

For analysis with Leximancer, all operational settings were set to default except for filtering. Filtering consists of removing synonyms, words used in a different context and name-like words (Leximancer, 2021). The dataset contains 15 categories, two of which are textual entries that describe the events of the incident and the actions taken, formatted in sentences. These two categories were used for the qualitative analysis. The analysis was broken down into four major categories; (1) incident type compared to actions taken over five-year intervals, (2) top five incidents and description analysis, (3) personnel and related descriptions analysis, and (4) theoretical frameworks and models. Within this, each analysis involved one to five separate analyses. As previously mentioned, the textual components within the dataset included the descriptions of the events and the actions taken. These were the two categories that were used for the analysis; the other 13 categories were either chosen or omitted to isolate the factors that were desired. For example, the analysis examining slips and falls over a five-year interval utilized data that was filtered to only look at the slip/fall events over the desired 5-year period, coupled with the textual entries of the associated actions taken, to see the impacts of the actions taken over time.

Content analysis, which is the analytical process outputted by Leximancer, was conducted to show main concepts within the data set and how these concepts relate to one another. The outcome of the analysis will show a visual map, concept lists and text query options (Cretchley, Rooney & Gallois, 2010). The concept map analysed the textual data to extract the frequent themes, which were then displayed into clusters of coloured circles. The coloured circles are heat-mapped, from hot to cold, in order of importance (Leximancer, 2021). The location and spacing of the circles depict the strength of the associations between each concept, with a strong relationship indicated by overlapping circles and a lesser association with circles that are farthest apart (Sotiriadou, 2014). As well, the representative size of each circle is indicative of how frequent that specific theme appeared within the data set, with a bigger circle demonstrating more frequent occurrence (Cretchley, Rooney & Gallois, 2010). The overall concept map provides an understandable and visual representation of the semantic nature of the data (Appendix E; Appendix F). The concept lists and text query options give researchers the choice to read specifics of each concept to better understand the relationship, if the visual concept map is not intuitive (Cretchley, Rooney & Gallois, 2010).

Theoretical Frameworks and Models

Due to the nature of the data set, it is not possible to apply these frameworks and models to individual incidents, therefore these models will be applied to the whole data set to identify commonalities that might occur within the field. For the safety pyramid, ratios will be determined based on the number of incidents falling into each hierarchical category. These ratios will be matched to existing knowledge regarding the safety pyramid. The Swiss Cheese and HFACS model were analysed via contributory factors identified within the data set. The data was sorted based on each contributory factor such as: workplace, task, personnel, and organizational factor. For context, workplace factors werre elements related to the nature of the working environment, which influenced the chance of an event occurring. Various workplace factors included but are not limited to: workplace unsuitable for the job, poor maintenance of housekeeping, tools, or materials unsuitable for the job or used incorrectly, or sub-standard interfaces. Task factors weres the second contributory factor, these are factors that relate to the physical job itself, which contribute to an incident occurring. Task factors included, but were not limited to: tasks poorly designed, improper workload, incorrect or poorly performed job hazard assessment, emergency plan not prepared or communicated sufficiently, teamwork conflict, and various factors within procedures of safety systems such as unavailable resources, unclear, out of date, or not used information. The third classification system is personnel factors, relating directly to the individual performing the task. These factors can arise from mental or physical deviations such as competence, poor fitness or health, fatigue, stress, job motivation and satisfaction, and included the misuse of prescription or recreational substances. The last factors were associated with organizational elements. These are factors that are generally not tangible, but rather systematic implementations or ideologies that transmit down through the systems in place. These systems can impact the likelihood of an event happening; examples of these factors included: inadequate or poor leadership or supervision, poor safety culture, poor change management and inadequate systems to address procedures, processes, auditing, improvement, and reactive and proactive systems. From these four contributory factors, ratios were determined to identify which factors within the field might have related to a higher injury occurrence. The findings were compared to existing literature in both models, to identify where possible barriers might exist.

CHAPTER 5

5.0 RESULTS

This section presents the results of the qualitative analyses. The results have been divided into two stages: Leximancer analysis and theoretical framework analysis.

5.0.1 QUALITATIVE ANALYSIS

Qualitative analysis was conducted in two stages. Leximancer analysis to produce concept maps of the data, and theoretical framework analyses for visual representation of the data. This was a retrospective analysis of an existing dataset.

5.0.1.1 LEXIMANCER ANALYSIS

Due to the scope of the dataset, the Leximancer analysis was broken down into three different groups. This allowed for analysis of the specific factors of interest (Incident Type compared to actions taken, over five-year intervals; Top five incidents and description analyses; Personnel and related descriptions analysis). The thematic analyses are detailed below.

1. Incident Type compared to actions taken, over five-year intervals

The top five incidents, in terms of the greatest number of times the incidents were identified within the dataset, were individually compared against the actions taken. These five incidents were: 1) slips and falls, 2) tool use, 3) light vehicle, 4) improper lifting, and 5) drilling machinery related incidents. The data used within this section is the same as analysis 2. Top five incidents and description analyses, however the difference being this analysis looks at the data compared to actions taken, whereas section two evaluates the same data against the textual descriptions of the incidents opposed to the actions taken.

The purpose of this was to see how, and if, the actions taken over time varied. The data was divided into five-year intervals, known as ‘time series analysis,’ to analyse a series of data points over time. Dividing the data into yearly segments was chosen to capture an average of the data in case there was an outlying year. The time frame of five years was specifically chosen because of the abundance of health and safety literature that utilizes five years as an interval of time to analyse data successfully and statistically (Soleimani & Bagheri, 2022; Lingard et al., 2017; Ahmad et al., 2015).

Slips and Falls

There were 1083 incidents involving slips and falls. Figure 1 shows the three concept maps for the years 2005-2009, 2010-2014, and 2015-2019. Figure 2 is an example of what an analysis synopsis looks like within Leximancer and provides reference to the frequency with which each theme was extracted from the year 2010-2014 within slips and falls.

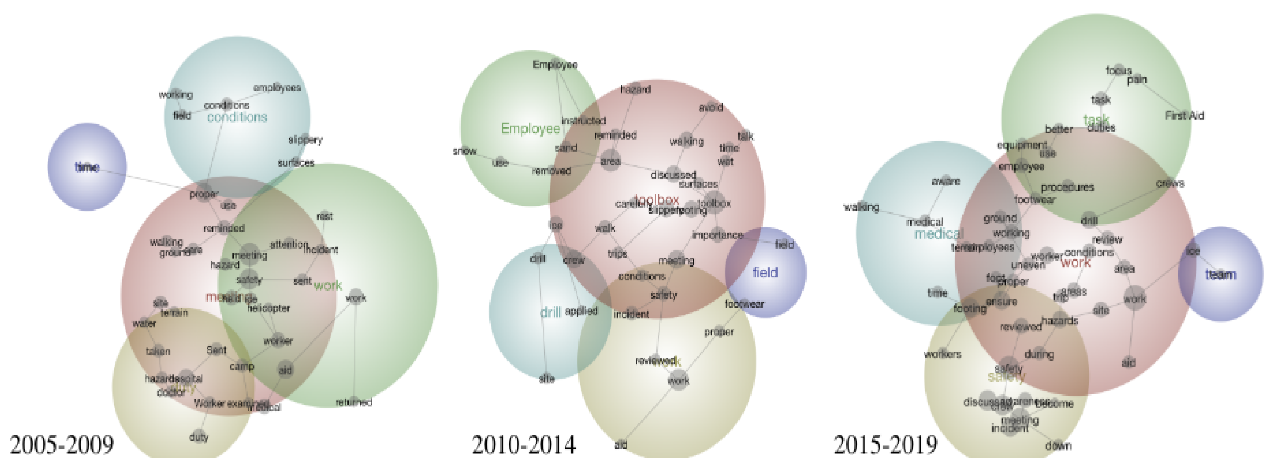

Figure 1. Concept map generated by Leximancer. The themes are listed in order of presentation based on the heat-mapping technique. For the time spanning 2005-2009, five major themes were apparent: Meeting (red), Duty (yellow), Work (green), Conditions (blue), and Time (purple). For the time spanning 2010-2014, five major themes were apparent: Toolbox (red), Work (yellow), Employee (green), Drill (blue), and Field (purple). For the time frame between 2015-2019, five major themes were apparent: Work (red), Safety (yellow), Task (green), Medical (blue), and Team (purple).

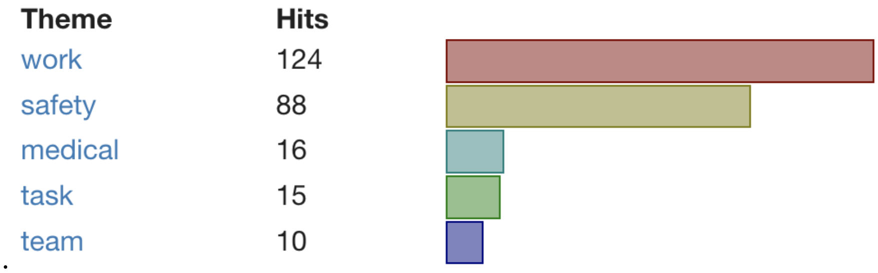

Figure 2. The analysis synopsis shows the number of times each theme was recorded for the year 2015-2019 within incident type slips and falls.

Tool Use

Within the dataset, 778 entries were classified under tool use as the incident type. The concept map (Fig. 3) depicts those 778 incidents whose themes were most prevalent over five-year intervals.

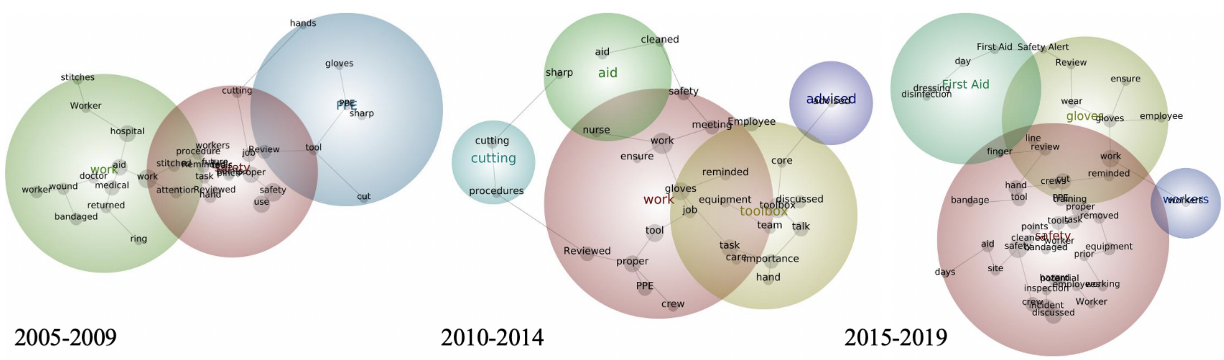

Figure 3. Concept map generated by Leximancer, for the incidents classified under 'tool use', for the time periods of 2005-2009, 2010-2014, and 2015-2019. The themes are listed in order of presentation based on the heat-mapping technique. The period between 2005-2009 resulted in three major themes: Safety (red), Work (green) and Personal Protective Clothing (blue). Incidents classified under tool use between 2010-2014 resulted in five major themes: Work (red), Toolbox (yellow), Aid (green), Cutting (blue), and Advised (purple). For the time frame of 2014-2019, four main themes emerged: Safety (red), Gloves (yellow), First Aid (green), and Workers (purple).

Light Vehicle

A total of 589 entries were classified under light vehicle as the incident type. These entries were divided by counts spanning five-year intervals. Figure 4 represents the concept maps associated with each period.

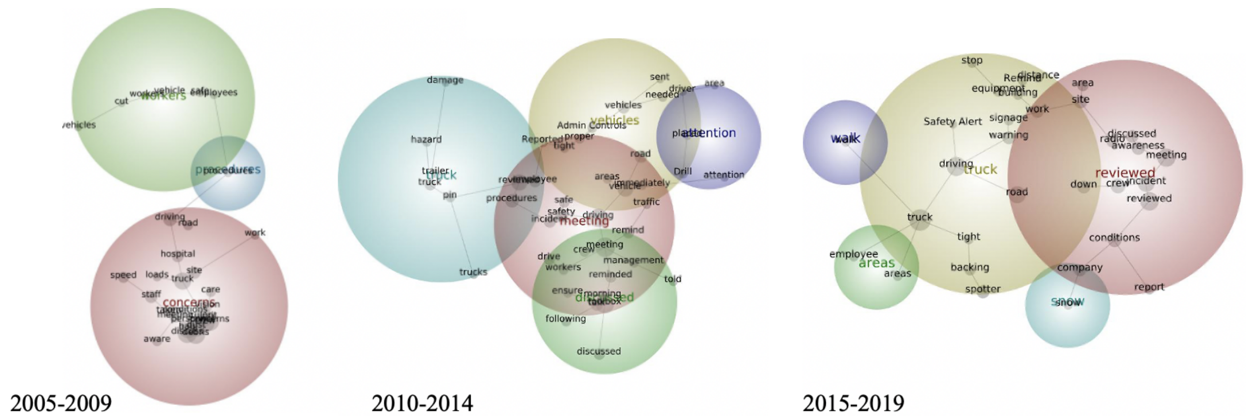

Figure 4. The concept map generated by Leximancer, examining themes with the incident types classified under light vehicle. The themes are listed in order of presentation based on the heat-mapping technique. For the period between 2005-2009, three main themes prevailed: Concerns (red), Workers (green), and Procedures (blue). For the time frame 2010-2014, five main themes were revealed: Meeting (red), Vehicles (yellow), Discussed (green), Truck (blue), and Attention (purple). Within the years of 2015-2019, five main themes were prevalent: Reviewed (red), Truck (yellow), Areas (green), Snow (blue), and Walk (purple).

Improper Lifting

A cumulative total of 530 entries were classified under improper lifting as the incident type. Through the iterative process of Leximancer, concepts maps were individually created covering five-year intervals of these 530 results. Figure 5 shows the maps of the Leximancer analysis output.

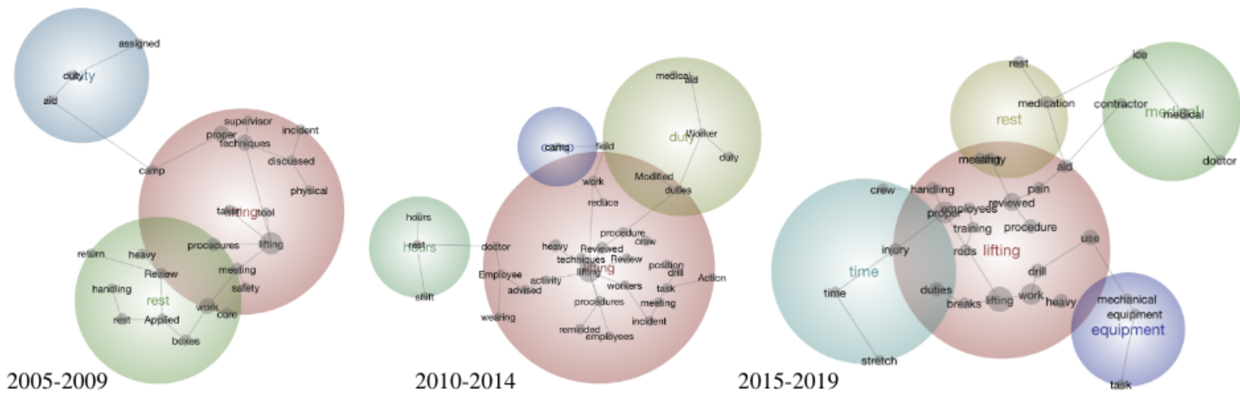

Figure 5. The concept map of seeded terms prevalent within the classifications filed under improper lifting. The themes are listed in order of presentation based on the heat-mapping technique. For the time frame of 2005-2009, three themes were revealed: Lifting (red), Rest (green), and Duty (blue). Within the time of 2010-2014, four themes were revealed: Lifting (red), Duty (green), Hours (blue), and Camp (purple). Within the time period of 2015-2019, five themes were revealed: Lifting (red), Rest (yellow), Individual (green), Time (blue), and Equipment (purple).

Drilling Machinery Related

A total of 528 incidents were filed under the classification of incident type due to drilling machinery related. Through analysis conducted through Leximancer, concept maps were created for each five-year interval (Fig. 6).

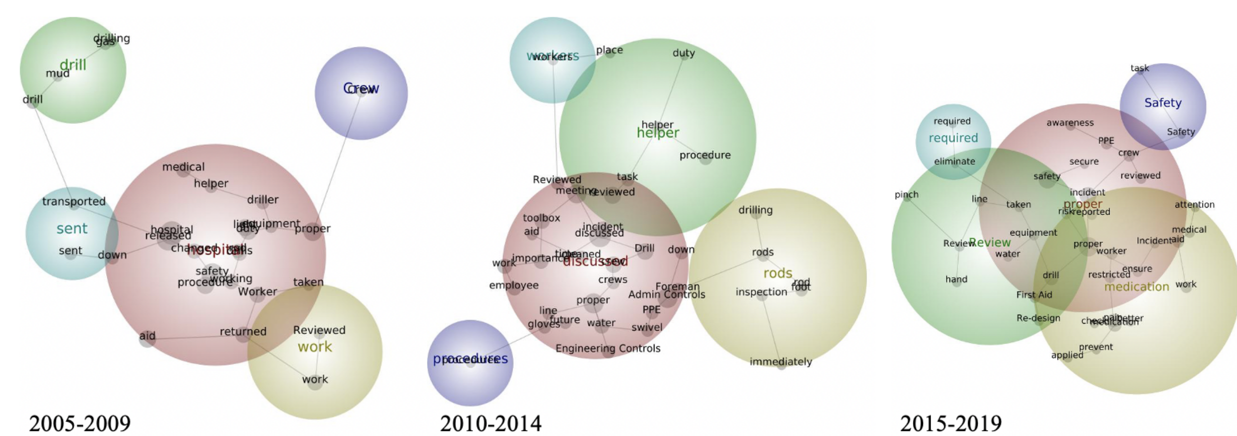

Figure 6. The concept map of seeded terms prevalent within the classifications filed under improper lifting. The themes are listed in order of presentation based on the heat-mapping technique. For the time frame of 2005-2009, the Leximancer analysis resulted in five major themes: Hospital (red), Work (yellow), Drill (green), Sent (blue), and Crew (purple). Within the

period of 2010-2014, the five major themes are: Discussed (red), Rods (yellow), Helper (green), Workers (blue), and Procedures (purple). The five major themes within the years 2015-2019 were: Proper (red), Medication (yellow), Review (green), Required (blue) and Safety (purple).

2. Top five incidents and description analyses

The top five incident types, slips and falls, tool use, light vehicle, improper lifting, and drilling machinery related account for 53% of the total incident count. This is a significant amount considering there are 26 possible incident types, and the top 5 incidents account for more than half of the total dataset. For this reason, the top five incident types were analysed individually. This will show if individuals filling out the survey reports are using the same key words when describing incidents. These key words, called seeds, will be highlighted to show the main concepts involved within each incident type.

Slips and Falls

Based on the output (Fig. 7; Fig. 8), 39 word-like concepts, and 2 name-like concepts emerged. The 42 concepts are displayed on the heat map and spread out between the five themes: Slipped (red) containing 23 of the 42 concepts, Fell (yellow) containing 11 concepts, Employee (green) consisting of 9 concepts, Snow (blue) consisting of 3 concepts and Wearing (purple) containing one main concept. Seven of these concepts overlap, hence why the cumulative total is greater than the total concepts emerged. Slipped had 755 hits, fell had 421 hits, employee had 315 hits, snow had 57 hits and wearing had 19 hits.

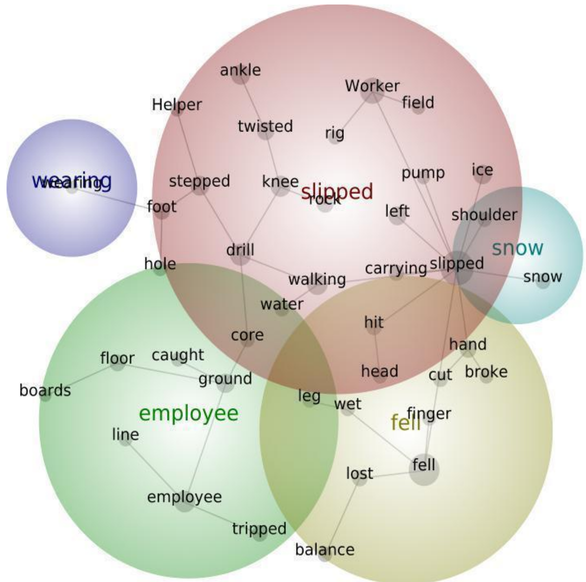

Figure 7. The concept map of seeded terms within the five major themes. This concept map is generated from the data consisting of the incident type, slips and falls, across the entire dataset.

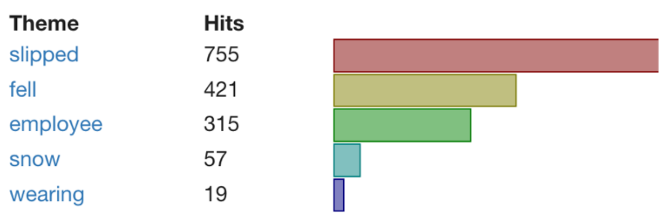

Figure 8. The analysis synopsis showing the number of times each theme was recorded within incident type slips and falls. Within operational setting of Leximancer, theme size was set to default setting of 60%, hence the number of hits is relative to the number of themes generated.

Tool Use

Based on the output, a total of 48 concepts emerged. The concept map generated by Leximancer (Fig. 9) visually displays the results of the output: Finger (red) 11, Drill (green) 15, Hit (yellow) 5, Camp (purple) 1, with 16 overlapping concepts.

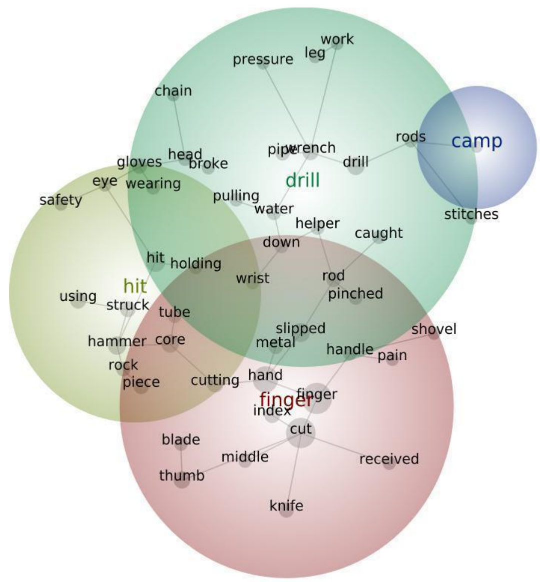

Figure 9. The concept map of seeded terms within the four major themes. This concept map is generated from the data consisting of the incident type, tool use.

Light Vehicle

Through the iterative process, 45 word-like concepts in the thesaurus were identified (Fig. 10). These 45 concepts are spread-out within five main themes. These five themes are as follows, in order of heat-mapping relevance: Truck (red), Road (yellow), Damage (green), Camp (blue), and Brake (purple).

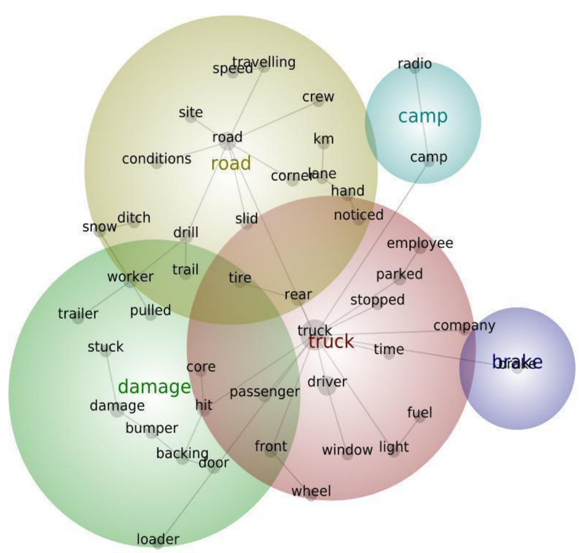

Figure 10. The concept map of seeded terms within the five major themes. This concept map is generated from the data consisting of the incident type, light vehicle.

Improper Lifting

Examining the descriptions of the events classified under improper lifting, 36 word-like and 3 name-like concepts were identified (Fig. 11). Of these 39 seeds, 21 concepts overlapped, which is important to note that there is similarity in which the incident reports were filled out.

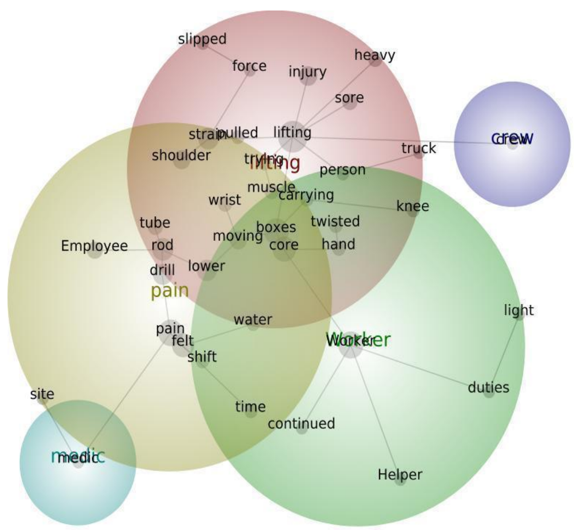

Figure 11. The concept map of seeded terms within the five major themes: Lifting (red), Pain (yellow), Worker (green), Medic (blue), and Crew (purple).

Drilling Machinery Related

Based on the output, a total of 45 concepts emerged, 42 word-like and 3 name-like. The concept map generated by Leximancer (Fig. 12) visually displays the results of the output: Rod (red), Drill (yellow), Driller (green), and Noticed (purple).

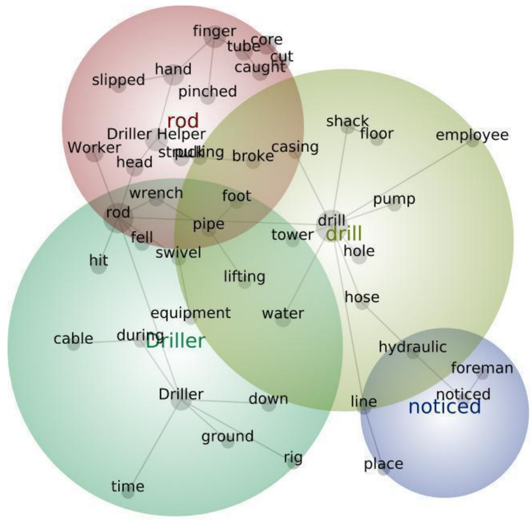

Figure 12. The concept map of seeded terms within the four major themes within drilling machinery related incident type.

3. Personnel and related descriptions analysis

This section will address the key occupations within mineral exploration and the associated OHS concepts extracted from the event descriptions.

Contract Workers

Of the 3,853 documented employment statuses, 1,385 incidents involved contract workers, accumulating 36% of the total recorded incidents. For this reason, contract workers have been selected as a key factor to examine. The Leximancer analysis revealed five overall themes (Fig. 13): Drill (red), Finger (yellow), Truck (green), Helicopter (blue), and vehicle (purple). Within the five themes, four specifically were of importance based on the number of times each concept was detected. The top four themes are relatively close with the number of times each concept was detected, however there is a large gap between the fourth and fifth theme (Fig. 14).

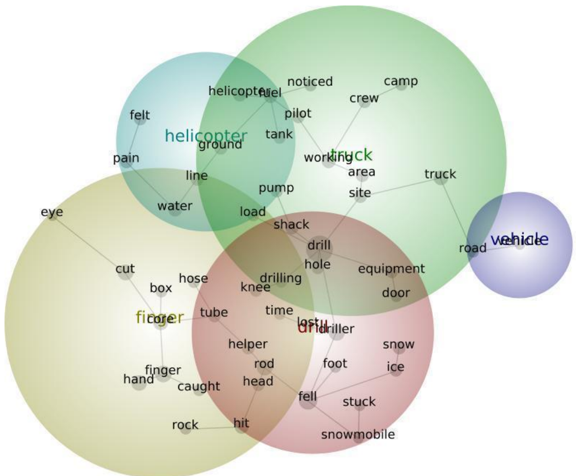

Figure 13. Leximancer concept map of the incidents classified under contract workers, representing the five themes and related world-like concepts.

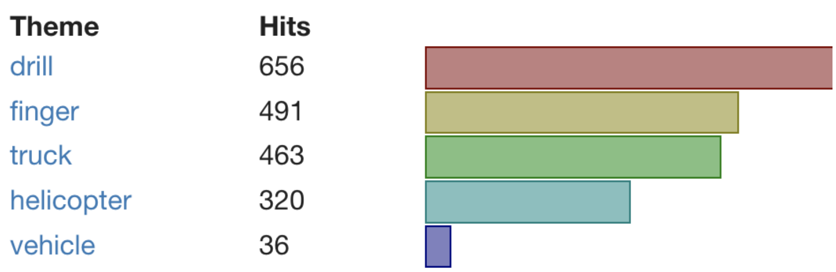

Figure 14. The analysis synopsis showing the number of times each theme was recorded within incident descriptions involving contract workers. Within operational setting of Leximancer, theme size was set to default setting of 60%, hence the number of hits is relative to the number of themes generated.

Driller

Within the dataset, a total of 881 incidents were recorded with Driller as being the main occupation. Within these incidents, four major themes prevailed (Fig. 15): Drill (red), Rod (yellow), Worker (green), Road (purple). Within this, 51 major concepts were pulled out. Some of these concepts are shown in figure 16, capturing the concepts that were most relevant in the dataset.

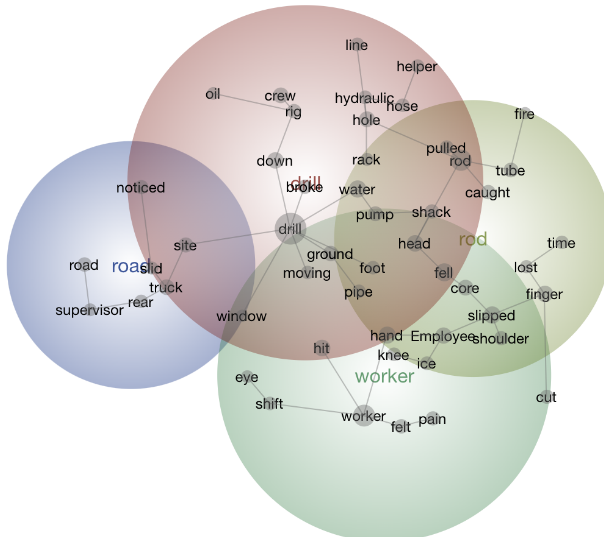

Figure 15. Leximancer output of incidents classified as driller as the occupation. The concept map shows the four major themes and displays them via a heat-mapping system.

drill	268	100%
worker	156	58%
rod	123	46%
fell	82	31%
slipped	69	26%
hit	68	25%
down	65	24%
water	63	24%
hand	63	24%
truck	63	24%
finger	60	22%
head	54	20%

Figure 16. The top 12 word-like concepts associated with the concept map for the occupations recorded as 'Driller' (Fig. 15). Within the operational setting of Leximancer, theme size was set to default setting of 60%, hence the number of hits is relative to the number of themes generated.

Driller Helper

Drill Helper is by far the most stated occupation within this dataset, making up 1,349 of the total incidents. The Leximancer analysis of these 1,349 descriptions generated five major themes, displayed in a heat-mapping scheme (Fig. 17): Rod (red), Drill (yellow), Pain (green), Truck (blue), and Aid (purple). Within these five themes, 50 word-like concepts were generated.

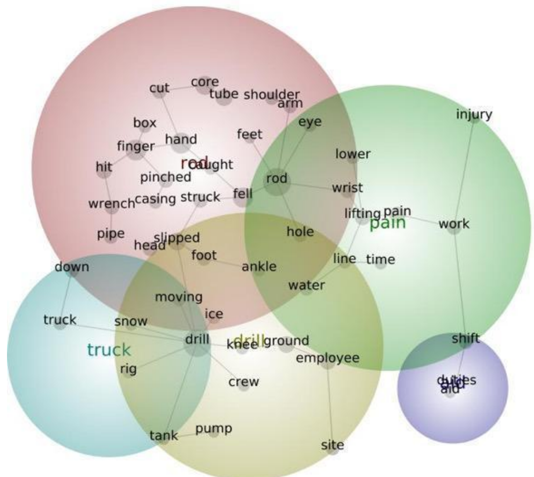

Figure 17. Leximancer output of incidents classified as 'Driller Helper' as the occupation. The concept map shows the five major themes and displays them via a heat-mapping system.

Field Assistant

A cumulative total of 519 incidents were filed under 'field assistant' as the occupation. That data was entered into Leximancer and the results were conveyed in a heat-mapped concept map (Fig. 18). The analysis revealed seven themes within the data: Slipped (red), Knee (yellow), Drill (light green), Pain (green), Water (blue), Bear (teal), and Wet (purple). Within these seven themes, 44 word-like and one name-like concepts were revealed.

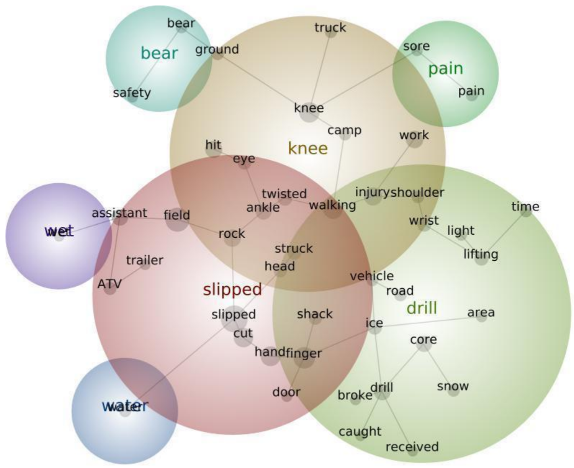

Figure 18. Leximancer concept map of incidents classified under 'field assistant'. This concept map shows the seven major themes and associated concepts.

Field Work

687 incidents were classified under 'field work' as the occupation. The Leximancer analysis revealed five themes (Fig. 19): Fell (red), Injury (yellow), Camp (green), Snow (blue) and Core (purple).

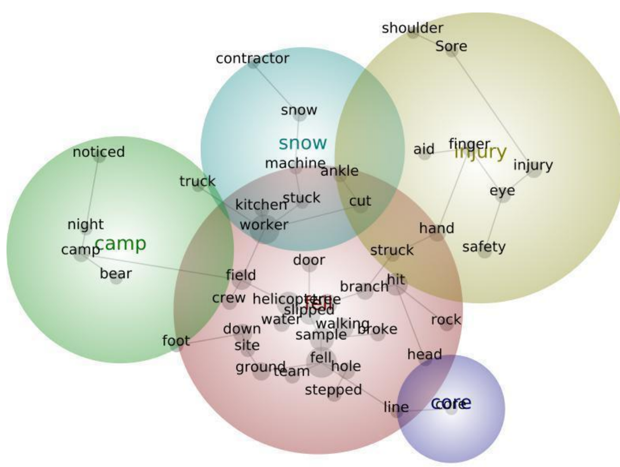

Figure 19. Leximancer concept map of incidents classified under 'field work'. This concept map shows the five major themes and associated concepts.

Geology Related

Geologist (n=589), Geophysicist (n = 125), and Geological Technician (n=12) were grouped together for this analysis. The reason for grouping is because preliminary data of each of these three occupations resulted in very similar themes and word-like concepts. Together, these three occupations make up for 726 incidents. The analyses of these incidents resulted in four major concepts (Fig. 20): Core (red), Truck (yellow), Helicopter (green), and Camp (purple). Within these, 46 word-like concepts emerged, which relate to the grey lines within the map.

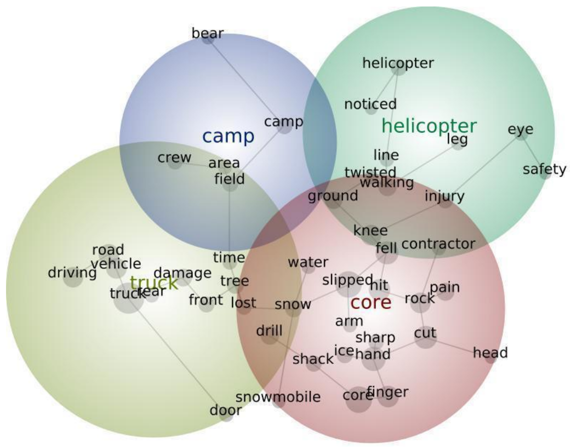

Figure 20. Leximancer concept map of incidents classified under 'Geologist, Geophysicists and Geological Technician'. This concept map shows the four major themes and associated concepts.

Heavy Equipment Operators & Light Vehicle Operators

For this analysis, Heavy Equipment Operators (n = 71) and Motor Vehicles Operators (n = 232) have been grouped together. This is because a preliminary Leximancer analysis showed a high result of the same seed concepts. To avoid redundancy, these have been grouped. The Leximancer analysis revealed five prominent themes (Fig. 21): Truck (red), ATV (yellow), Loader (green), Time (blue), and Contact (purple). A total of 46 word-like and one name-like concept was extracted.

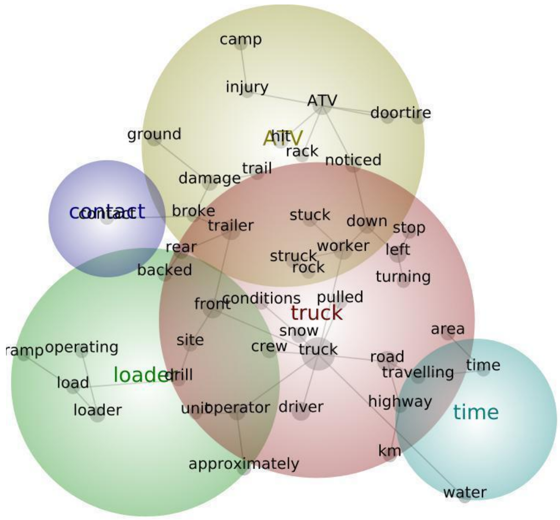

Figure 21. Leximancer concept map of incidents classified under ‘Heavy Equipment Operator, and Motor Vehicle Operator’. This concept map shows the five major themes and associated concepts.

Pilot

The occupation ‘pilot’ is not ranked as one of the occupations with the highest count, with 57 entries, however, was chosen for analysis based on the risk associated with the occupation. The Leximancer concept map revealed two themes (Fig. 22): Helicopter (red) and Pilot (green). Within these two themes, 27 word-like concepts emerged.

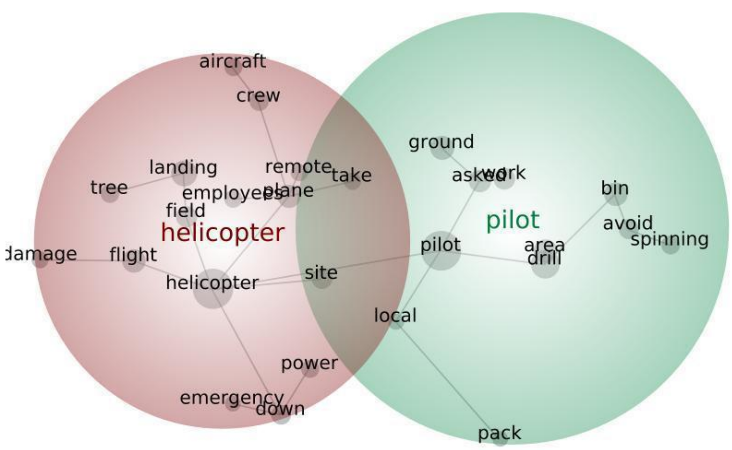

Figure 22. Leximancer concept map of incidents classified under ‘Pilot’. This concept map shows the two major themes and associated concepts.

5.0.2.1 THEORETICAL FRAMEWORKS AND MODELS

The Safety Pyramid

For the safety pyramid, ratios were determined based on the number of incidents falling into each hierarchical category: major injury, minor injury and near hit incidents. These outcomes were matched to existing knowledge regarding the safety pyramid. The safety pyramid designed by H.W Heinrich suggests that for every major injury, 29 minor injuries and 300 near hits will occur, resulting in the ratio of 1:29:300. Within the dataset, fatalities were analysed for the major injuries, first-aid, medical-aid and non-medical were included for minor injury analyses, and near miss/near hit made up the near hit category.

The data reveals six fatalities, 3,171 minor injuries, and 1,733 near misses, resulting in a ratio of 1:528:288. According to this ratio, for every 1 fatality, there would likely be 528 minor injuries and 288 near misses.

The Swiss Cheese Model

Applying the swiss cheese model to this data, guidelines were followed from research conducted by Bonsu et al. (2016). This follows a framework focusing on a systems approach, categorizing data into three divisions: causal analysis, agency and barrier analysis and metadata. Casual framework analyses incident causality consists of categorizing data into three components: direct cause, workplace factor and systemic factor. Agency and barrier analysis is best used for individual incidents where specific information regarding potential safety barriers is broken down. The metadata section is best described as descriptive data within the data set. The metadata highlights information about the incident that may have influenced the incident. Some of the data could include day of incident, place of incident, employment status, age of victim or work experience (Bonsu et al., 2016). For the first analysis, causal analysis will be conducted. With respect to the dataset, direct cause is associated with personnel factors, workplace factors include workplace and task factors, and systemic factors relate to organizational factors. The nature of the dataset is not conducive to analyse each incident individually, therefore, incidents falling within the top three activities will be evaluated: drilling, field work and travel, and transportation. For this research, an analysis of the causal factors was examined as it provides a broadened perspective of barriers that might exist in relation to incident causation. Leximancer (Version 5.0, 2021, Leximancer Pty Ltd., University of Queensland) was used to extract key themes and related word-like concepts. The results of this analysis will highlight the 'holes' in the layers of causality; in relation to the swiss cheese model, representing the active and latent failures.

Agency and barrier analysis are made up of two categories, safety barriers and incident-causing agencies. Since the present data is not conducive to display the safety barriers in place, the incident-causing agencies will be examined by identifying the nature of injury within the corresponding top three activities. Specifically, the agencies involved in the incidents are the source of which damage or harm was undue. Lastly, metadata is best described as data about the data, that considers various factors that may have influenced the incident occurring. To examine metadata, the present data will be broken down in relation to the corresponding top three activities to show various factors including: day or night, male or female, contractor or employee status, and place of the incident.

1. Drilling

2306 incidents were filed under drilling related activity.

Causal Analysis

Table I. Mapping of the incident causal factors for drilling related activities.

Incident Type	Direct Cause	Workplace Factor	Systemic Factor
Drilling Related Machinery (n=456)	Rod (n =143); Water (n=20); Foot (n=9); Shoulder (n=9); Hydraulic (n=8)	Rod (n=100); Hit (n=34); Line (n=15); Rig (n=13); Overshot (n=9)	Slightly (n=3); Struck (n=2); Hand (n=2)
Tool Use (n=290)	Hand (n=76); Worker (n=62); Piece (n=10); Water (n=7); Leg (n=6)	Finger (n=57); Wrench (n=36); Drill (n=34); Hammer (n=14)	N/A
Improper Lifting (n=215)	Pain (n=76); Shoulder (n=50); Rods (n=13); Site (n=12)	Pain (n=45); Lifting (n=43); Helper (n=14); Sore (n=9); Tube (n=8)	N/A
Slip / Fall (n=350); Figure 23.	Drill (n=63); Shoulder (n=25); Walking (n=20); Knee (n=15); Pain (n=8)	Fell (n=130); Slipped (n=125); Foot (n=39); Site (n=14); Hazard (n=12); Drilling (n=9)	Feed (n=5); Lifted (n=4); Hand (n=2)

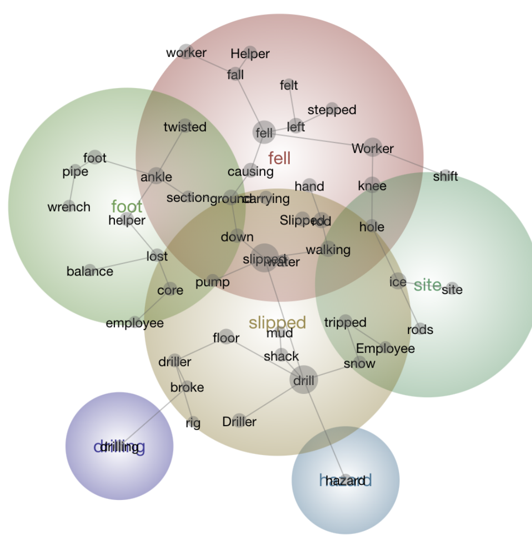

Figure 23. Leximancer concept map of incidents recorded under drilling related machinery, with slip / fall as the contributory factor. From this concept map, analysis was broken down into the three categories, direct, workplace and systemic factors.

Agency and barrier analysis

Table II. Mapping of the incident-causing agencies within drilling related activities.

Incident Type	Incident-Causing Agencies
Drilling Related Machinery (n=456)	None (n=152); Bruise / Muscular (n=126); Cut (n=65); Skeletal (n=23); Sprain (n=20)
Tool Use (n=290)	Cut (n=79); Bruise / Muscular (n=55); None (n=44); Skeletal (n=16); Cut (n=15)
Improper Lifting (n=215)	Sprain (n=51); Bruise/Muscular (n=50); Skeletal (n=7); None (n=7)
Slip / Fall (n=350)	Bruise / Muscular (n=110); Sprain (n=83); None (n=96); Skeletal (n=31)

Metadata

Table III. Mapping of metadata within drilling related activities.

Incident Type	Occupation	Employment Status	Gender	Day Vs. Night
Drilling Related Machinery (n=456)	Driller Helper (n=29); Driller (n=142)	Employee (n=203); Unknown (n=138); Contractor (n=92)	Male (n=306); Unknown (n=116); Female (n=1)	Unknown (n=183); Day (n=153); Night (n=86)
Tool Use (n=290)	Driller Helper (n=143); Driller (n=65)	Employee (n=128); Unknown (n=77); Contractor (n=57)	Male (n=191); Unknown (n=56)	Unknown (n=105); Day (n=96); Night (n=48)
Improper Lifting (n=215)	Driller Helper (n=128); Driller (n=46)	Unknown (n=82); Employee (n=77); Contractor (n=46)	Male (n=146); Unknown (n=68); Female (n=1)	Unknown (n=99); Day (n=66); Night (n=40)
Slip / Fall (n=350)	Driller Helper (n=180); Driller (n=87)	Employee (n=130); Unknown (n=110); Contractor (n=87)	Male (n=229); Unknown (n=78)	Day (n=129); Unknown (n=116); Night (n=61)

2. Field Work

1533 incidents were filed under field work related activity.

Causal Analysis

Table IV. Mapping of the incident causal factors for field work related incidents.

Incident Type	Direct Cause	Workplace Factor	Systemic Factor
Slip / Fall (n=374)	Fell (n=59); Knee (n=31); Area (n=10); Tripped (n=8); Free (n=3)	Fell (n=149); Slipped (n=141); Hand (n=48); Ice (n=18); Injury (n=15); Helicopter (n=11)	Twisted (n=2); Ankle (n=2); Worker (n=2)
Tool Use (n=161)	Hand (n=45); Chain (n=10); Striking (n=7); Sample (n=5)	Finger (n=37); Cut (n=33); Aid (n=6); Leg (n=5)	N/A
Field Work (n=160)	Employee (n=38); Hand (n=15); Helicopter (n=4); Survival (n=4)	Employee (n=28); Cut (n=9); Day (n=9); Aid (n=6); Work (n=3)	N/A
Improper Lifting (n=94)	Pain (n=40); Bag (n=11); Injured (n=5); Contractor (n=4)	Pain (n=16); Strain (n=9); Sore (n=6); Work (n=5)	N/A

Agency and barrier analysis

Table V. Mapping of the incident-causing agencies within field work activities.

Incident Type	Incident-Causing Agencies
Slip / Fall (n=374)	None (n=92); Bruise/Muscular (n=82); Sprain (n=81); Cut (n=46); Skeletal (n=22)
Tool Use (n=161)	Cut (n=61); None (n=37); Bruise/Muscular (n=28); Sprain (n=5); Cut (n=5)
Field Work (n=160)	None (n=37); Cut (n=26); Sprain (n=9); Bruise/Muscular (n=8);
Improper Lifting (n=94)	Bruise/Muscular (n=28); Sprain (n=16); Skeletal (n=8); Cut (n=3)

Metadata

Table VI. Mapping of metadata within field work activities.

Incident Type	Occupation	Employment Status	Gender	Day Vs. Night
Slip / Fall (n=374)	Field Work – Not Specific (n=97); Field Assistant (n=78); Geologist (n=69); Other (n=45); Driller Helper (n=14); Labourer (n=12)	Unknown (n=146); Employee (n=133); Contractor (n=66); Visitor (n=2)	Male (n=172); Unknown (n=110); Female (n=46)	Day (n=173); Unknown (n=147); Night (n=9)
Tool Use (n=161)	Field Work – Not Specific (n=53); Field Assistant (n=33); Geologist (n=17); Labourer (n=11); Line Cutter (n=8)	Employee (n=54); Unknown (n=52); Contractor (n=42)	Male (n=68); Unknown (n=39); Female (n=19)	Day (n=79); Unknown (n=46); Night (n=8)
Field Work (n=160)	Field Work – Not Specific (n=45); Geologist (n=22); Field Assistant (n=17); Other (n=5); Surveyor (n=4)	Employee (n=62); Contractor (n=23); Unknown (n=18); Visitor (n=2)	Male (n=55); Female (n=29); Unknown (n=10)	Day (n=84); Unknown (n=8); Night (n=2)
Improper Lifting (n=94)	Field Work – Not Specific (n=30); Field Assistant (n=18); Geologist (n=13); Other (n=10); Labourer (n=6)	Unknown (n=40); Employee (n=27); Contractor (n=22)	Male (n=41); Unknown (n=19); Female (n=6)	Day (n=33); Unknown (n=29); Night (n=5)

3. Travel – Transportation

851 incidents related to travel – transportation activities.

Causal Analysis

Table VII. Mapping of the incident causal factors for travel – transportation related incidents.

Incident Type	Direct Cause	Workplace Factor	Systemic Factor
Light Vehicle (n=335)	Truck (n=225); Drill (n=192); Employee (n=178); Helicopter (n=32)	Truck (n=304); Drill (n=178); Fuel (n=29); Camp (n=27); Trailer (n=14)	Helicopter (n=27); Property (n=10)
Helicopter (n=87)	Pilot (n=72); Load (n=27); Fell (n=8); Floor (n=2)	Pilot (n=67); Slinging (n=13); Tail (n=9); Field (n=8); Light (n=6); Engineer (n=5)	Drill (n=24); Field (n=10); Door (n=5); Site (n=2)
ATV (n=62)	Trailer (n=49); Employee (n=44); Road (n=35); Broken (n=5)	Road (n=26); Trailer (n=23); Caused (n=11); Rolled (n=6); Drilling (n=2)	N/A
Heavy Equipment (n=61)	Trailer (n=46); Worker (n=35); Rock (n=10); Driver (n=4); Rig (n=4); Approached (n=3)	Engine (n=37); Operator (n=34); Skidder (n=7); Forklift (n=3)	Tires (n=4); Driver (n=2)

Agency and barrier analysis

Table VIII. Mapping of the incident-causing agencies within travel – transportation activities.

Incident Type	Incident-Causing Agencies
Light Vehicle (n=335)	None (n=308); Bruise/Muscular (n=8); Cut (n=6); Skeletal (n=2)
Helicopter (n=87)	None (n=79); Sprain (n=2); Cut (n=2); Bruise/Muscular (n=1)
ATV (n=62)	None (n=22); Skeletal (n=13); Bruise/Muscular (n=12); Sprain (n=2)
Heavy Equipment (n=61)	None (n=48); Skeletal (n=3); Cut (n=2); Sprain (n=1)

Metadata

Table IX. Mapping of metadata within travel – transportation activities.

Incident Type	Occupation	Employment Status	Gender	Day Vs. Night
Light Vehicle (n=335)	Motor Vehicle Operator (n=76); Geologist (n=70); Driller (n=44); Other (n=43); Driller Helper (n=19); Labourer (n=18)	Employee (n=174); Unknown (n=75); Contractor (n=52)	Male (n=185); Unknown (n=76); Female (n=27)	Day (n=183); Unknown (n=73); Night (n=36)
Helicopter (n=87)	Other (n=30); Geologist (n=13); Pilot (n=10); Driller (n=6); Motor Vehicle Operator (n=5)	Unknown (n=37); Contractor (n=32); Employee (n=10)	Male (n=38); Unknown (=37); Female (n=3)	Day (n=46); Unknown (n=31); Night (n=1)
ATV (n=62)	Field Assistant (n=14); Driller (n=14); Geologist (n=10); Motor Vehicle Operator (n=9); Driller Helper (n=8)	Unknown (n=43); Employee (n=12); Contractor (n=5); Visitor (n=1)	Unknown (n=34); Male (n=19); Female (n=7)	Unknown (=44); Day (n=14); Night (n=2)

Heavy Equipment (n=61)	Heavy Equipment Operator (n=18); Other (n=14); Driller (n=8); Motor Vehicle Operator (n=5); Drill – Not Specific (n=4)	Unknown (n=22); Employee (n=15); Contractor (n=11)	Male (n=28); Female (n=19)	Unknown (n=22); Day (n=18); Night (n=6)

HFACs Model

The HFACs model was analysed via contributory factors identified within the data set. The data was sorted based on each contributory factor: workplace, task, personnel, and organizational factor. The HFAC model evaluates four levels of failures that contribute to incident occurrence (Fig. 24.): (1) unsafe acts, (2) preconditions for unsafe acts, (3) unsafe supervision, and (4) organisational influences. Therefore, the data was subdivided into categories that relate to each theme. Unsafe acts consisted of injuries classified as personnel factors within the data set. Preconditions for unsafe acts included incidents classified under workplace factors. Unsafe supervision included data classified under task factor, and organizational influences included data that was classified as organizational factors within the set.

Leximancer analysis was conducted to identify the themes and concepts within the entire system, ultimately those that allowed the incident to occur. The analysis determined the number of times each factor was mentioned and the themes within: Unsafe acts (n = 1107) (Fig. 25), Preconditions for unsafe acts (n = 3505) (Fig. 26), Unsafe supervision (n = 1751) (Fig. 27), and Organisational influences (n = 184), (Fig. 28).

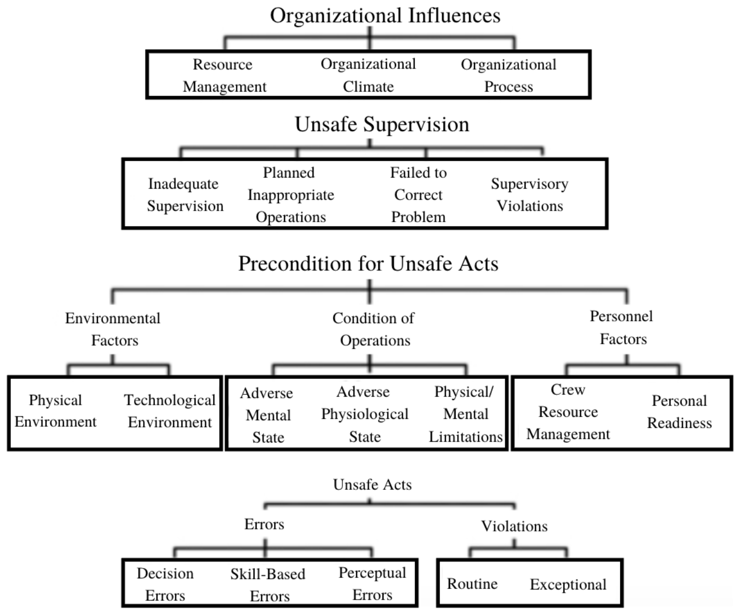

Figure 24. HFACS taxonomy framework of the four levels of failures that contribute to incident occurrence (*Human factors analysis and classification system*, 2021) adapted by Bond (2022).

Unsafe Acts

Figure 25 depicts the Leximancer concept map, displaying the four major themes: Drill (red), Worker (yellow), Truck (green), and Site (purple). The themes and word-like concepts will be analysed to determine if incidents described within this category do represent personnel factors.

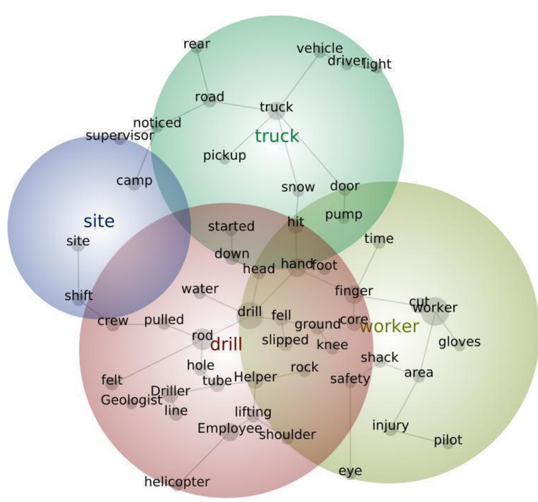

Figure 25. Leximancer concept map of the incidents classified as personnel factors representing the four themes and related world-like concepts.

Preconditions for Unsafe Acts

Figure 26 depicts the Leximancer concept map, displaying the five major themes: Drill (red), Employee (yellow), Truck (green), Driller (blue), and Camp (purple). The themes and word-like concepts were then examined to determine if incidents described within this category do represent workplace factor events.

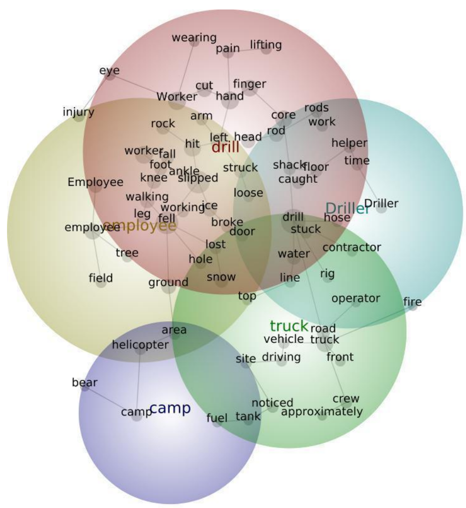

Figure 26. Leximancer concept map of the incidents classified as workplace factor representing the five themes and related world-like concepts.

Unsafe Supervision

Figure 27 depicts the Leximancer concept map, displaying the five major themes: Hand (red), Drill (yellow), Truck (green), Crew (blue), and Driller (purple). The themes and word-like concepts will be analysed to determine if incidents described within this category does represent task factors.

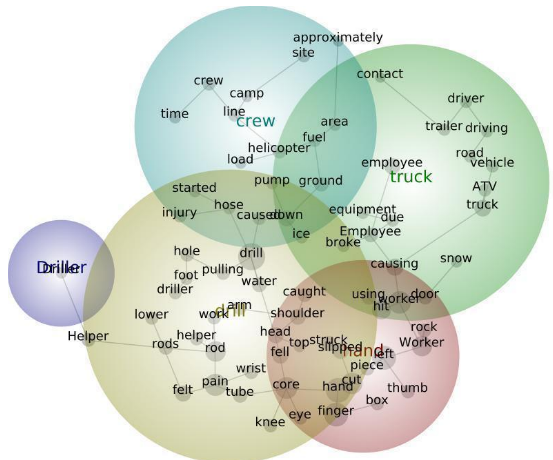

Figure 27. Leximancer concept map of the incidents classified as task factors representing the five themes and related world-like concepts.

Organisational Influences

Figure 28 depicts the Leximancer concept map, displaying the four major themes: Drill (red), Employee (yellow), Sling (green), and Field (purple). The themes and word-like concepts will be analysed to determine if incidents described within this category does represent organizational factors.

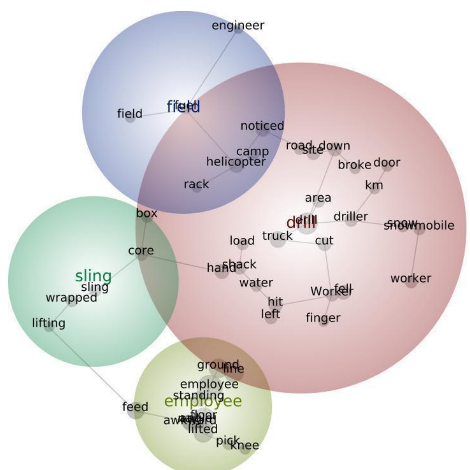

Figure 28. Leximancer concept map of the incidents classified as organizational factors representing the four themes and related world-like concepts.

CHAPTER 6

6.0 DISCUSSION

This study retrospectively analysed health and safety reports within the mineral exploration field, for the past 15 years. The purpose of this study was to determine areas of importance relating to various factors within the field, and to identify the relationships between such factors. The product of this study has captured the unique nature of the mineral exploration field by providing evidence into why and how injury occurrence prevails.

6.1 QUALITATIVE ANALYSIS

Qualitative analysis was conducted in two stages, Leximancer analysis and theoretical framework analyses. Both will be discussed to identify areas of importance within the dataset. The individual concepts and themes pulled from the Leximancer analysis will be represented within the text below by *italicized font.*

6.1.1 LEXIMANCER ANALYSIS

1. Incident Type compared to actions taken, over five-year intervals

Slips and Falls

The descriptive textual entries for each injury, classified as a slip or fall, are depicted by the concept map (Figure 1), showing the themes present between the fifteen-year intervals. The terms change; however a theme emerges from all three time intervals: *team meetings*, *toolbox meetings* and *safety*. The themes *meeting* and *toolbox* include the top hits between 2005-2014, whereas *safety* is the second highest hit for the year 2015-2019. All entries pertaining to these themes were reviewed to see the context in which the themes were used. After review, these themes are coming from the context that team meetings or toolbox meetings were in fact held, opposed to the context of no team meeting or toolbox meeting held. This finding is consistent with what is expected in the literature, as toolbox training has been noted to be a highly important component within safety management (Varley & Boldt, 2002). Toolbox training is defined as brief and informal training or discussions conducted on site by a competent person, either pre-task or post-incident, with the intention of bringing together the work team to discuss, teach, or learn ways to enhance the working environment (Varley & Boldt, 2002; Weinstock & Slatin, 2012; Al-shabbani, 2019). In relation to this data, it is encouraging that emphasis is continually placed on toolbox meetings as such discussions can bridge the gap between safety standards and behavioural intentions relating to hazard identification and incident prevention. The occurrence of the term *safety* shows that there is a level of safety culture where personnel are reiterating the importance of safety in the post-incident toolbox meetings. A safety culture that focuses on toolbox meetings and safety encouragement promotes an environment where workers can be open to discuss their experiences and knowledge, and provides learning opportunities. Wallerstein (1992) states that empowerment education is a component of safety culture that has the goal of worker action and empowerment, and if the workers are engaged in the discussions, a greater knowledge translation is gained (Eggerth et al., 2018). This fosters an environment that encourages the individuals to comfortably discuss skills, knowledge, and past experiences during the informal toolbox sessions, which facilitates learning across all levels of worker experience (Eggerth et al., 2018). The benefits found within toolbox training can be correlated to the reduction of incidents due to workers' improvement of safety knowledge, hazard identification skills and increased safety behaviour (Al-shabbani, 2019; Jeschke et al., 2017; Kaskatus et al., 2016). With this, previous research has shown that working environments involving multiple job sites with a mix of professions provides a challenging environment in terms of implementing initiatives that promote a safety culture (Lehtola et al., 2008). Despite the constraints inherent within the field that can impede the fostering of a safety culture, toolbox training is just one approach that can be implemented to open OHS dialogue between foreman and workers. On the contrary, even though toolbox meetings came up a lot, suggesting that there was in fact a meeting, the incident still happened. This view could suggest that maybe toolbox meetings aren't very productive if they are not delivered in a proper manner that is conducive to the field environment, as in the field these discussions are often informal in nature (Jeschke et al., 2017). Factors that can enhance toolbox talks can include, but are not limited to: open dialogue for workers to express concerns, offering learning opportunities, and supervisor support (Eggerth et al., 2018; Flin et al., 2000; Cooper, 2018). As the analysis revealed these discussions take place after the incident, another consideration would be to initiate pre-task toolbox talks, as these have shown to increase workers level of awareness of potential hazards and proper preventative safety controls prior to starting a work task(Al-shabbani, 2019; Olson et al., 2016).

The second notable finding within the Leximancer analysis is the reoccurrence of the theme *work* in all three analyses. The term *work* was recognized in two dominant contexts, *return to work* and *work conditions*. Return to work in a clinical setting means the procedural steps taken to integrate an injured worker back into the workforce, by modifying job tasks if appropriate. Generally, a return-to-work plan is created by safety personnel with the appropriate knowledge of steps that need to be taken to safely integrate the worker back into the job. In this case, return to work was used as a follow up statement after some sort of intervention, such as first aid or time off, was needed. Rarely in the field did workers require a formal return-to-work plan, but rather were permitted to go back to their normal duties after the injury was addressed. This suggests that many injuries were classified as minor, and generally did not require a formal safety plan or invasive medical treatment. The incidents relating to *work* addressed factors that could have played a role in the incident occurrence. All entries stated either *workload*, *work conditions*, *work environment*, or *work procedures*; this shows a sense of awareness of surroundings by the individuals involved, and a level of assessment by safety management in the period following the incident. Follow-up statements to these injuries placed emphasis on the need for workers to be aware of their working conditions and suggested adjustments that should have been taken to address task hazards and reduce injury occurrence.

Tool Use

The descriptive textual entries for each injury classified as tool use is depicted by the concept map (Figure 3), showing the themes present between the fifteen-year intervals. The top theme that is present over two of the three five-year intervals is *work*. There are two dominant themes related to *work*: *return to work* and *working conditions*. Within this, the main concepts that break down the incidents involving the theme *work* are *hospital, aid, medical, bandaged, worker* and *wound.* These concepts give more insight into the incidents to show whether they relate to return to work or working conditions. Conclusions can be drawn just from looking at these concepts to see what level of injury was sustained; it seems as though there is a mix of lesser scale injuries and injuries requiring medical treatment. *Hospital* and *medical aid* indicate the incidents resulted in an injury where medical attention was needed. *Wound* is also one of the most common themes, showing that the incidents were severe enough to break the skin and create an open wound. More frequently the theme of *return to work* was stated over working conditions, this can be attributed to the injuries sustained related to the nature of the work. Due to the fact many of the incidents resulted in some sort of medical intervention, return to work discussions would be required. Return to work discussions involve foreman or safety management formally discussing options with the worker on safe ways to integrate the worker back into the environment, including modified duties, reduced working hours or change in working environment all together.

Within all three five-year intervals, safety culture is evident. The years 2005-2009 and 2014-2019 the theme *safety* was the top hit, and the years 2010-2014 the theme *toolbox* was the second highest most prevalent theme. When broken down, the main concepts involved in the theme *safety* were *use, proper, review, job, tools, procedure, workers, hand, reminded,* and *attention.* These concepts give a strong indication that safety culture is an important component within the nature of the working environment. Specifically highlighting the terms *use, proper, review, tools, procedure, reminded* and *attention* are strong indicators that discussions were had with the supervisors to the workers post-incident on the importance of being aware of surroundings, attention to task at hand and importance of being continually educated on proper ways to manipulate tools and conduct tasks. Research has shown that pre-task toolbox talks can bring an added benefit to OHS communication (Al-shabbani, 2019; Olson et al., 2016). Pre-task talks focus on hazards, incident causes and how to mitigate associated risk, and are delivered to the workers before the task is conducted. Briefing the workers pre-task compared to post-incident is beneficial because workers gain an increased level of awareness of potential hazards and proper preventative safety controls (Al-shabbani, 2019; Olson et al., 2016). Having these discussions shows there is a level of commitment to the organisation's health and safety and promotes patterns of behaviour that influence the workers to have the same level of commitment and proficiency to the safety standards (OSH, 2015). The theme toolbox also indicates a presence of safety culture, when broken down the main concepts are *talk*, *importance*, *employee* and *discussed*. These concepts are clear indicators that discussions are being had post-incident with the workers regarding the incidents and corrective actions. This promotes an environment where workers are not afraid to come forward with errors or events leading to the incident as they will not be punished, but rather praised for being honest and aware. These toolbox meetings can be related to components within safety culture, such as safety systems, competence and procedures and rules. Safety systems within the scope of safety culture can be tied to toolbox meetings because these meetings reinforce safety commitment, effective communication, and procedural protocols by openly discussing the incidents (Vecchio-Sadua & Griffiths, 2003; Flin et al., 2003; Brown, Willis & Prussia, 2000). The next component within safety culture is competence, and is reinforced by toolbox meetings as supervisors are reiterating the importance of proper tool handling, review of procedures, and focus of attention to the task. Competent workers are those who are properly educated and qualified for the task, and perceive they have the skills to carry out such tasks (Flin et al., 2000; Cooper, 2018). Having open discussions allows supervisors to review tasks or procedures if needed, enhancing the competency of the workers. The last component of safety culture, procedures and rules, is a big component of toolbox meetings because generally following procedures and rules reflect a top-down approach. This means the attitudes of upper-level personnel can positively influence the behaviours of those around them. Individuals are more likely to follow procedures and rules if they see their superiors adhering to such rules. By having the supervisors reinforce these in toolbox meetings, it shows the workers that there is a standard to be taken when following procedures and rules. With that, following a proper procedure is only one aspect of promoting safety culture and should be further reinforced by the workers actions. Addressing safety components through toolbox discussions are only one part of gaining a positive safety culture, as there is great benefit added if supervisors are actually observing change of workers behaviours through safety leadership skills.

The next dominant theme that is prevalent in two out of the three five-year intervals is *personal protective equipment (PPE)* and *gloves*. The concepts associated with these themes were *correct / incorrect*, and *improper*. Most of the incidents involving *gloves* and *PPE* included statements made that reinforced the importance of wearing PPE when working, such as *improper use of PPE* or *insufficient PPE*. The mention of PPE and gloves again adheres to the safety culture in the organisation. Organisations that lack a safety culture fail to place importance on the use of proper PPE; for example, in relation to the data, this could relate to why in many situations there was no correct PPE worn. On the contrary, organisations that actively speak up about the importance of PPE fosters a stronger safety culture as workers are made aware of the risks and encouraged to protect themselves. Regarding the dataset, it is unclear which level of safety culture is prevalent. Connections can be made to state that a safety culture is prevalent within this working environment based on the previous conclusions drawn and the fact that the statements focus more on the importance of proper PPE. However, due to the frequency in which PPE comes up and the nature of the entries stating either incorrect, improper or reminding workers to wear PPE indicates that rules were not being followed correctly which led to the incident occurrence. This shows there could be a potential general lack of appropriate wear within the workplace, in which more effective rules and awareness should be enforced.

The last theme that is dominant in two of the five-year intervals is *first aid* and *aid*. This is significant in two ways. Firstly, the requirement of first aid or aid in general indicates the injuries sustained were severe enough to require a degree of intervention. First aid refers to a minor incident that requires immediate attention at the location of injury; aid may either be self-administered or provided by another person who is not a medical professional. Medical aid refers to medical treatment administered by a medical professional, such as a nurse or Doctor, and can be on or off site at a hospital or clinic. The nature of injury falling under aid can be small such as a scrape that requires a band aid or a laceration that requires stitches at a hospital. The nature of each injury varies, but the concept of needing medical intervention is constant. Secondly, *first aid* and *aid* being prevalent themes indicates there is a safety culture in place that fosters an environment to promote incident reporting and allows individuals to seek medical attention when needed. Since first aid refers to lesser scale injuries that are treated onsite by non-medical personnel and often by the individual itself, the discretion to report is on the individual who sustained the injury. The fact these incidents were reported rather than being treated and not reported indicates there is a duty the workers feel obligated to report every incident, regardless of scale. It would be easy for the workers to self-administer a Band-Aid, not report and then continue the task since no medical professional or off-site intervention was needed.

The data shows these two terms (Aid and First Aid) were increasing in importance over the time periods, as shown by the introduction and recurrence of these terms in the years 2010 and onwards, demonstrating that individuals who reported the incidents were likely encouraged to keep reporting as required in a longitudinal way across the industry (Figure 3). This finding is an indicator that for the most part workers feel obligated to report even the smallest incidents, alluding to a safety culture that places importance on incident reporting. Although the terms revealed in the analysis allude to a strong adherence to report incidents, by contrast, the findings of the Safety Pyramid as depicted in section 5.0.2.1 would show a ratio of 528:288, demonstrating a substantial number of near misses going unreported. This could be attributed to underreporting, or the severity of injuries sustained within the field. The concept of underreporting and The Safety Pyramid is further discussed in section 6.1.2, theoretical frameworks, and models.

Light Vehicle

The dominant themes within this analysis (Figure 4) reveals trends associated with transparency related to incident causation. *Concerns, procedures, attention, review, discussed* and *meetings* were the prevalent themes relating to a strong safety culture where incidents are openly discussed between supervisors and workers. The first theme, concern, includes concepts such as *crew, debris, discuss, dust, site, speed*, and *driving*. From these concepts workers are speaking about the conditions of the working environment they perceive to be a hazard to safety; *Debris, dust, site, speed*, and *driving* are the main indicators that there could have been external factors present that led to the occurrence of the incident. The following themes, *procedures*, *attention*, and *review*, relate to worker competency, top-down influences of rule and procedure following, and reinforcement of safety systems from an organisational standpoint. These three themes reiterate that within this field with incidents relating to light vehicles, there is a strong reiteration between supervisors and workers on the importance of awareness of surroundings.

The last themes, *discussed* and *meetings*, portrays the notion of healthy communication and the desire for corrective actions to be taken. The meetings and discussions can involve supervisors, foreman, work crew and safety management; it is important to note that discussions between the foreman and the workers, compared to safety management and workers, are most valuable as the perceptions the foreman hold regarding safety practices and climate are best translated to the workers (Zohar & Luria, 200; Zohar, 2010). For such discussions and meetings to be most valuable, the workers must be involved. Meetings that are management-driven with limited worker engagement are least effective at communicating safety needs (Jeschke et al., 2017). It is likely that within the mineral exploration field, like other high-risk industries, the meetings, and discussions are relatively informal and along the lines of toolbox meetings (Jeschke et al., 2017). In these instances, safety management would likely not be present for the toolbox meetings and would likely be between the foreman and crew onsite, before or after shifts.

Improper Lifting

The most important theme, lifting, occurred the most throughout all three of the five-year intervals (Figure 5). This is no coincidence as the injury type was improper lifting, however, what is notable are the concepts that are associated with this theme. The concepts have been grouped into two distinct categories: the first relating to communication, and the second relating to physiological awareness. Within the category of communication, the main concepts were *meetings, reviewed, reminded*, and *advised*. All entries within the Leximancer analysis were reviewed to see the context in which these concepts were used. These concepts, *meetings, reviewed, reminded*, and *advised,* were used in descriptions of the actions taken, after the incident, and were used in the context of discussions happening. This is important to note because it shows that discussions are in fact happening, rather than the textual entries stating that no discussions were had. Once again, these meetings bring together the working team and supervisors to discuss, teach, or learn ways to enhance the working environment (Varley & Boldt, 2002; Weinstock & Slatin, 2012). Focusing on leading indicators, such as safety meetings, are beneficial in high-risk industries as blame is redirected from the individual and allows for the discussion of preventative measures and an open dialogue on those tasks which are likely to lead to injury including ways to mitigate. Open communication that bridges the gaps between safety standards and reality is one of the many ways in which the mineral exploration field will become safer.

Regarding the second category relating to physiological awareness the main concepts were *proper, work, techniques, procedures, position, rest* and *heavy*. These concepts are notable because it shows that time is being taken to review the mechanisms of injury, and possible ways the incident severity could have been minimised. Specifically focusing on bodily awareness such as *proper, work, techniques, position* and *heavy,* reiterates the importance of workers taking care of their actions to preserve and maintain their health. This again alludes to a strong safety culture that places importance on worker health and the scientific consensus on ergonomic principles, rather than production. Workers that feel pressured or rushed to finish a job often disregard the proper safety protocols thereby possibly jeopardizing their own health to complete a task (Cooper, 2018). Key concepts that emerge from the data such as *proper, techniques,* and *position* go against work pressure by showing that organisational systems would rather workers conduct their jobs properly by focusing on correct techniques and positions.

Drilling Machinery Related

The top themes within all three five-year analysis (Figure 6) coincide with the injury severity of the incidents. The themes *hospital, sent, medication* and *require* were some of the most common and all allude to the severity of the injury that was sustained and the interventions that were needed. When broken down the themes reveal the following concepts: *released, aid, light duty, returned, medical, pain,* and *restricted*. Conclusions can be drawn from the concepts alone by showing the nature of injury is relatively severe with incidents involving drilling machinery. Specifically, being sent to the hospital and requiring medication or medical aid show the injuries were not near misses or minor injuries that could be treated onsite with first aid, unlike the previous findings for “Tool Use”. The Leximancer analysis is distinctive in this way as similar themes can have different outcomes allowing for a unique opportunity to compare and contrast various aspects within mineral exploration. There were common key concepts which highlighted in many cases workers sustained injuries that resulted in the need for restricted work or light duties when returning to work. This is significant because the more severe an injury in the field, the more resources would be required. Such resources can include intervention plans to integrate the worker safety back into the work by configuring job tasks to ensure the injured worker remains safe, and adheres to the protocols while in the recovery phase. This underscores the need for more caution when handling drilling related machinery, which is consistent with the literature that states workers are more at risk of injury when working with heavy equipment (Nasarwanji, Pollard & Porter, 2018; Ruff, Coleman & Martini, 2010).

The next theme that is present amongst all intervals is *crew, helper,* and *workers*. When dissected some descriptive entries reveal the context in which the terms helper and crew were used (Figure 29). These entries show a common concern when it comes to working with helpers and that is the helper’s competence is heavily influenced by the upper-level worker. Meaning, the upper-level workers such as Drillers and foreman have a responsibility of ensuring the safety of those working below them. With this responsibility comes the understanding that the helpers should be working safely and following proper protocols. These entries are the perfect depiction of how errors can occur when influences from above are not attentive, thereby causing a chain reaction down the systems. Helpers can lack training, experience, competence, and confidence thereby are unable to identify hazards or follow safety protocols as efficiently as those above them (Groves, Kecojevic & Komljenovic, 2007; Bahn, 2013). Drill foreman or Drillers that are not adhering to implemented safety standards are inadvertently putting themselves and the helpers at a great risk for incident causation. Although every worker should personally be committed to adhering to the safety standards of the organisation, this is not always the case, and the workers' intentions are influenced by their superiors.

It is interesting to note that the concepts within the third time period vary from the previous ten years, as the themes are not particularly focused on the individuals themselves, but rather ensuring proper safety standards and requirements are met within the working environment. This suggests a shift towards a working environment that places a no-blame system on the individuals, and fosters a united understanding on the importance of identification of preventative measures. This thinking is more aligned with an organisation that can better anticipate where failures or vulnerabilities lie by focusing on risk analysis, rather than singularly placing blame on the workers themselves. As opposed to stating crew or helpers, the reports in the recent timer period are increasingly focused on the bigger picture of how and why these incidents might have occurred.

Driller was rushing and not properly training the helper.
Rig Foreman is responsible for the **crew** to **follow procedures**.

Figure 29. Examples of textual entries describing incidents involving the key themes helper and crew. Examples pulled from synopsis of Leximancer analysis for years 2005-2009 and 2010-2014. Blue words indicate frequent concepts pulled from the main themes.

2. Top five incidents and description analyses
Slips and Falls

The first two themes, *slipped* and *fell*, are related to each other and are significant due to the frequent usage of them within incident description, together stated 1176 times. This finding is consistent with the literature, as slips and falls remain one of the top causes of injuries sustained at work (Al-Rubaee & Al- Maniri, 2011; Bell, Gardner & Landsittel, 2000). The main concepts that co-occurred with these themes were *knee, ankle, foot, hand, carrying, hit, lost, twisted, rock, ice and drill*. These concepts can be broken down into three categories: environmental conditions, work related tasks, and anatomical location. The concepts related to environmental conditions are *drill, ice,* and *rock*. One reason why mineral exploration is considered a high-risk industry is the nature of the working environment, the subjectivity to difficult weather conditions and various terrains such as icy and rocky landscapes; additionally, slips and falls are more likely to occur in colder environmental conditions (Figure 30) (Vingård & Elgstrand, 2013; Smith et al., 2015; Singer & Kouda, 1999; Bell, Gardner & Landsittel, 2000). Mineral exploration efforts are conducted year-round, posing greater risk for all those involved, notably those working in the field. Personnel such as geologists and field assistants are at a heightened risk for slips and falls as working duties include traversing through rough terrain, carrying heavy samples and conducting hands-on work (Nolan 1962; Cranstone, 2004). It is no doubt that ice and rock were stated as the most frequent co-occurring themes, as both terrain types naturally increase the level of difficulty for walking (Gao & Abeysekera, 2004; Manning et al., 1991; Sherrington, 2020). Slips occur when there is insufficient resistance between footwear and walkway surface, causing the individual to be unable to counteract the resultant force (Gao & Abeysekera, 2004). The most dangerous and frequent type of slip occurs at the heel strike when the foot is touching down (Manning et al., 1991). It is important to note these two key terms so organisations and individuals can take more precautionary measures when working in such conditions. The specific PPE requirements within the field are difficult to narrow down due to the scope of individuals who would be working in snow and ice covered environments. This being said, a recommendation would be to consider more control over precautionary measures such as wearing high ankle boots when traversing through rocky terrain to limit ankle sprains from slips, pre-mapped routes through less extreme terrain, tethered ropes between workers to take the burden of load during a slip or fall, increasing friction on icy conditions via crampons, salt, or sand where applicable on icy conditions, and increased awareness when walking on certain conditions.

> Worker was carrying a carton of explosives while walking towards a raise. Stepped on a **rock** and **twisted** his **ankle.**
> Walking on the tundra, stepped on **rock**, **twisted ankle.**
> **Slipped on ice, injured knee**
> Stepped on uneven ground while unloading **drill** rods from the tractor and **twisted ankle**
> Worker walking outside from the kitchen facility to dump some garbage when he **slipped** and **fell** on the **icy** walk, injuring his lower back

Figure 30. Examples of textual entries describing incidents involving slips and falls. Examples pulled from synopsis of Leximancer analysis from the entire dataset. Blue words indicate frequent concepts pulled from the main themes slips and falls.

The concepts involved with work related tasks are *carrying, twisted, lost*, and *hit*. *Carrying* and *twist* are two concepts that are directly related to the workers task load; if there is a discrepancy between the workers' perceived capability and the lifting amount, mass or twist angle, there is an increase in the risk of occupational injury (Isa et al., 2013; Barnetson, 2010). Aside from perceived abilities, workers increase their risk of occupational injury if rushing through tasks due to external pressures such as time pressure or product incentives (Flin et al., 2000; Mearns, Whitaker & Flin, 2003). It is important for companies to uphold a positive safety culture that focuses on the workers' wellbeing rather than production or output, as this will translate down to the frontline by reducing external pressures that could potentially result in rushing, lack of awareness or deviating from proper protocols (Mearns, Whitaker & Flin, 2003).

The concept *lost* was generally used in a context where workers lost their footing, resulting in a slip or fall. These cases ranged from individuals physically carrying loads, losing balance, or misplaced footing. The concept *hit* was frequently stated in the context of hitting an object on the descent of a slip. In this context of hitting an object on the descent of a fall, it is important to note that in most cases the injury was not sustained directly by the slip or fall, but rather due to hitting an object on the way down. If the slip or fall did not occur it can be assumed the injury would not have been sustained, but in these cases, it is important to note that the individuals were generally breaking their fall with a body part or falling into something and that is where the injury occurred (Figure 31).

Walking inside the trench, lost footing, **fell** and right **hand hit** a **rock**.
Fell and **hit hand** resulting in sore finger.
Manipulating a rod the driller lost the balance of it and **hit** is driller on the **head.**
Worker **hit** ribs on a toolbox.
Hit knees on **rock**.
Contractor **tripped** and **hit** chin on a spool of wire.

Figure 31. Examples of textual entries describing concepts relating to the word 'hit' within incidents involving slips and falls. Examples pulled from synopsis of Leximancer analysis from the entire dataset. Blue words indicate frequent concepts pulled from the main themes slips and falls.

The most common anatomical locations are *knee, ankle, foot,* and *hand*. The frequent occurrences of these locations are notable, as lower limbs and hands are the two most common body parts to be injured (Love et al., 2019; Sorock et al., 2001; Sorock et al., 2002). In general, injuries related to foot/ankle/toe are likely to result in a more severe level of injury (Love et al., 2019). An increase in severity of injury is related to a greater overall burden to the individual and the organization, by affecting worker morale, creating workplace stigmas, affecting safety culture, and increasing financial burden (Barnetson, 2010; Hrymak et al., 2007). It is interesting to note that injuries related to lower backs and hitting the head were not as prevalent, as the occurrence of these two injury types has long been recognized as a common condition within workplace injuries amongst high-risk occupations (Dasigner et al., 2000; Kontos et al., 2017). Low back pain (LBP) is most related to workplace tasks such as lifting, carrying, and bending, which could be a contributing factor as to why LBP was not stated within injuries related to slips and falls (Dasigner et al., 2000). Concussions from slips and falls would have a high burden to the workplace if these injuries were occuring at a high rate, but the data shows hitting the head is infrequent within this classification (Kontos et al., 2017; Khanzode et al., 2010). After dissecting the text synopsis from the Leximancer analysis, it can be concluded that these specific anatomical locations *knee, ankle, foot,* and *hand* were stated because the individual either broke the slip or fall with their hands or twisted their ankle on an object resulting in the slip or fall. One way for organisations to reiterate the importance of OHS is to look for patterns within incident causation and promote the findings to raise awareness (Altius Group, 2021). These frequently injured anatomical locations are one example of how workplaces can focus on the findings to promote educational pieces regarding at-risk body parts within incident prevention.

Tool Use

The output from the Leximancer analysis revealed four themes with 16 overlapping concepts (Figure 9). Within these themes, there were multiple concepts that frequently occurred. These themes can be broken down into anatomical location, tool use associated with work related tasks, PPE and drilling related activities.

In relation to anatomical location the frequently documented body parts were f*inger, index, thumb,* and *hand*. This finding coincides with literature that has demonstrated hand and finger injuries are the most frequent body parts to be injured at work (Sorock et al., 2001; Sorock et al., 2002; Love et al., 2019; Courtney & Webster, 1999; Kamol, 2018). Specifically, the index finger is most at risk for injury, which relates to the current findings as the index finger was one of the most documented parts on the hand to be injured (Sorock et al., 2002). This finding is highly relevant as the requirement of hand involvement in manipulating tools and operating machinery within mineral exploration is amongst many job descriptions, which increases the risk of hand injury across the field. It is important to note that hand injury susceptibility is reliant on various factors such as tactile ability, perceptual motor skills, job experience, and behavioural complexes like risk-taking (Punnett, 1994; Sorock et al., 2001). This demonstrates the importance of having skilled workers who are compliant to safety protocols and adhere to maintaining high health and safety standards.

The concepts related to tool use associated with work related tasks were *cutting, knife, metal, slipped, hammer, core, struck, hit,* and *rock*. The present data coincides with literature stating that powered machines, small metal objects and non-powered hand tools such as hammers and knives, are more likely to result in injuries compared to other types of tool usage, especially in high-risk industries (Sorock et al., 2002; Dababneh et al., 2004). Additionally, non-powered hand tools are responsible for nearly three quarters of all compensable hand tool injuries (Dababneh et al., 2004). From a safety perspective, the research showing that non-powered hand tools are responsible for a vast majority of incidents suggests that possibly within the field most of safety attention is focused on larger powered tools, leaving a gap when it comes to tools seen as less dangerous. This brings awareness to the fact these non-powered tools result in more incidents and can aid the industry to refine this category of incident. In relation to injuries because of tool use, laceration is the most common type of injury, followed by crush and avulsion (Sorock et al., 2002; Kamol, 2018). Maneuvering tools require a force output by the individual which is called load; reducing the load has been seen to allow better manual control and handling and reduce overall risks associated with load experienced by an individual (McPhee, 2004). This finding shows the importance of ensuring individuals are using machinery and tools that are appropriate for their load capacity. For example, it would be beneficial for the industry to review these small, non-powered hand tools through ergonomic assessments by documentation of which tools are most likely used and the force being applied to find recommendations for more appropriate tool choices (Torma-Krajewski et al., 2007). In turn, having an individual with an altered sense of their perceived capabilities would increase the risk for injury as the load does not meet their physical abilities. Additionally, it is believed that if tools were designed with ergonomics and user comfort in mind, then injuries can be reduced simply due to proper design principles (Dabebneh et al., 2004).

PPE is any type of equipment that an individual physically wears to reduce exposures to hazards of the jobsite; the concepts related to PPE within the data revealed two main concepts, *gloves* and *wearing*. In most instances the descriptive textual entries revealed individuals were wearing some variation of PPE, however the circumstance of the event still managed to result in an injury (Figure 32). In related fields, a reduced injury occurrence is associated with the correct usage of PPE (Nakua et al., 2019). The corrective use of PPE coincides with workers adherence to outstanding safety culture and the hierarchical factors that influence PPE usage and availability, management's role in safety regarding PPE usage needs to be taken into consideration (Ammad et al., 2021). Additionally, the quality of the PPE is an extremely important factor in determining if works ware PPE, as there is an association between workers choosing not to wear PPE if there is inadequate fit, garment comfort and breathability and overall wearability and functionality (Ammad et al., 2021; Hinze & Teizer, 2011). The fact injuries were still sustained brings about a few questions: are individuals educated about which gloves are correct to wear for each work circumstance? Are companies supplying the right range of gloves for different types of work? And, are the Drillers and Drill Helpers keeping the gloves properly organised to use the right ones on particular jobs?

Worker was moving a barrel from which the top had been **cut**, the sharp edge of the barrel **cut** through his **glove** and onto his **finger**.
While hanging trailing cable on the screen, employee's **glove** was **punctured** by a piece of screen resulting in a **laceration**.
Water and rock dust came into **eye** when **hitting** core with a **hammer**. Wearing safety **glasses** at the time.
Employee was wearing nitrile **gloves**, not work **gloves**.

Figure 32. Examples of textual entries describing concepts involving PPE within tool use incidents. Examples pulled from synopsis of Leximancer analysis from the entire dataset. Blue words indicate frequent concepts pulled from the main themes slips and falls.

The concepts related to drilling related activities were *drill, wrench, rod, water, pipe, head,* and *helper*. The first six of these concepts relate to the heavy machinery of the drill. Heavy machinery is any heavy-duty piece of equipment or machinery primarily used for industrial, construction and forestry related tasks. Many of the projects that employ heavy equipment are considered high-risk industries, due to the various hazardous work environments involved. In related high-risk fields, research has shown the utilization of heavy equipment ranks amongst one of the highest contributory factors for injury occurrence (Gürcanlı, Baradan & Uzun, 2015; McCann, 2006; Hinze & Teizer, 2011). This is primarily due to reduced visibility, working conditions, risk perception and contact with heavy objects and equipment (Hinze & Teizer, 2011; Gürcanlı, Baradan & Uzun, 2015; McCann, 2006).

The drilling industry has historically relied on manual processes for manipulating drill rigs, involving the usage of heavy equipment (Magana-Mora et al., 2021). Relying on manual operation of drill rigs can increase various safety risks for the individuals involved as decisions are left to the discrepancy of the experienced Driller (Magana-Mora et al., 2021). In turn, organisations have upgraded to automatic processes, including drilling and drillhole control, which can positively impact health and safety and mitigate other injury risk factors (Magana-Mora et al., 2021). However, when manual manipulation is required, it has been shown that injuries can be reduced when spotters or helpers are present to aid the operator (McCann, 2006; Gürcanli, Beradan & Uzun, 2015). Refer to Appendix H for a diagram of the drill rig and associated parts.

The descriptive entries for injuries involving the head as a component of the drill machine made up 98% of entries, the drill head is where the drill rods attach to the drill bit. These entries included frequent associations between words such as *pipe, caught, down, handle, holding, broke, rods* and *hit*. The frequency of these words are important because they demonstrate factors that played a role in incident causation. *Pipe, handle,* and *rods* are terms that relate to the physical pieces of equipment. Drilling equipment has been previously noted as having higher associated risks because of the size of the machinery and the complexity involved. This heavy equipment naturally increases the risk of hazards to workers; *Pipe, handle,* and *rods* are key indicators of the particularly high hazard materials. These key terms associated with *head* show the importance of safety measures and precautions to minimize the risk between the equipment and the workers. The terms *caught, down, holding, broke* and *hit* are descriptive factors within the incident causation and highlight the complexity involved with drilling machinery and the dynamic interactions between the moving parts of equipment and the workers.

This concept, head, mainly was stated in relation to the component of the drill. However, the entries stating *head* in terms of anatomical location made up 2% of all entries. Although not as frequent, this key term shows how potentially serious injuries could be involving the heavy machinery coming in contact with the head. Injuries to the head are related to more serious injury levels, can be extremely debilitating to the worker and comes with high economic burden in terms of associated medical expenses and lost wages (Kontos et al., 2017; Khanzode et al., 2010). With that, head injuries sustained from struck-by incidents, such as the descriptive factors pulled from the data, are the most severe and are the highest risk for fatality (Chang et al., 2015; Konda et al., 2016). Research from related high risk fields such as construction has demonstrated the importance of proper PPE for the head and ensuring proper education to at-risk demographics, such as young and older workers (Long et al., 2013; Konda et al., 2016; Colantonio et al., 2009).

The last concept that related to drilling machinery was *helper*. By nature, Drill Helpers are typically younger or less experienced workers and relate to a more frequent occurrence of less severe injuries (Groves et al., 2007; Alessa et al., 2020). Coupling the inherent risks with drilling machinery with the inherent risks of younger less experienced workers, creates an environment that brings even higher levels of risk to the workers. Knowing this can allow the implementation of added resources to be made available to this demographic of workers, to place emphasis on how serious injuries can be when working with drilling machinery, and the proper procedures to follow when in this environment.

Light Vehicle

The Leximancer analysis revealed five major themes (Figure 10), within those, three dominant themes were most frequent: *truck, damage,* and *road* for Light Vehicle incidents. Within the theme truck the following concepts were noted: *driver, rear, parked, front, employee, passenger* and *noticed*. The most significant concepts relate to the positioning of where the damage on the vehicle was sustained, *front* and *rear*. It is no surprise that rear was a key term highlighted in the descriptions, as research has continually shown incidents involving backing up or the rear end of vehicles are more prevalent and contribute to a higher number of incident occurrences. In related high-risk industries, studies have shown that personal and property damage is more likely to occur from vehicles moving in the rearward direction (McCann, 2006; Chappell, 1992). More specifically, individuals on foot around the moving vehicle are more likely to sustain injury due to reduced operator visibility paired with height of the individual (McCann, 2006; Udemba, Tahsin & Purswell, 2021). In the construction industry in Ontario, policies are in place to ensure a signaller is always present for vehicles moving in rearward directions (IHSA, n.d.a; IHSA, n.d.b). This could be a recommendation within the mineral exploration field, to mandate an act such as requiring signallers, to mitigate these rearward incidents.

Within the main theme damage, the following concepts appeared: *backing, hit, door, bumper,* and *trailer*. In many of the cases, the property damage sustained to the vehicle was null or minimal. The *door, bumper*, and *trailer* were the three locations that were most susceptible to damage. This is understandable as the bumper and trailer are lower positioned areas of the vehicle and are less visible for the operator to see. As such, bumpers were designed to protect the internal systems of the vehicle (Natarajan, Joshi & Tyagi, 2020). Within mineral exploration many adverse weather conditions can occur, in turn increasing the hazards of light vehicle operating. Currently, there is no standalone sensor that can detect objects in target to be hit in extreme weather conditions (Bhadoriya, Vegamoor & Rathinam, 2022). This is important to note because operators need to be aware of the loss of accuracy when operating in weather conditions such as fog, rain, or snow. In these cases, it is recommended to use flaggers on foot to guide the operator into safe positioning, keeping attentive focus on the positioning of the flagger (McCann, 2006; Gürcanli, Beradan & Uzun, 2015). When using flaggers in the field, enforcing strong policies are important to ensure the safety of these individuals. These policies can include the requirement of flaggers to be clothed in high visibility clothing, and the proper usage of hand signalling (Fan et al., 2014). Next, the door is the other location that was increasingly stated, predictably due to the moving parts and the susceptibility of movement from external factors such as weather conditions like wind.

Within the main theme, road was related with the following concepts: *drill, slid, snow, site,* and *ditch*. Many contributing factors play into vehicle incidents and near misses, two main factors are driver alertness and weather conditions (George, 2007; Davis & Rohlman, 2021). Diver alertness is an extremely important factor, especially in mineral exploration, as exploration efforts are operated both day and night. Shift work and multiple days on rotation can affect sleep schedules and increase tiredness (Härma et al., 1998). Specifically, tiredness can influence many skills such as motor, cognitive, and perceptual, altering the ability to quickly make decisions, thus associated with workplace safety behaviour and incident occurrence (George, 2007; Sneddon, Mearns & Flin, 2013). Secondly, weather conditions, particularly winter weather conditions, continue to be a leading factor in vehicle incident causation (Davis & Rohlman, 2021). This is consistent with the data as *snow* and *slid* were two top factors, highlighting the importance for vehicle operators to be more attentive to surroundings, and extra cautious when driving in hazardous conditions.

The next two concepts, site and drill were stated in the context of individuals driving to and from the drill site where the incident was sustained on the road to the site. This finding shows that extra caution should be used when operating on drill site access roads and trails. A few factors could play into the frequent occurrence of incidents happening on drill site access roads, such as the increased use of vehicles needed for drilling, remote locations of the drill site so vehicles are needed to transport workers to and from the site, the quality of road and levels of access maintenance, and operator fatigue driving to and from the camp after a full day's work. Frequently, the final access to a Canadian drill site may be a simple bulldozed trail in the bush following a dirt or gravel road such as a timber company logging road. There may be infrequent snow clearance on such an access though the crew must drive it at least twice a day for shift changes. If there is time pressure due to production expectations, driving faster than the access merits can occur. The crew is expected to bring in all supplies to the drill on this access and bring out the drill core to the geologist who is usually logging the core away from the drill site.

Improper Lifting

The Leximancer output displays five major themes (Figure 11). Of these, *lifting* and *pain* were most frequently stated. The main concepts that were pulled out of textual entries relating to lifting were as follows: *Boxes, core, strain, injury, shoulder, sore, heavy, wrist* and *carrying*. The most frequently used keywords within textual entries involving the theme *pain* were *rod, lower, drill* and *tube*. There are two groups of work in which these terms occurred: the handling of drill core in boxes by the Driller, Drill Helper and Geologist and Geologist Assistant, and the handling of drill rods and drill core tubes, as handled by the Drill Helper.

In relation to the terms associated with *lifting*, the main anatomical locations were *shoulder* and *wrist*, and main injury type was *strain*. Shoulder injuries are common in workplace settings where heavy lifting, especially overhead, is required (Beach, Senthilselvan & Cherry, 2012; Kim, Chung & Park, 2003; Bao, Howard & Lin, 2019). Proper ergonomic factors should be considered when manipulating heavy materials, particularly manual rod handling when the drill is not automated. Simple measures such as limiting overhead lifting and encouraging proper work posture can reduce the prevalence of shoulder injuries (Beach, Senthilselvan & Cherry, 2012; Kim, Chung & Park, 2003). The *wrist* is another common area of injury due to the nature of the wrist joint and the susceptibility to absorb force (Kamat et al., 2017; Kunda, Frantz & Karachi, 2013). Particularly, wrist injury occurrence is associated with repetitive tasks, notable in mineral exploration as many occupations within the field are subject to repetitive motions tasks (Bao, Howard & Lin, 2019). Pinch force, which is the force exerted between the thumb and the forefinger when conducting gripping or pinching tasks, another common factor associated with wrist injury (Bao, Howard & Lin, 2019). Many tasks within mineral exploration such as tool use, drill handling, geological tasks, and kitchen tasks required fine motor skills and the frequent occurrence of pinching and gripping. To reduce wrist injury associated with pinch force, suggestions such as limiting the repetitive force between the thumb and forefinger, using proper ergonomic techniques, stretching, and taking frequent breaks can be implemented.

Next, strain injuries were the most frequent in relation to lifting. This is concurrent with current literature in other high-risk fields, as strain is the most frequent injury (Bao, Howard & Lin, 2019; Beach, Senthilselvan & Cherry). In construction specifically, strain injuries account for over one-third of all lost workday injuries (Schneider, 2001). One of the most frequent types of strain injuries is due to repetitive motion, affecting muscles, tendons, and other soft tissues, and is a result of movement that is repetitive, sustained postures, and forceful movements (Helliwell, 2004; Breslin et al., 2013). Repetitive strain injuries can be preventable in the workforce if procedures are in place to allow workers doing repetitive tasks sufficient time throughout the task to allow their muscles and tendons to relax and recover. If recovery periods do not happen, local blood flow restricts and buildup of metabolites occurs, thereby damaging structures over time as the muscles and tendons become overworked. Special consideration should be noted with workers manually handling equipment, as forearms and wrist are most susceptible to such trauma. Repetitive strain injuries are hard to heal and can contribute to lost workdays, ultimately affecting worker and production longevity. If the limitation of repetitive motion or sufficient rest periods are not feasible within the field, a notable resource that can be used as a guideline when determining appropriate lifting techniques and weight limits is the Liberty Mutual Tables (Snook & Ciriello, 1991; Steele et al., 2014; Potvin et al., 2021). These tables are guidelines for manual material handling tasks and include factors such as hand height, lifting and forward reach distance to determine the maximum acceptable load. Online forums such as the Liberty Mutual Manual Materials Handling Population Percentiles are available through Liberty Mutual Insurance and are populatable to determine the correct loads for lifting, lowering, carrying, pulling, and pushing actions. Following these guidelines can allow for proper ergonomics when carrying out tasks and can ultimately minimize injury occurrence.

The next main concepts related to *lifting* were *boxes, core, heavy* and *carrying*. The concepts involving all these themes are mainly involved with drilling related activities, with individuals sustaining injuries because of manually handling objects that were too heavy. Specifically, manually lifting core boxes seems to be the main activity that led to injury occurrence. Special attention should be noted with individuals manipulating core boxes. Specific systems can be put in place to relieve the burden of individuals when manually lifting, such as incorporating protocols requiring multiple individuals to lift heavy boxes or using ATVs with trailers for longer commutes. In various occupational settings, interventions have been designed to limit the amount of manual manipulation required, such as specifically limiting lifting between knee to shoulder and assistive devices to help reduce manual exertion (Bahn, 2013; Lee et al., 2006; Wiehagen & Turin, 2004). Although effective for those fields, it would likely be hard to implement such interventions within the mineral exploration field environment.

The following theme *pain* showed concepts that were all related to drilling related activities: *rod, lower, drill* and *tube*. These findings have similarities to those findings included within section 2. Top Five Incidents and Descriptions Analyses, particularly within the discussions around tool use and improper lifting. The data does not state if these injuries sustained were under the operation of automatic, semi-automatic, or manual drilling operations. It can be predicted that because manual rod lowering and manipulating were required, these drilling systems were not automated. Aldred et al., (2005) state the use of automated systems, even semi-automated systems that still negate a degree of human involvement, are significantly safer and proven to increase safety of individuals and efficiency of production. Further studies have shown that higher injury rates, especially to limbs, are reported for drilling rigs that require manual operations (IADC, 2013). For those companies that do not employ automated or semi-automated drilling rigs, increased safety awareness and precautions should be enforced as manual drilling rigs are related to a higher injury risk, due to more human manipulation. These findings reiterate the fact that drilling remains a high-risk industry due to the physical involvement required by workers. Additionally, these four concepts can be related to musculoskeletal injury if individuals are working at exceeded load values and/or lift frequencies. If the industry has yet to do so, a physical demands analysis (PDA) of Drillers and Drill Helpers would be beneficial. The PDA documents and analyses the physical, cognitive, and environmental demands of essential and non-essential tasks (Workplace Safety and Prevention services, 2020; Occupational Health Clinics for Ontario Workers, n.d.). The outcomes of PDA can show key information regarding the physical demands of a job and how they relate to worker injury. For example, a PDA would likely support why shoulder injuries are frequent injuries for Drillers and Drill Helpers, due to the frequency of heavy overhead lifting (Blache et al., 2015; Shanahan et al., 2011).

Drilling Machinery Related

The Leximancer output displays four major themes, all relating to the actual processes involved with drilling (Figure 12). These themes also overlap strongly with the discussions above in Section 2 regarding tool use and improper lifting. Firstly, it is interesting to note that the terms within this category were frequently overlapping, displaying that the incidents were commonly described using the same key terms. This shows consistency within organisations and how the incidents are reported. *Drill* and *rod* were the two dominant themes relating to the drilling processes, in which the terms *shack, floor, hole, hose, hydraulic, core, wrench, caught, pinched,* and *finger* were frequently stated. These themes are important to note because it shows areas within the drilling process that contribute to injury occurrence. *Shack, floor,* and *hole* relate to the working conditions of the drilling environment. For drilling, fixed or mobile drilling rigs are used, whereby every time a rig is set up safety management and drilling teams are faced with new hazards during the drilling processes, requiring decision making that is individual to those circumstances (Asad et al., 2017). As such, the themes relating to the working conditions show areas within the rig setup that should require extra attention when establishing the rigs and while maintaining safety standards throughout the duration of the drilling processes.

The next themes: *hose, hydraulic, core* and *wrench* demonstrate tools and materials that were frequently stated in relation to injury occurrence. These findings coincide with literature that states non-powered hand tools such as wrenches are more likely to result in injuries compared to other types of tool usage, especially in high-risk industries (Sorock et al., 2002; Dababneh et al., 2004). Studies in related high-risk fields have shown that higher injury occurrence is associated primarily with machinery usage (Ural & Demirkol, 2008). This is prevalent to drilling operations as human involvement is needed to handle the machinery pertaining to the core, hoses, and tubes within the rig. With this information, a greater health and safety emphasis should be placed by focusing on intervention-based safety systems. Awareness for the individual will help to inform individuals working within the rigging operations to ensure they are mindful and aware of the potential hazards when working with such equipment.

The last themes, *caught*, *pinched* and *finger* demonstrate actions that led to injury occurrence, and areas that are most prone to becoming injured. The data here shows findings that are consistent within research conducted in other high-risk related fields; caught in seems to contribute to a substantial number of incidents (Pollard et al., 2014; Lind, 2008; Mital et al., 2000). Comparable studies also show that pinching and caught in injuries are highly susceptible when manually handling pipes and equipment due to the unsteady and heavy nature of such materials, as well as such materials generally located in confined spaces where the distance from material to hand is small (Tixier et al., 2017). The data revealed that finger was the most common body part to be injured within drilling processes, which is comparable to research from high-risk industries such as mining, where wrist, hand, and finger injuries are the most prevalent amongst miners (Alessa, Nimbarte & Eduardo, 2020). Fingers are most susceptible to injury within high-risk fieldwork due to the requirement of physical handling of tools, equipment, machinery, and the various hazards associated with such activities (Alessa, Nimbarte & Eduardo, 2020). Specifically, fingers are intricate structures involving many bones and soft tissues, thereby allowing for a wide range of capabilities, as well as increased risk for injury due to the many parts involved. As fingers are complex, there is an increased cost associated with finger injuries if medical intervention is needed, contributing to a potentially higher number of lost workdays (De Putter et al., 2012; Eisele et al., 2018; Sorock et al., 2001). Additional safety efforts should be focused at providing workers with the proper tools and resources to ensure high levels of competency and focus of attention to the task at hand while manually handling rods and drilling related machinery within the rigs is present. Greater attention should be given to those manually handling rods and drilling related machinery within the rigs.

3. Personnel and related descriptions analysis
Contract Workers

The Leximancer analysis showed four dominant themes with incidents involving contract workers as the personnel status (Figure 13); *Drill, finger, truck*, and *helicopter* were the four themes. Firstly, the relationship between contract workers and drilling operations is extremely important because drilling companies employ the drilling crews, who often source contract workers. This creates a dynamic environment allowing for the pairing of experience between the company and the workers, through a contracting relationship (Kellog, 2011; Blackley et al., 2014; Graham, 2010). Related findings show that contract workers overall have a higher injury occurrence, compared to other occupations within drilling related fields (Blackley et al., 2014; Graham, 2010; Osmundsen, Toft & Dragvik, 2006). In general, contracting is on the increase, as more industries are choosing to outsource (Graham, 2010). An increased employment of contractors relates to an increased variation of safety systems within the workers present at each drilling rig. Safety and risk perception can differ between contract workers and companies, even though contract workers should adhere to the written and verbal agreements set by the hiring company (Graham, 2010; Osmundsen, Toft & Dragvik, 2006). Contract workers can be subject to lack of awareness of safety procedures, thereby less committed to them (Graham, 2010). Additionally, if incentives are offered to the contracting partners, then there is an even greater risk of deviation and adherence to safety protocols (Osmundsen, Toft & Dragvik, 2006). Although hiring contract workers can be justified economically, greater safety emphasis should be cautioned by the hiring companies. The data shows contract workers make up 36% of the total types of employment statuses; this is a significant finding because it shows that contract workers within the field are the most employed personnel. Because of this, a more indepth exploration of ways to mitigate the effects of contract workers are needed by the hiring company.

Secondly, the data revealed frequent low grade finger injuries that required minor intervention. Contract work was associated with a high occurrence of finger related injuries (Graham, 2010). As previously mentioned, finger injuries within the workplace are amongst the highest anatomical locations in high-risk industries, and have a higher cost associated if medical intervention is needed (Alessa, Nimbarte & Eduardo, 2020). These findings are important to note because contract workers are already at an increased risk for injury, coupled with the high occurrence of finger injuries, allowing for greater opportunities for contract workers to become injured (Graham, 2010).

Driller

The Leximancer analysis revealed four major themes with Driller being the main occupation (Figure 15). Of these four dominant themes, multiple factors emerged that are broken down into three categories: drill related, worker related and road related. The first category, drill related, shows factors including *pump, water, pipe, shack, tube, hydraulic*, and *hose*. The drilling process is performed by Drillers who have robust knowledge of geology and drilling conditions. The drilling processes rely on the individual experienced Drillers to operate the drilling machinery; however, this can lead to performance inconsistencies and increased risk of safety incidents during drilling operations. The incorporation of various factors such as human, geological, and mechanical factors increase the risk in drilling operations (Magana-Mora, et al., 2021). Relating to mechanical factors, most of the factors within the data relate to drilling machinery. This is notable and comparable to other high-risk fields where higher injury occurrence is associated primarily with machinery usage (Ural & Demirkol, 2008). Despite the experience of the Driller and the progressions made within the industry, health and safety awareness and risk management are needed as no two drill holes are the same (Magana-Mora, et al., 2021). Caution should be advised when manipulating machinery within the rigs, with extra focus on the machinery highlighted within the sub themes found in this work to be involved with injury occurrences (ie. pump, pipe, tube etc). It is possible there is a greater need to more carefully consider how the industry is conveying safety messages regarding these job tasks in particular, as they seem to be frequently stated throughout the text.

The next area of importance includes the factors that highlight the worker within the incidents. The dominant themes that were pulled out of the descriptive entries related to anatomical location such as *shoulder, head, foot,* and *hand*, instrument usage such as *core, pipe,* and *pump*, and mechanism of injury (MOI) such as *hit, slipped, cut,* and *fell*. In relation to anatomical location, literature has shown that hand injuries are amongst the most frequent body parts to be injured at work (Sorock et al., 2001; Sorock et al., 2002; Love et al., 2019; Courtney & Webster, 1999; Kamol, 2018). Improper lifting is one leading contributor of workplace shoulder injuries, where heavy lifting, especially overhead, is required (Beach, Senthilselvan &

Cherry, 2012; Kim, Chung & Park, 2003; Bao, Howard & Lin, 2019). Following proper ergonomic guidelines and having a sense of bodily awareness can reduce shoulder injuries (Kim, Chung & Park, 2003). In related high-risk industries, head and lower extremity injuries are common amongst environments where there is a risk of falling objects (Wu et al., 2012; Aneziris et al., 2014; Lipscomb, Schoenfisch & Shishlov, 2010). However, given the themes pulled out of the data, it is indicative that possibly the risk of falling objects is not the leading cause of these incidents, but rather factors such as pinch and hit, to be the leading cause to head and foot injuries.

The next themes relate to tool usage, which has been previously covered within drilling machinery related incidents. To recap, literature states that higher injury occurrence is associated with tool usage, specifically non-powered hand tools, especially in high-risk industries (Sorock et al., 2002; Dababneh et al., 2004; Ural & Demirkol, 2008). Regardless of if the drilling rigs are automated or manual, Drillers are at the forefront of machinery usage and therefore at higher risk for tool related injuries. When handling heavy machinery, the focus should be placed on proper safety maneuvering and hazard assessment, as higher injury rates naturally occur when utilizing such equipment.

The last theme relates to Mechanism of Injury (MOI), which is defined as the method of which the trauma was sustained to the body. As previously stated, the most notable mechanisms of injury within Driller related incidents were *hit, cut, slipped,* and *fell*. Firstly, being hit by an object can also be described as being struck by and is frequent in industries where machinery is moving or located overhead (Onder, 2013; Pratt, Kisner & Moore, 1997; Centre For Disease Control and Prevention, 2007; Yedulla et al., 2022). This is due to the nature of the working environment where hazards are increased when working with heavy machinery that is moving or located overhead, due to the possibility of errors in maneuvering the equipment, lack of maintenance efforts, the possibilities of machinery slipping or falling, and the dynamic interactions between human positioning with moving machinery (Esmaeili & Hallowell, 2012). During normal drill operations machinery and equipment is often being manipulated above the workers, and around the drill mast. Working around moving machinery is more dynamic than static equipment, as workers need to be very aware of their surroundings and positioning in relation to the moving equipment, as the interaction between two is constantly changing.

The next MOI is due to individuals being cut by objects, resulting in a type of wound or laceration to the skin. Cut wounds to the skin are very common within workplace injuries and continue to contribute to the need of medical aid on jobsites (Sorock et al., 2002; Kamol, 2018; Gaul, 2009; Yedulla et al., 2022). One factor that can lead to decreased wounds is the correct usage of PPE, where it has been shown in related fields to reduced injury occurrence (Nakua et al., 2019). Many other factors contribute to a laceration occurrence such as improper training, lack of safety protocols, time pressures, and working with hand tools to name a few (Gaul, 2009). The last two themes within MOI are slips and falls, again one of the top causes of workplace injuries (Al-Rubaee & Al- Maniri, 2011; Bell, Gardner & Landsittel, 2000). The risk of slips and falls are increased due to environmental conditions such as working in colder locations, work related tasks such as carrying heavy loads and PPE such as improper footwear (Vingård & Elgstrand, 2013; Smith et al., 2015; Singer & Kouda, 1999; Bell, Gardner & Landsittel, 2000). The conditions within the drilling shack play a role in the occurrence of slips and falls, as the terrain can be rocky, muddy, wet, or icy. Particular attention should be made to the walking areas within the rigs to ensure slipping hazards are minimized.

Since many commonalities are found between the data from this study and other high-risk industries like mining, recommendations can be taken from the related studies. These studies have shown that majority of incidents are related to machinery or being struck by an object and recommend education or training sessions to focus on the importance of using PPE, ergonomic carrying, use of hand tools, and increased compliance with existing health and safety regulations and company procedures (Pratt, Kisner & Moore, 1997; Onder, 2013).

Driller Helper, Driller Assistant

The Leximancer analysis (Figure 17) highlights themes that are important when looking at incidents related to Drill Helpers and Drill Assistants. These main themes, or factors contributing to occurrence, are mainly related to the drilling machinery and anatomical location of injury. In relation to the drilling related machinery, the literature repetitively states individuals working with heavy equipment, tools, or moving machinery are at an increased risk for injury occurrence. When working with such equipment that naturally pose a higher risk for incidents, it is important for the Driller and Driller Helper to mutually understand the risks involved and work in the best interest of each other. With this, the Driller and Driller Helper need to work together to create a team environment, as solid teams are advantageous to combat the uncertainty, risk and dynamic environments associated with drilling (Crichton, 2017). Teams operating in high-hazard environments, especially in drilling, face different risks as individuals can come from different disciplines and divisions of labour, making it harder to align perspectives, objectives, and motivations (Lauche et al., 2009; Haavik, 20ll). It is also as important for workers to be aware of workplace hazards, as well as possible barriers such as communication barriers, that may exist between the individuals they are working with. For example, it is common within Canadian drilling for a French-Canadian Driller whose first language is not English to work with a Driller Helper whose first language is English, or vice versa. This can create safety issues through poor communication. Strong communication is essential in safety prevention and safety culture, and if barriers exist between workers, then the established safety culture of the working environment can become tarnished (Vecchio-Sadus, 2007). As previously mentioned, team situational awareness is a relevant concept between Drillers and Driller Helpers, where they should both hold a collective understanding of the situation and work together towards a common goal within their respective roles (Stanton et al., 2017; Salas et al., 2015). Team situational awareness is beneficial to the safety of the working environment as those involved often engage in mutual task monitoring, where they are aware of their mutual situations and surroundings (Salas et al., 2015). Team situational awareness can be fostered by all members of the team having a solid understanding of their situational awareness, by remaining watchful, staying alert, and communicating effectively through information exchange, to name a few (Salas, Sims & Burke, 2005; Salas et al., 2015; Stanton et al., 2017). It is also important to note the dynamic interactions between Drillers and Driller helpers, as both bring different work experience to the jobsite. Drill Helpers are typically younger or less experienced workers by nature; these factors, younger and less experienced, bring two different components to the field; a higher injury occurrence, and differing learning styles compared to older more experienced workers. Firstly, experience plays a huge role in incident occurrence. Literature has shown the association between experience and injury is statistically significant, often associated with less severe injuries but more frequent occurrence for younger, less experienced workers (Groves et al., 2007; Alessa et al., 2020). Various factors elevate the risk for injury such as ability to identify hazards, lacking confidence or skills, or the obligation to adhere to safety standards (Groves, Kecojevic & Komljenovic, 2007; Bahn, 2013). The second factor that makes working with less experienced or younger workers unique is the learning attitudes of such a demographic. Younger generations are seen to benefit more from structured training on the job, rather than learning basic skills by observation (Reinke, 2005; Weihagen et al., 2002). Being informed of the learning styles of workers can enhance the learning process for them and ensure workers are properly informed and educated. Ways to enhance the learning process is to perform a job analysis, assess the helper to see which skills are already known and the accuracy of doing each task, and train and modify their skills to best suit organisational safety standards (Reinke, 2005; Hanvold et al., 2019). As the analysis revealed Drill Helpers to be the most frequently stated occupation for injuries, the above-mentioned factors are critical to try and reduce the number of incidents involving this type of personnel.

Field Assistant

The Leximancer concept map displays the common themes within incidents that involved field assistant as the main occupation (Figure 18). Within the analysis, three prominent themes emerged: *slipped, knee* and *drill*. First off, field assistants are conducting work within the field, subject to extreme terrain and weather conditions. Within Canada, a lot of the land Field Assistants are working in forested bush; one common hazard within these types of environments is fallen trees and logs that are often wet and slippery. The Field Assistants are not usually working on designated trails, rather traversing through the bush often encountering wet and mossy fallen logs and boulders. It is no surprise that slipped was the leading factor of incident occurrence, as it is well known that colder environments with rough terrain increase the likelihood of slipping (Vingård & Elgstrand, 2013; Smith et al., 2015; Singer & Kouda, 1999;

Bell, Gardner & Landsittel, 2000; Nolan 1962; Cranstone, 2004). As previously mentioned, a way to combat the risks of traversing in the field and limiting the risk of slipping would be to review available PPE such as excellent field boots like high ankle boots and crampons that might be better suited for this industry and investigating processes such as a tether system between workers, or removing unstable sections of outcrops as approaches to mitigate risk for the Field Assistant. Although outdoor environments have innate and unavoidable risks associated, training workers to critically assess the terrain to traverse on is another way to mitigate risk in the field (Cantine, 2021).

Next, *knee* was the most common body part to be injured. Occupations involving repetitive kneeling, bending, squatting, or lifting contribute to higher reports of knee injuries (Dulay et al., 2015). A connection can be made from the activities field assistants conduct and the prevalence of bending, squatting, and lifting. Additionally, due to the nature of the working environment slips and falls are a frequent occurrence. Namely, the knee is one of the main structures that is most vulnerable during a slip or fall due to its structure (Chen et al., 2013; Moore, Porter & Dempsey, 2009).

The final theme was related to drill. In most instances, the actual drill rig was not a contributing factor to injury occurrence, rather factors associated with drilling processes. Most cases involved lifting of some sort and traveling to and from the drill. The lifting injuries were mainly associated with core boxes, where workers were repeatedly lifting core that was too heavy for their capabilities and ended up injuring their wrists and shoulders. Traveling to and from the drill site to transport core and other materials was the other factor that contributed to injury occurrence. Roadway conditions, such as ice and snow, contributed to greater amounts of vehicle incidents.

This is all to say that assistants are generally subject to an increased risk of incident occurrence due to their younger age or less experience, in addition to the added risk factors of working in the field (Groves, Kecojevic & Komljenovic, 2007; Bahn, 2013). While conducting any geology work, field assistants should be informed of their surroundings, consider appropriate behaviour and safety prior to departure (Mansur et al., 2017). The influence of a positive safety culture can help combat injuries related to assistant work, because the group dynamics and leadership styles affect field work. The attitudes and behaviours from experienced and leading geologists are passed down to the field assistants; there should be a promotion of a culture of inclusion and safety, along with opportunities for personal growth to foster confidence and clear risk perceptions (John & Kahn, 2018). Another angle for the industry to focus on would be to provide a basic understanding of tissue limits, from an ergonomics perspective, to target approaches to better understand when and how these injuries occur in the field.

Field Work

Of the themes pulled out of the Leximancer analysis (Figure 19), three dominant themes arose: *fell, injury,* and *camp*. The theme *fell* will be broken down first, as it was the most frequently stated term with 320 hits in the descriptions. The key concepts relating to fell were *sample, helicopter, slipped, walking, tree, ground, hand, branch, hole, water, broke, global positioning systems (GPS)* or *radio* and *cut*. Of these, they can be broken down into three categories: work related, terrain related, and injury characteristics. To start, the themes involved with work related circumstances are those in which the individual was injured while conducting some sort of field work. Sampling is the first circumstance that was frequently stated; sampling is associated with inherent risks as individuals are traversing for the process of mapping and evaluating the land, collecting rocks along the way (Nolan 1962; Cranstone, 2004. Collected samples can be heavy, increasing the risk of injury if workers are lifting more than their individual weight capacity (Isa et al., 2013; Barnetson, 2010). Carrying heavy loads, particularly ones that obstruct the immediate visual field, coupled with varied walking surface conditions increases the risk of slips and falls (Bunterngchit et al., 2000). Also, geologists and field assistants working in the field not only carry heavy core boxes, they also are required to carry heavy loads such as rocks and soil samples in backpacks. Carrying weight on the back has shown to affect medial-lateral gait patterns by significantly impacting postural control (Qu, 2013). This can in turn increase energy expenditure and risk of falls (Qu, 2013; Rankin, Buffo, & Dean, 2014). Traversing also has unavoidable risks as outcrops and land can be uneven, providing ample opportunity for slips and falls. Special attention should be paid when traversing on uneven ground and carrying loads.

The next work-related circumstance included helicopter involvement; these incidents varied in context. There were two main instances where a fall occurred involving the helicopter: entering and exiting the machine and walking to the helicopter landing pad. Minor occurrences while entering and exiting the helicopter included boot laces becoming snagged on lower shock tubes, slipping on helicopter step when entering, or items falling out of the helicopter upon landing causing a tripping hazard. Walking to the helicopter landing pad, resulted in a fair number of falls. Many factors contributed to these occurrences; the landing pad not being completely cleared before helicopter landing or takeoff, causing debris to fly around resulting in a tripping hazard; helicopter landing on uneven ground which was unsafe for crew to walk on; helicopter landing on swampy areas, resulting in individuals having to wade through water posing a risk to slips and falls; and crew teams walking through bush, subject to deadfall, to get to the designated helicopter pickup site. Within incidents related to *falls*, the incidents involving helicopters were not due to mechanical errors within the actual machine, but rather factors external to the machine, such as those previously stated. The manuals and pocket guides created by PDAC, such as the e3 Plus: Framework For Responsible Exploration Chapter 16.0 Aircraft, should be highly encouraged for all individuals to extensively review prior to working with and around helicopters. The final work-related circumstance involved GPS or radio systems. Almost all cases involving falls were due to individuals using the GPS or checking their bearings and not watching their footing. As a result, the individuals inadvertently stepped into holes, on top of branches or over rocks, resulting in falls.

This next section will look at the same domain theme, *fell*, however focus on incidents that were terrain related. Within these incidents, the most common descriptive terms used were *slipped, walking, tree, ground, branch, hole*, and *water*. The usage of these terms demonstrates the highly varied topography which workers must traverse. This re-emphasises the importance of being alert when traversing, wearing proper footwear and if possible, choosing paths with the least number of obstructive hazards. Walking on uneven terrain causes the body to expend more energy compared to flat surfaces (Voloshina et al., 2013). This can become problematic for field workers who spend hours traversing through uneven terrain, as both mental and physical fatigue contributes to greater risk for falls. When the body is fatigued, gait patterns change increasing the likelihood of slipping, tripping, and falling (Parijat & Lockhart, 2008; Bautmans et al., 2011). If spending lengths of time traversing through uneven terrain, it is recommended to take frequent breaks and maintain caloric intake to maintain muscle strength.

This section will look at the injury characteristics within incidents where falls occurred. Hand and cut were the two commonly stated characteristics used when describing falls within the field. The *hand* and *wrist* are two of the most common body parts to become injured during a slip or fall, especially if the hand is outstretched (Gil & Weiss, 2020; Choi & Robinovitch, 2010; Palvanen et al., 2000). These types of injuries are called fall on outstretched hand (FOOSH) injuries. FOOSH is a common source of trauma to the wrist; it can be predicted that in most instances a natural bodily reaction when falling is to cushion the fall by either outstretching the hand or arm to try to prevent the body from landing hard on the ground. Additionally, when walking on uneven surfaces it can be beneficial to outstretch the arms to maintain balance (Lee-Confer, Kulig & Powers, 2022). This in turn can result in greater FOOSH injuries as the arms are already outstretched away from the body. The second commonly stated characteristic of injury resulted in a cut or laceration to the skin. Generally, lacerations were sustained on the way down from a trip or fall, where the individual was either cut by an object protruding from the ground, or by a piece of equipment they were holding. Terrain in the field naturally has obstacles such as rocks and tree branches, which can inadvertently become hazards if fallen upon.

The next dominant theme was injury, which was involved in 101 descriptions ranging from various incidents within the field. The Leximancer analysis revealed two common concepts: *eye* and *finger*. In terms of frequent work-related injuries, eye injuries and illness continue to cause significant disability (Peate, 2007; Almoosa et al., 2017). The eye is a delicate structure that can become easily damaged by even the smallest amounts of trauma (Almoosa et al., 2017). Working in the field increases risks to all body parts, especially the eyes, as they are the most fragile and PPE does not always stop all hazards from contaminating the eye. Within the descriptions most eye injuries involved a sort of irritant coming in contact with the eye, such as spray chemicals like paint or bear spray, foreign objects entering due to weather conditions and hammering rock, cross contamination from substances like diesel, or traversing through thick brush and the eye being poked by surrounding foliage. In many cases PPE was correctly worn, yet injury was still sustained to the eye. The finding that correctly wearing PPE can still lead to eye injury is not unheard of, as studies have shown that eye injuries are still likely to occur even when wearing PPE as compared to not (Thompson & Mollan, 2009). The analysis findings pertaining to eye injuries sustained while eye protection was worn could warrant a better form of eye protection. Goggles have been a source of PPE for fields such as construction, offering a protective seal around the eye to shield out any potential substances that could be damaging to the eye (Sehsah et al., 2020; Nath et al., 2020; Wong et al., 2020). Although the success of goggles has been seen in related fields, the environments within field work might not be conducive to goggle usage. The biggest factors pertaining to inhibiting workers from using goggles would be due to utilitarian factors. These are factors such as hot and wet weather causing the goggles to fog, individuals wearing prescription glasses making it difficult to wear goggles, or the nuisance of taking googles on and off between tasks are different examples of factors that relate to inconvenience of usage, ultimately led by utilitarian outcomes (Wong et al., 2020). Although wearing eye PPE is generally the safest way to protect the eye, individuals need to take all precautions such as minimizing cross contamination, being aware of surroundings and safely handling hazardous materials to maintain eye safety.

The second common concept was related to injuries sustained to the fingers. As previously stated, the fingers are at increased risk for injury in occupational settings where manual handling is required (Sorock et al., 2001; Sorock et al., 2002; Love et al., 2019; Courtney & Webster, 1999; Kamol, 2018). Most of the field work includes either traversing or working with the hands to collect, carry, and contain collected samples of rock and soil; the required activities within field work naturally increase the occurrence of finger injuries. Despite the frequent usage of manual handling, certain characteristics such as behavioural complexes like risk-taking, external pressures, motor skills, and PPE compliance increases finger injury susceptibility (Punnett, 1994; Sorock et al., 2001). Additionally, when dissecting the 101 incidents, all other areas of the body were mentioned such as hand, shoulder, foot, head, with MOIs being burned, scratched, punctured, and sprayed. This demonstrates that although it is still important to consider all body parts, an emphasis on approaches that target the eye and finger will have the biggest impact on reducing incidents, at least in the short term due to their prevalence.

The last dominant theme, *camp* was only mentioned 36 times, however still deemed important because it highlights two scenarios where camp life plays an important role in health and safety. There were mainly two instances in which the term camp was used.

The first scenario is where individuals returned to camp after field work and then became ill. Examples of such illnesses were noticing allergic reactions on their body, succumbing to heat stroke or physical exhaustion, or developing some type of infection. This shows how strenuous and all-encompassing field work can be, as individuals only notice the injury or illness once they are able to rest and reflect at camp.

The second scenario in which individuals stated camp within the description involved the conditions of the camp area. From the nature of the descriptions, it seems as though the conditions of the camp and surrounding areas are often less than adequately maintained. Many of the incidents could have been avoided if camp areas were maintained and hazards were reduced. For example, workers tripping over exposed cables, slipping on ice, handling rusty materials found on the ground or drinking untreated water. The risks of field work do not end once workers return to camp; camp needs to be seen as more of a refuge place, where workers should feel free from incident and have access to well stocked areas in which they can recover from the strenuous field work. However, the data analysis revealed the camps to be a contributor to incidents and injuries, and therefore should be respected as such and incorporated into the health and safety systems more thoroughly.

Geology Related

The Leximancer analysis broke down all descriptive entries with geology related as the main occupation (Figure 20). There were two themes that were stated substantially more than any of the other themes; 377 hits involved the main concept *core*, and 174 hits involved the main concept *truck*, whereas only 68 hits related to *camp*, and 37 related to *helicopter*. Within the hits related to *core*, various components were stated that contributed to incident occurrence. These concepts can be categorized into environmental conditions and anatomical locations. The environmental conditions that were stated were *snow, ice, ground*, and *rock* that resulted in *slipping, falling, hitting, cutting*, and *pain*. The role of geologists, geophysicists and geological technicians is to be in the field to collect data, observe and analyse their findings (Nolan, 1962). With this, geology related occupations are often working in the field, in remote locations, and are inherently exposed to various hazardous environmental conditions. Some conditions they are often exposed to were frequently stated within the textual entries of the incidents, including but not limited to rocky terrain, snow covered areas and icy patches. It is well known that slips and falls are more likely to occur in colder conditions, especially when the walking surfaces are covered in layers of snow and ice (Vingård & Elgstrand, 2013; Smith et al., 2015; Singer & Kouda, 1999). With this information, organisations should be able to reduce or mitigate the likelihood of slips and falls by taking preventative measures to reduce icy and snowy conditions, as well as ensure geology related individuals are recurrently educated on proper equipment and behaviours when conducting field work in adverse weather conditions. Encouraging workers to reference the Field Pocket Guide by PDAC is a great tool to ensure individuals are covering all the bases, such as weather appropriate clothing, before heading out into the field. Geology related occupations are not only subject to hazards of the outdoor environment, but they are also frequently working with instruments and tools, which put them at risk for tool use injuries (Sorock et al., 2002; Dababneh et al., 2004). Cutting was frequently stated within this data, for clear reasons such as the frequent handling of core samples, digging tools and instrumental use that requires fine motor skills and careful attention.

The second theme within *core* relates to anatomical location: *hand, finger*, and *knee*. These findings are consistent with literature that states the hand, fingers and lower limbs are the most frequent body parts to be injured at work (Love et al., 2019; Kamol, 2018; Sorock et al., 2001). As previously mentioned, the nature of Geology related work is to traverse varied terrain in the field and collect samples. These job tasks can include repetitive bending, kneeling, or lifting, factors which contribute to higher knee injuries (Dulay et al., 2015). The knee is a structure that becomes vulnerable during a slip or fall, especially if there is continually added strain on the structure from repetitive tasks or excessive external load (Chen et al., 2013; Moore, Porter & Dempsey, 2009). These factors again come down to the safety culture of an organisation: what safety systems are in place to encourage the proper PPE and protocols when working in the field? How do these individuals perceive risk and face risk when in the field? Is there work pressure that negatively influences behavioural decisions? Are the workers competent and experienced at doing hard labour in the field? These are examples of some questions management and organisations can ask when conducting job task analysis to see if individuals are best suited to conduct work in the field, for the needs of the organisation.

The next main theme was *truck* involving 174 incidents. The main concepts involved were *road, vehicle, driving, damage*, and *tree*. Geology teams rely on light vehicles (pickup truck, ATV, UTV, snowmobile) to transport them from field camp to field site. Conditions of the roads and trails vary between sites, with some being regularly maintained, and others grown in with less regular maintenance. It can be assumed that the majority of the roads geology teams commute on are relatively secluded with less access to regular maintenance; this is because a vast majority of the incidents involved concepts like deadfall, logs, trees, amongst other foliage, blocking the roadway or encountering the truck. When analysing these specific concepts, it is evident that many of them resulted in some sort of damage, to either property or an individual. Weather conditions were also a contributing factor as snow and ice-covered roads resulted in more incidents; this is again consistent with current literature stating incidents are more likely to occur in inclement weather conditions (Andrey et al., 2013). Even though individuals are likely to adapt to different driving conditions, it is not possible to completely offset the additional risks posed by adverse weather conditions (Andrey et al., 2013). Roadway safety continues to be an important feature in safety systems as operators need to be aware of external safety concerns while focusing on the task at hand (Smith, 2015).

Heavy Equipment Operators & Light Vehicle Operators

The Leximancer analysis shows the frequent themes and concepts within incidents involving heavy equipment and light vehicle operators (Figure 21). The overarching themes were *truck, ATV, loader, time*, and *contact*. When specifically broken down, all themes had relatively the same concepts within the textual entries. These concepts can be categorized into equipment, external safety concerns, and actions that contributed to incident occurrence. Within the category of equipment*, truck, trailer, ATV, loader, forklift,* and *dozer* were highlighted.

Focusing on heavy machinery, research in related high-risk fields have shown the involvement of heavy equipment ranks amongst one of the highest contributory factors for injury occurrence (Gürcanlı, Baradan & Uzun, 2015; McCann, 2006; Hinze & Teizer, 2011). Operating heavy equipment takes various skills to successfully maneuver the equipment, and requires special attention to safety hazards external to the vehicle (Saurabh et al., 2014). Many factors need to be evaluated during operation such as the machine's abilities and condition, reduced visibility, nearby locations of surrounding heavy objects and equipment, unsafe ground conditions, and machinery egress and ingress (Hinze & Teizer, 2011; Gürcanlı, Baradan & Uzun, 2015; McCann, 2006; Nasarwanji, Pollard & Porter, 2018; Ruff, Coleman & Martini, 2010). Research has shown the importance of pre-operational checks and maintenance to machinery, as poor maintenance and defective machinery contributes to heavy machinery incidents (Zhang et al., 2014). All types of heavy equipment have different operating systems, and literature has shown in related fields that adequate training, particularly those with less experience, is crucial to safely operate heavy machinery (Zhang et al., 2014; Groves et al., 2007).

Visibility is another determining factor that plays a role in many occupational injuries, particularly the jobsites working with trucks, forklifts, loaders, and bull dozers (Hinze & Teizer, 2011). Visibility can be reduced for numerous reasons such as weather conditions like fog and the overall structure of heavy equipment, which creates blind areas around the equipment (Saurabh et al., 2014; Ruff & Holden, 2002). Having spotters safely oriented around the machinery in visible view of the operator, as well as utilizing GPS systems are two ways in which factors associated with lack of visibility can be addressed (Ruff & Holden, 2002; McCann, 2006; Gürcanli, Beradan & Uzun, 2015). Spotters will also address the issue of bringing attention to nearby objects, so the equipment does not contact it. The ground location is also important with heavy machinery such as loaders and forklifts and workers should be used to doing a visual ground inspection before operation while loaders should be dumped at a safe distance from unstable areas of bank (Zhang et al., 2014). Machinery egress and ingress is another important factor when considering incidents involving heavy machinery. Most times, individuals enter and exit equipment in an automatic way by not consciously paying attention to their movements (Grogan et al., 2014). These are behavioural factors that can increase the risk for slipping and falling and should not be overlooked as slipping or falling while entering or exiting machinery is common (Choi & Lee, 2015).

Operators of heavy equipment are also subject to whole-body vibration; prolonged exposure of whole-body vibration can cause muscle fatigue, which could lead to the operator falling or misplacing footing during egress (Mani et al., 2010). The above summarizes various factors within heavy equipment operation that should or could have protocols attached to operation; the descriptive entries of such incidents are not indicative that such protocols exist within the industry. If some of these factors were ingrained, the analysis would have pulled key words relating to policy or rules. As this was not the case, it can be predicted this could be due to two reasons. One, the analysis suggests the industry has not done enough due diligence to consider how to mitigate risk from heavy equipment or two, individuals recording the incidents are not mentioning keywords relating to policies and procedures within the incident description, rather stating those keywords in the actions taken section.

The category of external safety concerns included weather conditions, roadway conditions and external hazards. These include *road, trail, ground, snow,* and *area*. Inclement weather conditions can be detrimental to the safety of both equipment and the operators Davis & Rohlman, 2021; Choi & Lee, 2015). Driver alertness and winter weather conditions are the two main factors that contribute to vehicle incidents (George, 2007; Davis & Rohlman, 2021). Adverse roadway conditions require extra focus of attention due to the increase of unpredictability. Reduced visibility is another factor associated with weather conditions that also increases the risk of incident causation (Choi & Lee, 2015). Roadway and trail conditions are extremely important when it comes to leading indicators in relation to vehicle and all-terrain utility vehicle safety.

Snowmobiles and all-terrain vehicles are very common within mineral exploration due to the need for travel options into field areas not accessible by paved roads. These vehicles generally travel on site access roads, which are informally created through various types of vegetation and terrain conditions. In the winter months, snowmobiles are the main source of transportation within the field; the operators of snowmobiles must be skilled and physically strong to handle the manoeuvring techniques of the machine (Plog et al., 2014). Maintaining trail conditions like freeing the pathways of fallen debris and having operator awareness of slopes, areas of near banks, and surrounding hazards is crucial to ensure operator safety (Wilkerson & Whitman, 2009). Physical hazards on the trails that may be less visible due to snow coverage, or trails through thick vegetation pose extra risk to the operator. Research has shown that several mechanisms of injury can be fatal to snowmobile operators; being thrown from the machine, striking a stationary object like a tree, or having the snowmobile flip or roll over contribute to the leading causes of operator injury and death (Plog et al., 2014). Another important consideration specific to mineral exploration is the risks involved with equipment, such as snowmobiles and bulldozers crossing ice. In many cases these types of incidents are associated with increased mortality rates (Sharma et al., 2020; Fleischer et al., 2013). These incidents generally result in drowning, where factors such as shock, unconsciousness and cardiac arrhythmia can contribute to these fatal events. It is important to note that behavioural choices made by the operator play into incident causation, such as obeying speed limits and wearing proper head protection (Plog et al., 2014; Sy & Corden, 2005). Resources such as the e3 Plus: Framework For Excellence in Health and Safety Responsible Exploration Chapter 15.0 by PDAC, is an excellent guide for individuals regardless of their experience, to bring awareness to the potential hazards associated with snowmobile use.

The actions that contributed to the incidents were *rear, pulled, hit, stuck, noticed*, and *damaged*. As mentioned, operating heavy machinery and vehicles comes with inherent risks. These risks are increased when various conditions are present, one of which being vehicles moving in rearward directions (McCann, 2006; Kazan & Usmen, 2018). One main reason for this is that operating vehicles in reverse often limits the available operator visibility (McCann, 2006; Udemba, Tahsin & Purswell, 2021; Hinze & Teizer, 2011). The recommendations for spotters have been made within the construction industry, as spotters can alert operators of potential hazards that otherwise the operator might not be able to see (McCann, 2006; Gürcanli, Beradan & Uzun, 2015). If not already mandatory within the mineral exploration field, a strong recommendation would be to ensure properly educated spotters are present with all vehicles moving in the rearward direction. This could be enacted by making all vehicle operators and passengers educated on proper spotting hand signals and hazards associated with vehicles moving in rearward directions, such as blind spots.

On the contrary, *struck by* incidents, especially striking workers on foot when the vehicle is backing up, is a major cause of injury and death in related fields (McCann, 2006; Kazan & Usmen, 2018). Operators have a responsibility to ensure due diligence by being aware of their surroundings, as well as maintaining vehicle safety standards; poorly maintained equipment and malfunctioning back-up alarms both contribute to higher levels of incident occurrence (Kazan & Usmen, 2018). Hit and struck by incidents from vehicles continue to be a leading cause of injury and death in related high-risk environments (Ruff et al., 2011; Janicak, 2011). Factors that contribute to this high occurrence are lack of machine maintenance, skill set required to operate sophisticated machinery, visibility, and training materials and safety cultures disseminating best practices.

Damaged was the last key term, which is important to note because it shows the extent to which property damage was sustained, that a significant number of incidents were severe enough to cause a degree of property damage. Damage to heavy machinery and vehicles is a burden to companies as the need for extra resources such as time and money is increased. Operating heavy machinery and vehicles is one occupation upon which mineral exploration relies on, which is why it is so important for companies to understand all associated risks that may limit individual harm and property damage.

Pilot

The Leximancer analysis (Figure 22) shows the two prevalent themes within the data relating to pilot as the occupational status. These terms are *helicopter* and *pilot,* and would not exist without each other. Within mineral exploration, the use of helicopters is inevitable to reach exploration areas that are beyond established transportation routes. The nature of which helicopters are required varies, from transporting cargo, people, or surveying the land, and helicopters remain a critical component to the success of mineral exploration (Morrish, 2017). Helicopter safety remains an important topic of discussion as helicopter operation requires a highly specialized skill set that requires pilots to be able to adjust to various external influences and the pilots need specific training and experience (Bye et al., 2018). Only a few studies have been published on helicopter involvement in high-risk industries, such as sling-loading (Manwaring et al., 1998; De Voogt et al., 2009). External loads, such as sling-loading, is needed within mineral exploration and naturally increases the risk of helicopter usage due to the specialized sling loads, the limited room for maneuvering in case of a crisis and the specifics of attaching loads (De Voogt et al., 2009).

Due to the severity of helicopter incidents, the related injuries tend to be severe in nature including death. This data also revealed incidents that were lesser scale in nature, however had the potential to put pilots and crew members in extremely compromising positions. The nature of incidents varied: some stated the injury occurred upon helicopter takeoff and landing, where the rotor downwash caused trees and other debris to be picked up, creating airborne hazards. Protocols to check the helipad prior to take-off or landing will minimize the chance of an adverse event occurring from downwash. In relation to ensuring the pad is cleared, in some instances pilots went to attempt landing however realized the designated spot was not sufficient, resulting in the pilot having to quickly make decisions to leave the landing site to find a better location for the field crew. Many descriptions stated the designated landing spot was not sufficient for landing due to factors such as unsafe ground for crew members like swampy areas or the presence of animals or pests in the area. Research with high-risk helicopters conducting sling-load operations has shown that additional ground members can reduce incident occurrence by assisting the pilot with visual lookout, to ensure the pad and surrounding areas are clear (De Voogt, 2017).

The next context in which helicopter was stated involved ingress and egress from the helicopter. Simple measures such as being aware of the helicopter's surroundings when entering and exiting can limit the associated risks. The last incidents involving helicopters included near misses and varied in nature. Some examples of the incidents where near misses occurred were: pickup time and location changing whereby crew members momentarily forgot their survival bags, team loading bags into the helicopter basket and realizing it likely exceeds the weight limit, or satellite tracking not working on the helicopter making it appear like the machine was grounded in one place.

To increase safety, companies hiring or contracting pilots should be aware of the skillset of the pilots such as hours flown and specific experience and training. Individuals working alongside helicopters need to refer to educational resources such as the e3 Plus: Framework for Responsible Exploration, section 16.7 Helicopters, by PDAC.

6.1.2 **THEORETICAL FRAMEWORKS AND MODELS**

The Safety Pyramid

Details of the incident rates are described in 5.0.2.1 theoretical frameworks and models and percentages are presented in Figure 23 within this text. According to the commonly cited work by H.W Heinrich's Safety pyramid, it states for every serious incident, many events are thought to occur with minimal injury, and further, an even larger number of events resulted in no injury. In fact, the opposite was observed in this study as most events reported were associated with minor injuries (Figure 33). Based on the ratio suggested by H.W Heinrich, the findings show that within the mineral exploration field lower severity injuries may not be used to predict the probability of a fatal event within the safety pyramid. Following the pyramid structure, this would indicate the industry should be better trained to recognize and report near misses. The analysis findings are consistent with literature that demonstrates caution should be exercised when following the safety pyramid structure; it should act solely as a guideline because the severity delineation approach used will influence the strength of the prediction on the pyramid (Moore et al., 2020; Yorio & Moore, 2018; Gallivan et al., 2008). The data reveals a 0.001% fatality rate, which is seemingly high. This rate can be attributed to the nature of fatalities within the field; Although fatalities are a rare occurrence, when they do occur, they are associated with a high multi-fatality rate, at 32% (Appendix G).

With this, the data shows a strong relationship between the number of reports for minor injuries compared to near misses, 3171:1733 simplified into a ratio of 528:288, compared to the suggested pyramid values of 29:300. Based on the pyramids structure, minor injuries should equate to about ten percent of all the near misses; The data would show that an estimated amount of nearly 5,000 near misses are being underreported. This highlights a common challenge within OHS known as underreporting. Underreporting less severe events is a common challenge for OHS organisations, and like other high-risk industries, is likely common within mineral exploration (Moore et al., 2020; Lander et al., 2010; Ural & Demikrol, 2008; Rebbit, 2014).

Underreporting is thought to be heavily influenced by safety culture and how the individual views and upholds safety standards (Reason, 1998; Toft, Dell & Hutton., 2012). For this reason, the incident ratio is sensitive to underreporting, suggestive of a workplace culture that needs change. In the case of this set of data, the early years of the PDAC-AME Survey Report suffered from underreporting of near misses simply because the report was voluntary and submitting them required extra work. At this time, it is also thought that the smaller companies likely did not report near misses either. On the contrary to underreporting, the findings of the ratio 528:288 could be based more so on the nature of the injuries being ranked more severe than not, opposed to the incidents not being documented. Although the safety pyramid has minimal merit, the output of such an analysis is still viewed as attractive from a preventative standpoint because it can show the underlying cause of the incidents and how they can cause a ripple effect up through the pyramid (Alamgir et al., 2009; Rebbit, 2014; Lander et al., 2010).

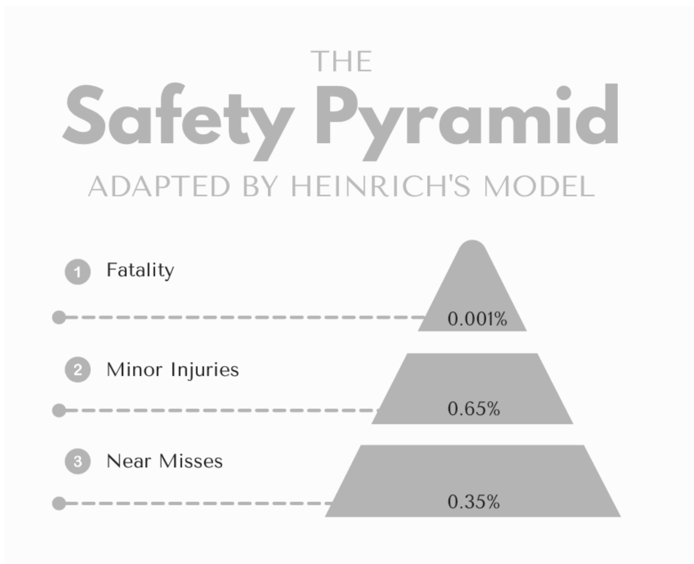

Figure 33. Percentage of incident rates across the three measured categories of fatalities, minor injuries and near misses with respect to the dataset. By explicitly following the safety pyramid structure, the expected percentages should be 0.001% fatality, 9% minor injury, and 91% near miss, whereas the data revealed 0.001% fatality, 65% minor injury and 35% near miss.

The Swiss Cheese Model

Guidelines were followed from research conducted by Bonsu *et al.,* (2016), following a framework that categorizes the data into three divisions. This new framework follows the basis of the Swiss Cheese Model by trying to understand the processes that lead to incidents within workplaces (Figure 34). This model uses techniques from the Incident Cause and Analysis Model to enhance existing knowledge of the Swiss Cheese Model by further understanding the factors that contribute to incident occurrence through highlighting contributing factors and latent hazards within the system (Bonsu et al., 2016; De Lander et al., 2006). Within the Swiss Cheese Model of safety management, each of these three divisions have unique underlying factors that are associated (Figure 35).

The first line-of-defense stems from **organisational influences**, which are viewed as latent failures. These **latent failures** include the access to safety management, the organisation of safety systems, and how workplaces are designed, built, operated, and maintained (Reason et al., 2006). The second line-of-defense are **workplace factors**, which are considered intervening factors, such as errors and violations in producing conditions. The last line of defence is the individual role within the incident, **active failures**, such as unsafe acts that cause errors and violations (Reason et al., 2006).

Since this data is exploring incidents within the top three activities, the conclusions of the results will vary in terms of the context in which the original ICAM and model by Bonsu et al., (2006) was conducted. As one incident is not being examined, it is not possible to know all the specifics and conclude findings based on the details; therefore, assumptions and conclusions will be drawn from this data to make up a comprehensive understanding of factors that could play a role in the top three activities. Detailed below are the findings from the analysis conducted.

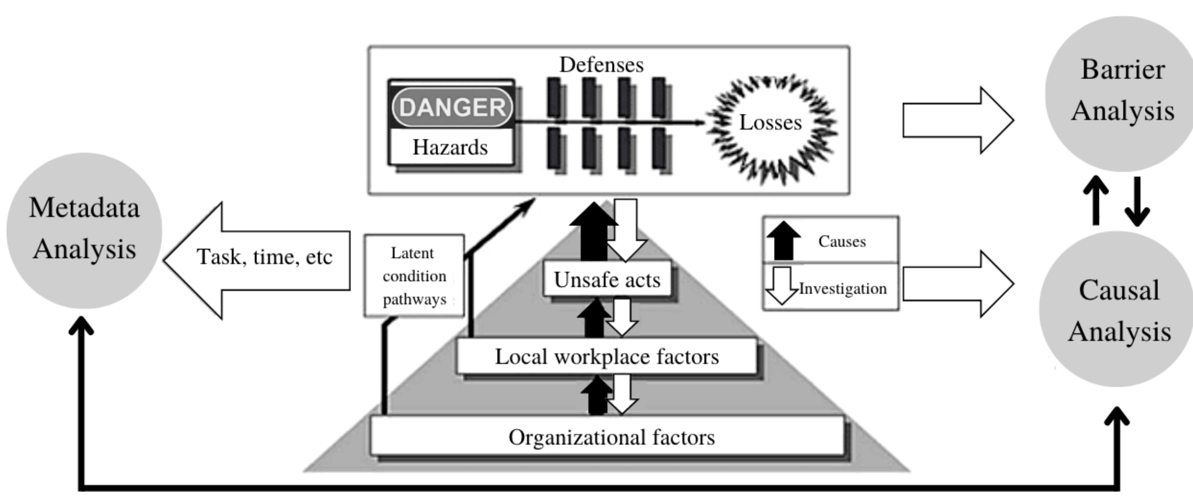

Figure 34. An analysis framework of the Swiss Cheese Model (Bonsu et al., 2016) adapted by Bond (2022).

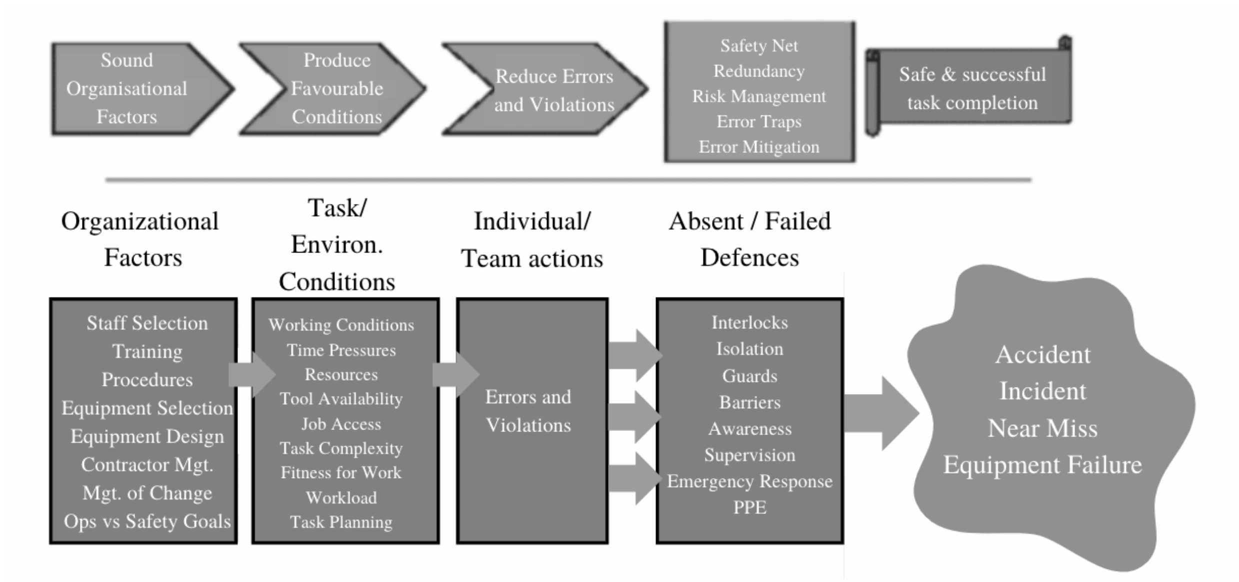

Figure 35. The ICAM model of incident causation by De Landre, Gibb & Walters (2006), adapted by Bond (2022).

1. Drilling

1.1 Systemic Factors

The first analysis looks at the causal factors associated with the incidents, examining the **direct cause**, **workplace factors** and **systemic factors**. In relation to the data used, direct cause included data from **personnel** and **task factors**, **workplace factors** were the same, and systemic factors used data from **organizational factors**. Starting from the latent failures, the systemic factors that played a role in incident causation will be explained. From the entire dataset relating to drilling activities, some systemic factors that were noted were *slightly, struck, feed, lifted* and *hand* (Table I). All stated factors are pertinent to organisational factors such as equipment design and selection, and training and procedural education. The selection and design of equipment contributes to how the machinery is handled. For instance, if individuals need to lift heavy objects, if the hand is placed in compromising positions, or pending the dynamic interactions between the worker and the moving machinery. Access to training and education of proper procedures will limit the risk of individuals being put in risky situations (Flin et al., 2000; Robson et al., 2007).

1.2 Workplace and Task Factors

The second analysis looked at the common workplace factors that were pulled from all incident types (Table I) and can be categorized into tool/machinery use (*rod, rig, wrench, drill, hammer,* and *tube*), anatomical location and injury (*finger, foot, sore*, and *pain*), and MOI (*hit, lifting, slipped,* and *drilling*). Key characteristics of workplace factors include tool availability, task complexity, workload, working conditions, and external influences like time pressures and workload (De Landre et al., 2006). The specific workplace factors such as tool availability, workload, conditions, and task complexity relate to the tools and machinery used with drilling related incidents. If suitable tools are not available for the worker, if workers are working under high workloads or poor conditions, or conducting precise tasks involving tools, these make up intervening factors that compromise the quality of the working environment. If these intervening factors persist, errors or violations may increase, increasing the risk of injury occurrence (Reason et al., 2006). The workplace factors like conditions, time pressures, resources and fitness for work relate to the findings within the data pertaining to anatomical location and injury and MOI. Unsafe working conditions increase the risk for improper lifting, slipping, and falling, and coming in contact with objects (Brown et al., 2000). Work pressures like time influences can put workers at risk for mental and physical burnout and fatigue, which can, in turn, affect motor skills and increase likelihood of experiencing an incident (Cooper, 2018).

1.3 Personnel Factors

The final analysis relates to direct cause, otherwise known as personnel factors. In general, these are active failures that relate to unsafe errors and violations of workplace procedures and behaviours (Reason et al., 2006; Reason, 1998; De Landre et al., 2006). The data revealed active failures (Table I) which are categorized into tool use and machinery (*rod, water, hydraulic, piece, water,* and *drill*), anatomical location and injury (f*oot, shoulder, hand, leg, knee,* and *pain*), and MOI (*walking*). A common theme within these three categories is that all incidents occurred due to a decision that was made by the worker, whether it be a slip or lapse, a mistake, or an intentional violation. Although these active failures are present due to behavioural choices of the worker, the behavioural decisions of an individual are influenced by risk perceptions, competence, and ability to adhere to safety standards by following procedures and rules. Due to the nature of the dataset, it is not possible to determine which factors influenced an individual's behaviour to act a certain way. The reality is that all three behavioural components could be applied to these incidents, and since there is no way of determining which factors contributed to the active failure, it is best for organisations to place a heavy emphasis on safety culture, so workers are properly educated in risk and hazard assessment, are educated and competent to safety execute skills and are motivated to follow safety standards. This reinforces the ideology that incidents do not occur on a linear spectrum because of one active failure but are influenced systemically through holes in defences within an organisation (Katsakiori, Sakellaropoulos & Manatakis, 2009; Toft, Dell & Hutton, 2012; Lenné et al., 2011).

1.4 Agency and Barrier Analysis

The mapping of the agency and barrier analysis was to determine information on the agencies involved in the incidents. The agencies are the source of harm to the individual. The analysis (Table II) showed the top agencies that resulted in some type of harm, revealing bruise and muscular, sprain, skeletal injuries, and abrasions to be the biggest agencies. What this shows is the possible absence or failed defences, such as guards, barriers, awareness, or PPE that contributed to the incident occurring. Bruise, muscular and skeletal injuries occur from some type of hit to the body, whether that be by an object or the individual falling and hitting an object. The suggestion to the industry is to review areas where bruising and musculoskeletal (MSK) injuries may be occuring to implement safe protocols to prevent the injuries from happening. Furthermore, cuts are sustained by an object lacerating through the skin, which can occur from improper use of tools, lack of PPE and lack of attentive awareness. This shows the possible failed defences that could result in workers becoming cut, and may represent protocols within the industry that should be reviewed. Finally, sprains could indicate lack of risk management to ensure workers are working within safe workload conditions, a lack of awareness of the challenging environmental conditions or inadequate PPE provision. Regardless, there are several avenues the industry could pursue to ensure protocols are sufficient for these field workers.

1.5 Metadata

The metadata, to recapitulate, is data within the survey reports that considers various factors that may have influenced the incident occurring, including: day or night, male or female, contractor or employee status, and place of the incident. The findings analyzed alone do not prove to be very significant, however when grouped together they can provide useful information on leading indicators. The metadata (Table III) revealed that Driller Helper and Driller were the two most common occupations to become injured. This is important to note because it shows the levels of risk that is inherent when working drilling rigs and can also allude to possible safety systems or lack thereof, that allow for recurring incidents to occur. Secondly, employee was stated most times compared to unknown and contractor occupational status. This is interesting, as previous studies have shown contract work to increase the risk for injuries due to the complexity of integrating workers into different working environments presented with tasks assignments, ultimately altering the viability of the safety culture within that organisation (Lippel and Walters, 2019; Blank et al., 1995; Clarke, 2003). The data then reveals most injuries to occur to the male workforce, which is likely relevant within mineral exploration, amongst other high-risk industries, as males generally make up a higher percentage of workers within the field (Choi et al., 2018; Regis et al., 2019; Kansake et al., 2021). Lastly, when omitting the data that was unknown, most incidents occurred during daylight hours, compared to night. This is a reasonable finding considering most mineral exploration efforts, besides drilling which usually operates 24/7, occur during daylight hours. As mentioned, the metadata alone is most useful when coupled together with other leading indicators that could have contributed to the incidents. Furthermore, organisations can take the findings from the metadata and work towards bridging the gap in safety management to specifically tailor educational resources to these demographics and certain situations.

2. Field Work

2.1 Systemic Factors

The first component of the causal factors analysis looked at factors within field work that revealed systemic factors that could have played a role in incident causation. The data for this section was scarce because few recurring key words or themes were present within the descriptive texts describing the events coded under organisational factors within contributory factors. The only three themes that were pulled from the entire dataset included *twisted, ankle*, and *worker*. A few predictions can be made from this analysis as to how these three themes possibly relate to organisational influences. One prediction is that there was a lack of leadership or supervision, allowing field workers to traverse through areas that were unsuitable or posed an increased risk of hazards. Inadequate systems to address procedures in these specific scenarios could have played a role too, where individuals were not fully aware of the dangers of the field work, possibly exposing them to tripping hazards.

Another explanation for this finding is the influence of poor safety culture. A few examples of how this safety culture can play a role are: fostering individuals to work through known, unsafe conditions such as rocky terrains, individuals being self reliant and wanting to portray their ability to handle the working environment, crew members working through hazardous situations through concerns of their production bonus, management pressures or not feeling inclined to follow proper PPE. Until a thorough review of the provided training, safety material and PPE expectations is completed, it is difficult to know which of these factors may be driving the incidents. There are likely some suggestions that can be made at the organisational level to promote a safer working environment through safety climate and change management to avoid the possibility of these factors influencing real world incidents.

2.2 Workplace and Task Factors

The second analysis within the causal analyses looked at workplace factors and task factors that could have played a role in incident causation. The data (Table IV) revealed many themes that are grouped into the following categories: MOI (*fell, slipped, ice, cut,* and *strain*), anatomical location (*hand, finger,* and *leg*), injury characteristics (*aid*), and *helicopter*. A main contributing factor here is the question of an unsafe working environment. This could be a workplace that is unsuitable for the job through poor maintenance of the area or the presence of hazards that may be totally natural such as fallen logs or rocks. The reason this is considered a main contributing factor is because of the occurrence of the multiple MOI's that were stated. The MOI's show that within field work, workers are subject to ground surfaces that increase the chances of slipping and falling, potentially leading to lacerations to the skin and sprains. These are physical characteristics of the job environment that increase the likelihood of an injury being sustained.

The anatomical locations show the areas of the body that were most susceptible to injury, because of the working environment. This could again result from working conditions that increase the risk of injury, availability of tools and resources such as proper PPE, the personal fitness for the job, and task complexity. Hand and finger can specifically be tied to the potential of lack of proper tool availability or PPE because of the close relationship between hand tool use and finger injuries (Alessa, Nimbarte & Eduardo, 2020). The correct type of gloves play a critical role within field work; some gloves are very protective however are cumbersome to do tasks that require dexterity, such as operating instruments like the GPS, therefore creating a divide between safety and efficiency. As previously mentioned, FOOSH injuries are common within the field environment due to the natural tendency to break the fall by outstretching the arms. Leg could be related to the nature of the working environment if it is slippery or rocky, as these factors increase the risks for slips and falls (Smith et al., 2015; Bell, Gardner & Landsittel, 2000). When individuals slip and fall, the lower limb is generally one of the areas to become injured (Chen et al., 2013; Moore, Porter & Dempsey, 2009). These points reemphaize the importance of correct footwear with proper soles that helo against slipping and falling.

The injury characteristics that were stated show the injuries sustained within the field were severe enough to need some degree of aid. Whether that be first aid or medical aid, it is equally important to note because it shows the importance of field workers being properly outfitted with resources like medical kits and GPS systems to provide care in the field if needed and have communications if extra care is needed.

In general, the last term, helicopter, can be causally or incidentally related to incidents. The data here shows helicopters to be causally related to incidents and highlights the nature of the environment surrounding the helicopter to be where the incident occurred. Based on the previous findings of incidents involving helicopters it showed the helicopter was generally not the main source of injury, rather injury was sustained in the areas surrounding the helicopter. This is important because it alludes to the fact that access paths to helicopter landing pads or cleared sites may not be entirely safe, and that extra safety should be cautioned when in these situations. Real world situations that can impact the health and safety of those working around helicopters can include time pressures and the sense of urgency; helicopters are very expensive to operate, therefore when the helicopter picks up the field crew in remote locations there tends to be an emphasis on getting into the machine quickly, increasing their risk of slips and falls. Additionally, a sense of urgency is created if the helicopter is operating under full power while waiting for the crew to load or unload, which generates a lot of noise and downdraft. This environment can induce urgency and even panic and can result in individuals not thinking clearly. It is worth reviewing the existing procedures for helicopters to determine whether gaps in safety systems can be closed from a procedural level.

2.3 Personnel Factors

The last component of the causal factors analysis looked at direct personal factors that played a role in incident causation. The data revealed recurring themes that are grouped into the following categories: MOI (*fell, tripped,* and *striking*), anatomical location (*knee,* and *hand*), occupational status (*employee,* and *contractor*), and equipment (*free, chain, sample,* and *bag*). The first notable finding is the MOI because it shows the possibility of how personal factors such as poor fitness, fatigue and stress can influence job tasks. Literature states that muscular fatigue can increase the chance of slips and falls due to the alteration of gait patterns (Parijat & Lockhart, 2008; Bautmans et al., 2011). This finding is particularly relevant for field workers within mineral exploration as it is a physical job that requires the expenditure of high amounts of bodily energy. Gait patterns may be further altered in detrimental ways by the chosen footwear required for extreme conditions in this industry, such as boots with ankle support, soles that resist slipping and in some instances toe protection. The hand and knee are two structures that are delicate in nature, and subject to frequent injury amongst workplaces (Love et al., 2019; Sorock et al., 2001; Sorock et al., 2002); behavioural deviations such as competence, job motivation and satisfaction, and violations of safety systems can alter proper workplace practices, and thus increase the susceptibility of injury to the structures of the body that are most delicate. The second notable finding in relation to MOI is that the MSK injuries within mineral exploration do not follow the typical MOI's compared to other industries. In most industries, the most common MOI's are related to chronic injuries, whereas the injuries prevalent within mineral exploration are acute. This shows that mineral exploration is truly unique and is really looking at different OHS challenges compared to other industries.

Next, occupational status is important to note because it is known that contractors, compared to company employees, can enter the work environment with an altered perception of safety systems, both subconsciously and consciously (Clarke, 2003; Gochfeld & Morh, 2007). The findings in relation to field work data revealed employees and contract workers to both be subject to injury, with employees (n=38) stated significantly more frequently than contract workers (n=4). Specifically in relation to employees, this finding is notable due to the knowledge of associated incidents involving contract workers. This finding could allude to the nature of the environment where most personnel conducting field work are employees rather than contractors. However, the fact both were stated reinforces the ideology of how behavioural influences, regardless of occupational status, can play a detrimental role in incident causation. Workers with many years of experience may assess risk differently compared to those who are new to the field due to various psychological complexes such as over confidence; both situations may put workers in jeopardizing positions by not accurately judging risks (Slovic, Fischhoff & Lichtenstein, 1982; Flin et al., 2003). In relation to field work, it is the professional Geologist who has a responsibility to assess the risk on the job and ensure the Field Assistant is not expected to do work outside their capabilities. The last notable category involved equipment use; a relationship can be made between a worker's physical fitness level and how they perceive risk while conducting a task. A risk assessment while using equipment such as carrying heavy bags, boxes of samples, chains and other tools varies between individuals and is generally conducted subconsciously. Individuals who perceive themselves differently from their actual physical abilities might have an altered sense of risk and are more likely to engage in activities that are dangerous to their physical being. Within the field, psychological pressures such as individuals wanting to feel a part of the team may also influence one's perceptions of risk in adverse conditions. Understanding risk through a defined lens involves controlling risk by recognizing that barriers within the field can influence individuals to perceive risk accurately, according to their physical abilities.

2.4 Agency and Barrier Analysis

The agencies and barrier analysis isolated sources of harm to the individual within field work (Table V). The analysis showed the top agencies to be *cut/puncture/abrasion, bruise/muscular, sprain, eye, skeletal,* and *no injury sustained*. The purpose of the agency analysis is to reveal the possible failed defenses that contributed to injury occurrence. The possibilities are vast in terms of barriers that could have been lacking, as virtually any hazard within the field could have resulted in any one of these agencies. Conclusions can be drawn based on common MOI as to how these injuries could have occurred within the field. Cut/puncture/abrasion, bruise/muscular, and skeletal injuries are most likely to occur by an object hitting the body; in relation to field work this could be the presence of hazards on the ground, such as rocks and fallen trees, or tools such as hammers and knives. Mitigating the risk in these situations can be traced back to highlighting the importance of wearing proper PPE and reinforcing the need to be aware of surroundings and actions while participating in field work. Sprains are likely to occur from falling or twisting; mitigations that might limit these occurrences include a review of appropriate PPE for traversing rough land, awareness of reading the terrain to pick paths that are better defined and highlighting common hazards that require caution. The industry could target these items to reduce the likelihood of having a sprain occur in the field.

The eye is the next agency that was identified and is very relevant to all occupations, notably those working in the field. The eye is naturally subject to injury due to its delicate structure, making the proper use of PPE at the utmost of importance (Almoosa et al., 2017). Although eye injury can still occur when wearing PPE, the injury severity is typically reduced (Thompson & Mollan, 2009). A proactive recommendation would be to review the types of eyewear protection available for use by field workers and determine whether better options would further limit the high chances of foreign objects entering their eye and causing damage. A policy suggestion could be to identify the most likely environments when eye protection is most useful if workers push back on constant use of that form of PPE.

The last theme that was identified stated that no injury was sustained. This is equally as important to note as the other injuries because it shows the prevalence of near misses within field workers and alludes to a strong reporting culture if this factor emerges as often as other body parts. Although this finding varies from the conclusions of the safety pyramid where many near misses were unreported, this finding is a function of how Leximancer pulls information based on the data specifically from field work related activities, highlighting the magnitude of near miss reports. Near misses provide information that can be used for incident prevention and can be used for learning opportunities (Johnson, 2002; Jebb, 2015).

2.5 Metadata

The metadata shows simple data that are important components within incident prevention and reduction (Table VI). Within the occupation section, those working in the field were the most susceptible to injuries, specifically field workers, and field assistants. Working in the field is associated with inherent risks that can be physically demanding. This finding is consistent with what was expected, as field work is one component within mineral exploration that contributes to categorizing it as a high-risk industry. Field work can be extremely risky and for these reasons would benefit from a top-down approach to safety management; providing frequent educational and training resources for field workers, that cover all aspects of potential hazards, will help mitigate risk for this population.

The most common occupational status documented within field work was either undocumented or employees. This finding may be an artifact of having many unknown employment statuses, simply due to the nature of reporting incidents that occurred in the field. Time constraints, lack of a suitable environment or adverse weather conditions are plausible reasons as to why the incident reports were not adequately filled out resulting in frequently omitting the occupational status of the injured worker. Another plausible reason as to the occurrence of undocumented occupational statuses could be attributed to near misses or hits. If no one was injured then likely the occupational status was left blank. The abundance of employees within the incidents is predicted due to the nature of the occupations seen within field work. It is interesting to note that injuries were also sustained to individuals just visiting the work sites, which was determined as visitor was documented as personnel type within the data pertaining to this section. This finding reinforces the importance of ensuring that all individuals participating in field work, regardless of their status, need to be properly educated prior to arriving onsite to protect against the inherent hazards.

The data shows that males were the most frequently stated gender to be injured; predicted with other high-risk industries where it is a male dominant field. Although males were most frequently stated, it is important to note the abundance of females documented shows gender diversity within the field. In fact, roughly 50% of geology graduates from North American

University are female (Gonzales, 2019). This demonstrates the need for enhanced safety systems to address the barriers pertinent to females (Michailidis et al., 2012; Owuamalam & Zagefka, 2014).

Lastly, during daylight hours was when most incidents occurred. This is reasonable as the majority of exploration efforts are conducted during the day; however, with work occurring from remote camps individuals are considered to be at work 24 hours a day. For example, if an incident occurs at camp during the night while individuals are sleeping, it is still considered a workplace incident. In addition, it is common for people cooking in the camps to be working during darkness, especially in the winter. As some incidents occurred during the nighttime, night safety is not to be overlooked when conducting risk assessments and delivering safety procedures as incidents are still likely to occur. In fact, literature shows that working during the night hours leads to negatively altered risk perception (Huang et al., 2007; Wagstaff et al., 2011). Across varying industries and occupations, there would naturally be fewer people working at night, which would in turn drop the number of incidents. However, sections within mineral exploration, such as drilling, operate on a 24/7 basis. By virtue of having less incidents depending on the time of day should not rule out the need to address possible safety barriers for all working hours. Additional research could consider the month incidents occurred to see further the impact of daylight and associated weather variables.

3. Travel – Transportation

3.1 Systemic Factors

The first causal analysis examined the systemic factors within travel and transportation incidents, revealing potential barriers that are transmitted down through the systems in place

(Table VII). These themes can be categorized into groups pertaining to equipment (*helicopter, drill, door,* and *tires*) and working environment (*property, field, site,* and *driver)*. The systemic influences within an organisation are generally not tangible but are influences that impact the likelihood of an event happening.

The first group, equipment, would likely be connected to systemic factors through concepts of poor safety culture, inadequate systems in place to address procedures, training equipment checks, or inadequate equipment design and selection at the procurement level. A commonality within all equipment-related factors is the lack of systems in place that accurately depict the safety needs of those working with such equipment.

The first term pertaining to equipment is helicopter. Working around helicopters can pose hazards to individuals if they are not fully aware of the proper protocols when entering and exiting the helicopter area; an organisation lacking safety culture can influence the way workers approach certain situations by observing the actions of the management and adherence to safety systems. If management deviates from proper safety protocols when working around helicopters there is a ripple effect where those same unsafe actions can be transmitted down the workforce (Clarke, 1999; Mearns, Whitaker & Flin, 2003; Ajith et al., 2011).

Drill is the second term associated with equipment and is another piece of equipment that could be influenced by organisational selections and maintenance of equipment. The type of drill, hydraulic versus manually operated, as previously noted in the discussion component of section 2. Top five incidents and description analyses: tool use, plays a role in the number of hazards present. Inadequate equipment design and selection of equipment are factors that directly affect the health and safety of frontline workers, yet is a decision that is far removed from those workers. If poor equipment design plays a role or inadequate maintenance is not provided by organisations, then it is ultimately the worker that is directly affected by these errors. Secondly, if there are no systems in place to address proper procedures and training for individuals working alongside drilling rigs, there is an increased risk of injury due to deviated risk perceptions and general lack of knowledge and awareness of potential hazards. There should also be a mechanism by which workers can transmit their dissatisfaction with tools or maintenance procedures back up the chain of command to enhance the safety system effect.

Door and tires are two components of vehicle equipment; these factors directly relate back to which vehicles were selected for work and the conditions they are in. Poor maintenance is a leading cause of incidents related to heavy machinery and vehicles (Zhang et al., 2014). Another organisational influence that could influence the damage to vehicles would be lack of systems to address procedures, auditing, improving, and proactivity of systems that currently exist (Reason et al., 2006; Madigan et al., 2017). The lack of all four of these factors directly affects the conditions of the working environment, posing an increased safety risk to divisions within organisations that are already at an increased risk of incidents, such as travel and transportation. The second group of themes that is influenced by systemic elements related to the work environment were constituting *property*, *field*, *site*, and *driver*. The relationship between nature of the working environment and systemic influences exists because if change is not addressed or made at the organisational level, that in turn influences the next level of defenses, which are workplace and task factors. Workplace and task factors are directly affected by the levels of attention and maintenance provided at organisational levels, therefore it is crucial to implement change management and be proactive in situations involving the working environment, to limit the potential for gaps to exist down the barrier line (Shappell & Weigmann, 2000).

3.2 Workplace and Task Factors

The second analysis examined workplace and task factors that could have played a role in incident causation (Table VII). These factors are grouped into the following categories: equipment (*truck, drill, trailer, engine, skidder,* and *forklift*), roadways (*trail, road,* and *rolled*), occupation (*pilot, engineer,* and *operator*), and location (*camp,* and *field*).

The first group, equipment, directly relates to conditions and influences of the workplace that affect the integrity of safety within those work environments. The most relevant factors in relation to equipment are poor maintenance of workspace, sub-standard interfaces, tasks poorly designed and improper or incorrectly performed job hazard assessment. Working with heavy equipment naturally increases the risk of incident occurrence due to the size of the machines and the diversity of associated hazards (McCann, 2006; Hinze & Teizer, 2011). The conditions of the workspace greatly influence the operations of heavy equipment and increase the hazards that operators need to be aware of; if the environment around the machinery is cluttered with debris or other machinery, the visibility is reduced and can affect the quality of job hazard assessment; if machinery is operating on sub-standard user interfaces, operators need to function at a higher level of intuition and distraction coping mechanism which can affect productivity, efficiency and safety.

The next group, roadway, is directly related to environmental conditions. The simple fact is that working conditions greatly affect the safety levels of the environment, and related jobs being performed in those environments. Although maintenance can stem from organisational influences, in these instances the direct work conditions are affected and contribute to holes within defense systems as per the Swiss Cheese model. Working conditions that are unsafe due to fallen debris or adverse weather conditions are directly correlated to an increase in incident occurrence; it is crucial that roadways and trails are kept in favourable conditions to limit the barriers within the working environment.

The next group, occupations, can relate to the task and environment conditions are job access, task complexity, fitness for work and workload. Pilots and engineers both need to operate at high levels of functioning at all times as their working environment is dynamic and requires specialized skill sets. If access to job prospects is limited, organisations need to ensure that the individuals chosen to work alongside regular employees are suitable for the task through their trained skillset, fitness for work and available induction training. Standards also need to be in place to ensure personnel working at high levels of both mental and physical expenditure are not given unrealistic workload conditions, as that can lead to increased levels of fatigue and burnout. Workloads need to be realistic and not influenced by external pressures such as time or financial incentives. The final group, location, is also directly correlated to environmental conditions. Those working in the field need to be fully equipped with the proper resources to handle the associated inherent risks; tool availability, task complexity, fitness for workload, and task planning are crucial factors that relate to task and environmental conditions that if properly executed can lead to favourable working environments.

3.3 Personnel Factors

The last component of the causal factors analysis looked at direct personal factors that played a role in incident causation (Table VII). The data revealed recurring themes that are grouped into the following categories: occupation (*employee, pilot, worker,* and *driver*), equipment (*truck, drill, helicopter, load, trailer,* and *rig*) and characteristics of the incident (*fell,* *broken,* and *approached*). Although these factors have been stated within the previous levels of analysis, they can directly relate to the individual performing the task. Occupation is the first group to be examined; behavioural influences like competence, fatigue and stress can greatly influence the degree to which workers safely conduct their tasks. Like all occupations that require specific skill sets and levels of competence, pilots and drivers have an especially mentally demanding job because of the degree of complexity their tasks involve. Any degree of undesirable levels of stress or fatigue can negatively impact the success with which the jobs are carried out.

The next group, equipment, seems to have highlighted mostly heavy equipment. Again, behavioural influences such as competence, fatigue, stress, and job motivation play a detrimental role within incident causation. Heavy equipment operators need to operate at a high level of focus because of the many variables associated with the job task, therefore, workers need to be mentally healthy and free of external stressors to ensure the jobs are carried out as safely as possible. For situations involving drill use, the conditions and sit conditions can be left to the responsibility of the Driller or Drill Foreman; The Driller is often the person who checks the machine prior to work and gives clearance that it is safe to operate. In these instances, the Drillers need to be aware of all potential hazards and be able to recognize when equipment is not safe for operation.

The last group, characteristics of the incident, relate to both mental and physical aspects of direct factors. Workers need to be physically able to carry out tasks that require physical strength like carrying. Also, workers need to have a clear perception of their abilities, the risks around them and feel confident in their abilities to complete their assigned tasks. This will allow for quick reaction times and appropriate responses if hazards are to slip through the various layers of defenses that exist at the direct level.

3.4 Agency and Barrier Analysis

Within travel and transportation, the factors within the agency and barriers analysis are very similar to those identified within drilling related activities and field work (Table VIII). The mapping revealed the top agencies to be no *injury sustained, bruise/muscular, cut/puncture/abrasion* and *sprain*. Although the data seems similar to findings in related fields, there are differences present because these incidents relate directly to travel related incidents. The nature of injuries sustained vary between different fields of work. Firstly, *no injury sustained* was most frequent. The reason for this may be twofold: the damage was sustained to property rather than an individual, or the incident did not result in any sort of damage to either an individual or property and was considered a near miss. Acquiring data on near miss incidents is extremely important within incident prevention because it brings awareness to the potential hazards that could have resulted in an incident occurring should the circumstances be slightly different (Wright & van der Schaaf, 2004). Having a large number of near misses also shows the safety culture and integrity of the workers and how they feel obligated to report small scale incidents. The integrity of the workers transmits to the overarching safety systems organisations have set and the degree to which these standards are followed.

The next agencies resulting in the least frequent occurrence were *bruise/muscular, cut/puncture/abrasion* and *sprain* injuries, and can be grouped together to show the level of injury that was sustained was severe enough to cause a level of harm. These findings overall show the importance of preventing hazards from slipping through the various defense layers to ultimately prevent injuries of this nature, and possibly worse, from being sustained.

3.5 Metadata

The metadata reveals possible characteristics that contribute to higher incident rates (Table IX). Firstly, the metadata shows various types of occupational statuses to be involved within incidents relating to travel and transportation. This is important to note because it shows it is not always operators trained to work with specialized transportation equipment that become injured, individuals working various occupations that do not specialize in such operations like geologists, field assistants, and Drillers are also involved in these incidents. This finding shows that increased levels of training are needed from an organisational viewpoint to educate all types of personnel who might be working with travel related equipment, regardless of if it is not their sole job task. There could be many types of scenarios where personnel such as field assistants and geologists utilize travel equipment such as pickup trucks, ATVs or UTV or snowmobile, so it is important for those individuals to be educated in all contexts.

Next, unknown was the most dominant employment status to be documented within these incidents. A few predictions could be made regarding this, based on discussions held with industry partners. Firstly, individuals involved with travel related incidents may be away from the worksite and not have a vehicle that is fully equipped with incident reporting documents or be aware of such resources. This results in information being missed upon reporting as there is no structured checklist which states the needed information. Secondly, incidents are being filled out after the fact, opposed to when the incident occurred, resulting in either information missing or forgotten. Additionally, the person filling out the incident report is not familiar with the occupational status of the individuals involved with the incident and select unknown as they see that as the best fit option in that situation. With relation to the PDAC-AME survey specifically, there is a high likelihood that the person filling out the survey was not in the field with the crew when the incident occured. Lastly, there can be a mixture of employees and contract workers in the same vehicle, making it difficult to specify on the report which employment status was involved. This can be especially true with near misses and reporting incidents when no one is hurt, as generally the selection made would be unknown.

Next, employee was documented almost twice as much as contractors. This could be attributed to the nature of the job tasks involving equipment operation, where generally those tasks would be designated to employees rather than contractors. Additionally, research has shown that it can be difficult to integrate contract workers into H&S systems, potentially contributing to the fact that contract workers report less near misses compared to employees explaining the numbers of documented employees compared to contract workers (Lippel & Walters, 2019; NewsRX, 2019).

In terms of gender, male was most stated. As previously mentioned, this is an expected finding due to the nature of the work. However, as females are still prevalent within this field of work, organisations need to be aware of the fact that since the turn of the century more women are choosing jobs within male-dominated areas (Atwater & Van Fleet, 1997).

Lastly, the most documented incidents resulted during daylight hours, with less than 6% of these incidents occurring during nighttime hours. This is interesting to note because most incidents related to travel and transportation occurred during the time with most the visibility. Literature shows that incidents that occur during nighttime hours are frequent and often severe in nature (Liu et al., 2019). However, the outcome of this data is expected as most mineral exploration efforts are conducted during daylight hours, especially considering most of Canadian field work is conducted during the summer rather than winter months making for very long daylight hours in the North. This shows extra caution is needed, even during hours with visible daylight, as time of day is not a clear indicator of incident occurrence. Again, further research could be conducted to see the month of incident and any related seasonal factors. In conclusion, the metadata shows details about incidents that could play a viable role within incident causation when analysed together.

Human Factor Analysis (HFAC) Model

The HFAC Model was chosen as a framework of analysis due to its good recognition and reputation and previous use in high-risk industries (Shappell & Wiegmann, 2000; Patterson & Shappell, 2010; Nwankwo et al., 2022; Kaptan et al., 2021; Theophilus et al., 2017; Zhang et al., 2020). The HFACs Model is a broad framework in which the analysis will identify active and latent failures within the entirety of the dataset. The HFACs model was chosen to supplement the previous frameworks followed, by showing an alternative view on factors that can culminate with an adverse event. HFACs Models are generally applied to one incident, however, the nature of the dataset is not conducive to analysing each incident independently. Therefore, the components that comprise the HFAC Model were applied to the dataset as a whole to gather an understanding of failures within the field that culminated within all incidents. It can be hard to implement change within all levels of mineral exploration, therefore understanding the broad factors that are present in the field can act as a starting point for organisations and leaders to use when beginning to mitigate risk within the field. The framework follows the ideology that at least one failure will occur at all four levels of the framework within an incident; if preventative measures are taken to stop the failure from occurring then the event could be prevented. This makes it crucial to thoroughly examine all possible factors that could lead to an adverse event.

1. Unsafe acts

Unsafe acts are defined as errors or violations conducted at a personal level and are the first levels of human factors that lead to an adverse event. These comprise factors such as errors in decisions, skills, perception and competence, and violations of routines within job tasks. The data showed the important factors to be *drill, worker, truck,* and *site* (Figure 25). *Drill, truck*, and *site* are areas within the workplace that influence errors and violations made by individuals. Both drill rigs and trucks involve machinery that requires a specialized skill set; skill-based errors can come into play when working with equipment that is specialized during the operator's execution of a routine. Errors can even occur during skills that are highly practiced where operators are proficient, due to failure to prioritize attention, or through the creation of a negative habit (Shappell & Wiegmann, 2000). Decision and perceptual errors can also play a role when operating specialized machinery and are based on actions or behaviours by the individual. Errors occur when the operator's decision-making ability is degraded (ie. when fatigued or distracted), and the consequential behavioural outcomes affect the task, and further, can result in an unsafe situation. Routine violations can occur in areas such as field sites and drill rigs when the individuals are used to the area, and create unintentional habitual actions (Shappell & Wiegmann, 2000). These violations can often be tolerated by the governing body, however, should be addressed immediately to prevent other individuals from adopting unsafe practices. The last factor that was identified within the data specifies *worker* as a main theme. This is relevant within unsafe acts because the worker is the key determining factor whose actions influence the occurrence of an unsafe act.

2. Preconditions for unsafe acts

Preconditions for unsafe acts is the second level within the HFAC framework and focuses on the conditions and practices of individuals in relation to completing a work-related task. This level is made up of two main categories: substandard conditions of operators and substandard practices of operators (Figure 36). Both categories will be addressed in relation to the data findings. The findings present five main factors within preconditions for unsafe acts: *drill, employee, truck, driller,* and *camp* (Figure 26). The first noteworthy factor is the occurrence of the term employee. This is understandable within preconditions for unsafe acts because the individual is the one who is affected by this level within the HFAC model. This section will showcase how the individual plays a significant role within contributing to potential failures of systems. The two themes drill, and Driller are closely linked, and therefore likely share some of the same preconditions for unsafe acts. People referred to as "Drillers" are the supervisor at the rig unless a designated Foreman is present and are at the forefront of drilling operations. They are highly skilled individuals who have a diverse understanding of drilling operations, moving and the dismantling of rigs. The safety of the drilling rigs is heavily influenced by the practices conducted by the Drillers and behavioural influences, as they are not only operating the machines, but their attitudes and perceptions are relayed to the Driller Helpers. If substandard practices are used by the Driller, those conditions can influence Driller Helpers to adopt such standards, lowering the safety of the entire worksite. Some substandard conditions of operators that are preconditions for unsafe acts are adverse mental states, adverse physiological states, and physical or mental limitations. Adverse mental states can include but are not limited to complacency, mental fatigue, motivation deviations, task saturation and loss of situational awareness (Shappell & Weigmann, 2000). Adverse physiological states are factors that are equally as important to evaluate and can include physical fatigue, medical illness, and impaired physiological state. Lastly, physical and mental limitations are factors that can contribute to substandard conditions of the Drillers. As Drillers hold seniority status at drilling operations, the values and attitudes they hold are conveyed to many other workers in the vicinity. Substandard practices are factors that can inadvertently influence the integrity of the drilling operations. Some ways to mitigate the impact of substandard practices would be to have leadership present at the worksite, better communication to all workers, use of available resources and safety talks. Workers should know that the same standard of practice is expected for all equipment operators, whether that be drilling rigs or operating trucks. The theme truck was a common factor highlighted within the precondition of unsafe acts. There needs to be awareness of the possible substandard practices and conditions of operators, regardless of the size of the machine, as operating any type of equipment comes with inherent risks. Addressing adverse mental and physical states prior to operation can reduce the preconditions for unsafe acts, hopefully stopping the domino effect from transmitting through the rest of the HFAC factors.

Camp was the last precondition for unsafe acts. When “camp” is referred to in incident reports this can have two indications – one being that the work was integral to the operation of the camp such as the cook in the kitchen, running camp equipment like generators, etc. or that it occurred within the camp but was unrelated to running the camp; For example, an injury caused during geological work on the drill core may occur in camp, but not be related to running the camp itself. Camp was a precondition for unsafe acts and relates to the environmental factor’s component within this level. Environmental factors are the physical and technological environment (Chauvin et al., 2013). The physical environment refers to external settings such as the weather and terrain, and the ambient environment such as exposure to toxins, heat, and vibration. The technological environment refers to design and user interfaces of equipment. Issues at both the physical and technological level should be considered within incident causation, however, in relation to preconditions for unsafe acts pertaining to camp, the physical environment is most relevant.

The conditions of camp and field camp vary between locations and within organisations and is reliant on the availability of resources. When individuals approach camp they are often off duty and take the time at camp as down time to rest and recover. In an ideal setting, the camp atmosphere would reflect safety and comfort by allowing workers to rest their mind and body. However, situational awareness cannot be turned off around camp because of the remote nature of the camp setting. Hazards are still present, and the camp environment will always be subject to operational settings such as weather, altitude, and terrain. Adverse camp conditions can greatly affect the conditions and practices employed by workers, both subconsciously and consciously. Organisations should consider situational factors when designing, maintaining, and improving camp life. In conclusion, the mental and physical conditions and practices of individuals are factors that are undeniably influenced by external factors and can be difficult to identify, however do play a detrimental role within this framework. Using these factors as a guide can allow incident investigators to identify failures at the individual level that culminated in an event.

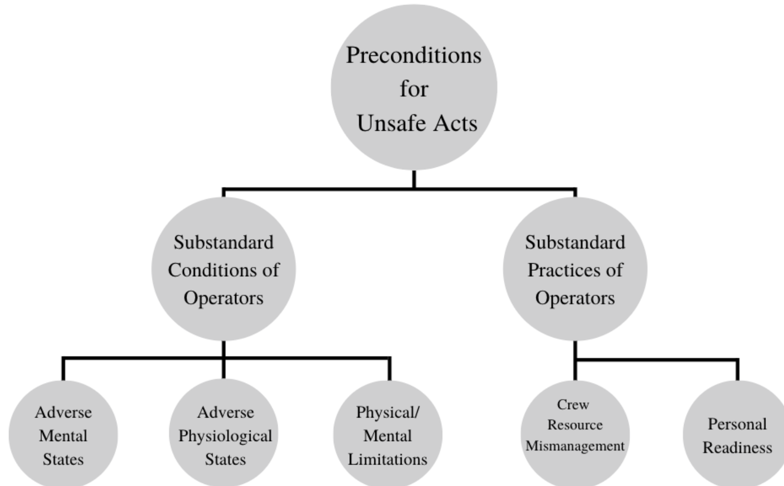

Figure 36. Categories of preconditions of unsafe acts (Shappell & Wiegmann, 2000), adapted by Bond (2022).

3. Unsafe supervision

Unsafe supervision is the third level within the HFACs framework, and as the name alludes to, focuses on components within supervision and leadership that can lead to failures within the system (Figure 37). The data revealed *hand*, *drill*, *truck*, *crew* and *driller* as the main factors relating to unsafe supervision (Figure 27). The first division within the unsafe supervision hierarchy is inadequate supervision and is relevant to all five factors found within the data. Within drilling specifically, the role of supervision is to ensure workers are adequately equipped with the proper training to handle the equipment, awareness of hazards, and access to PPE. A lack of oversight can affect workers' levels of risk perceptions and their availability to recourse, in turn increasing the risk for failures and for potential incidents to occur.

The next component, planned inappropriate operations, refers to actions that are allowed during certain scenarios or emergency situations, but are not prohibited during regular operations. This situation can relate to all levels of mineral exploration, especially during heavy equipment operations and field work where multiple crew members are present. In these situations, the individuals are put at unacceptable levels of risk through the mismanagement or assignment of various aspects of work. This could be the failure of risk management, improper crew pairing or altered operational tempo reducing the prevalence of proactive planning and preparing. The third component is the failure to correct known problems, where deficiencies are made clear to the supervisor, yet no change is implemented. This theme again is relevant within all fields of mineral exploration but focusing on equipment usage such as drilling and heavy equipment operation, it is extremely important because research has shown that preoperative checks and proper maintenance are factors that can prevent incidents from occurring (Zhang et al., 2014). Some general examples would be if defective or subpar components of the machine are brought to the attention of the supervisor and no corrective action is taken, or if supervisors are informed of specific hazards within the field and there is no initiative taken to correct the safety hazard. The safety culture of an organisation can play a role in unsafe supervision by influencing decisions the supervisors make.

A lack of safety culture could leave the supervisor, for example the Driller or Drill Foreman, feeling no moral obligation to report unsafe tendencies or initiate corrective actions. The final component within unsafe supervision is supervisory violation, referring to supervisors that knowingly disregard safety rules and regulations in place. This could be supervisors failing to enforce proper rules within drilling rigs, turning a blind eye to unsafe behaviour, production pressures especially when bonuses are involved or inadequately reporting health and safety documentation. Ultimately, unsafe supervision truly does start from a top-down approach through an organisation's safety culture. These conditions stated are perfect examples of how the safety culture of an organisation greatly influences the moral obligations of supervisors, and what might be viewed as minor offences to some supervisors can have detrimental effects on the integrity of health and safety systems.

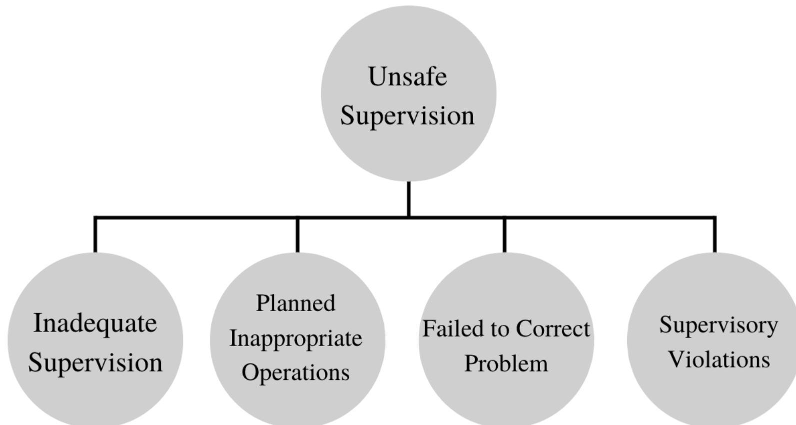

Figure 37. Bond (2022) visualization of the categories of unsafe supervision adapted from Shappell & Wiegmann (2000).

4. Organisational influences

The final level within the HFACs framework is organisational influences and can be divided into three categories: resource management, organisational climate, and organisational processes. These three will be examined with respect to the dataset. The data showed *drill*, *employee, sling,* and *field* to be the most common themes within organisational influences (Figure 28).

Resource management refers to the decisions made at an organisational level that determine how assets are distributed throughout the organisation. These assets could be in relation to monetary allocation, new equipment facilitation or human resource availability. The safety within drilling operations is heavily influenced by resource management because it is within this component that the selection of competent workers and proper training takes place. Management needs to ensure they are hiring competent Drillers and Drill Helpers to handle rigging operations safely and effectively. Along with the selection of individuals, the selection of equipment also happens at the resource management level. Equipment needs to be up to par and meet proper safety standards. In terms of field work, resource management needs to ensure that monetary resources are allocated so that individuals in the field can safely conduct their tasks with the proper PPE, tools and equipment, and affiliated resources to ensure the safety of all members while in the field.

The second category within organisational influences is the organisational climate. For important reasons, safety culture has been thoroughly discussed throughout this paper. The safety culture within drilling rigs, field operations, and helicopter related work specifically is a crucial component within incident causation. The structures and policies in place are written regulations that all workers should be made aware of; these structures and policies are easier for workers to follow and understand because they are generally relating to tangible outcomes. Safety culture on the other hand, involves unspoken perceptions, beliefs, and values that employees hold and share within a workplace. Safety culture can be harder to measure because it is fostered by attitudes of the organisation but transmitted across and down through the workforce by those unspoken perceptions, beliefs and values. Focusing on the findings from the data, the working atmosphere within the organisation pertaining to field work and related activities, such as helicopter use involving slinging operations, holds some of the strongest influences within these activities.

The norms and rules that organisations enforce will dictate how individuals operate in these high-risk settings. With slinging, for example, workers around the helicopter need to know exactly the role they play within the operation. Ground workers need to know which task they are assigned to, who is communicating with the pilot, taking time to not rush around the machine, and ensuring all items are securely stowed.

All factors can be indirectly heavily influenced by the safety culture within an organisation through these expectations of the organisational climate. If the workers are not working together as a cohesive unit, do not support risk management or are working under external pressures, the integrity of the organisation's safety culture comes into play, making safety to not be deemed as the highest priority. The above example of slinging is a good representation of how procedures are in place to prevent incidents related to these operations. Other risky situations should be treated with as much importance as slinging by having set procedures and guidelines in place to reduce incident occurrence.

The last component within organisational influences are the operational processes that encompass the decisions and rules that govern the operations and procedures within an organisation. This is essentially how the vision of the organisation is carried out. Specific qualities of operational processes that affect the integrity of operations such as time pressures, incentives, production quotas or lack of planning, are relevant to the themes, *drill*, *employee, sling,* and *field,* that were pulled from the data. These factors directly affect the attitudes of management, who then, in turn, directly influence the attitudes of the frontline workers. The procedures that take place at organisational levels like the safety standards that are upheld, the risk management availability, standards of documentation and availability of safety programs guide the behaviours that are acted out throughout the system (Shappell & Wiegmann, 2000). Mineral exploration is a diverse field considering all the domains within the sector and the collaborative occupations onsite. From an organisational viewpoint it can seem overwhelming to implement change that is going to affect all fields within this sector; looking at the key findings from the data and seeing how it relates to these frameworks, like the HFACs model, is a great starting point that will aim the organisation in a direction allowing for better safety consciousness.

CHAPTER 7

7.0 GRAND SUMMARY

This next section will provide an overview of the previous chapter by concluding with summary statements that represent areas the writer believes the industry needs to focus on to enact safety culture change. These areas are determinant on the frequency of their recurrence within the analysis. The structure of the following themes are in no representative order of greatest to least frequency, occurrence or importance, as they are all believed to be equally as critical. Additionally, comparisons between industries are made to show similarities and differences across findings in other industries.

1. The first recurring theme within the analysis was the presence of PPE. Most notably associated with tool use and field work activities and involving most frequently the eyes and hands. Some key recommendations based on the data and associated literature would be to re-assess PPE accessibility and wearability within drilling, tool use, and field work. The PPE not only needs to be easily accessible and of high quality, but it should be comfortable and not interfere with the operations of the task. Individuals need to be confident in their ability to safely complete their job task while wearing proper PPE, minimizing the likelihood of PPE refusal or removal if not comfortable. Another recommendation would be to assess protocols and resources in place which emphasise that it is mandatory and important to wear proper PPE when required. The resources made available to the workers should state that following PPE protocols is not a guideline or recommendation, but rather a mandatory component of the job task. An environment with open communication between workers and supervisors is important to understanding workers concerns relating to PPE wearing, as workers can express any concerns relating to wearability, comfort and potential limitations or inconveniences to the job tasks.

2. The second recurring theme throughout the analysis relates to risky activity protocols. This involves the presence, or lack thereof, of protocols to protect individuals, and the levels of adherence to these protocols. Risky activities within the analysis are mainly related to drilling operations, field work, helicopter usage and heavy equipment operations. Within drilling operations, existing safety protocols could be reviewed to see if potential gaps exist that were identified by the data analysis and literature findings; proper PPE, team situational awareness, hazards related to conditions of working environment, and proper tool handling are all aspects that should be considered. Next, the risky activities associated with field work can be minimized by reviewing the recommendations for proper PPE and enforcing strict policies, assessing proper tool handling within the field, and modifying job tasks, depending on the individual's physical capabilities and load. Also, reiterating the importance of the guidebook provided by PDAC, which should be encouraged to all individuals conducting field work. Next, the data showed the risky activity associated with helicopter usage were mainly from individuals using the helicopters for transportation and slinging. For this reason, it should be mandatory for all individuals working with and around helicopters to become educated on the manuals and pocket guides created by PDAC, such as the e3 Plus: Framework For Responsible Exploration Chapter 16.0 Aircraft. This is an excellent resource that covers the main areas of risk that were identified by the data analysis. Lastly, risky activity protocols associated with heavy equipment operations need to review the most common themes derived from the data analysis; situational awareness, spotters, distracted driving and fatigue.

3. The third recurring theme is related to heavy equipment, involving fatigue, distracted driving, and protocols surrounding operations. Recommendations based off the data and associated literature would be to explore options such as limiting drivers operating under fatigue, more education and protocols revolving around distracted driving, and enforcing strict protocols associated with heavy machinery usage by including increased awareness regarding hazards of operating vehicles in rearward directions, the benefits and risks associated with spotter use, and situational awareness.

4. The fourth recurring theme is related to manual manipulation and labour. This recurring theme was frequently related to drilling operations and field work. The recommendation would be to review key aspects such as lifting, carrying, and MOI's by conducting specific job-related physical demands analysis.

5. The fifth recurring theme is the importance of toolbox talks. Toolbox talks surfaced a lot throughout the data analysis; this is an important consideration for the industry because it shows the efforts made to communicate risks and hazards are present, but the data was unable to determine what level of structure these talks were following. A question remains, if the meetings were effective, why are they so strongly associated with accidents? Chapter 9 will cover how the industry could implement a structured toolbox format into the field which could potentially help with the effectiveness of these talks.

6. The sixth and final recurring theme is related to environmental hazards. The working conditions and environmental hazards arose frequently within the data. The main hazards were in relation to wet and winter conditions, and MOIs such as slipping and falling. The industry needs to place attention on safety to workers that are in environments which are subject to adverse weather conditions. The importance of appropriate PPE, as well as awareness and maintenance of working conditions emerged in the data and were supported by literature.

7. This section will cover some main similarities between the presented data and related industries. The first similarity is in relation to heavy machinery. Mining and construction literature have demonstrated through various studies that the involvement of heavy machinery exposes operators and surroundings individuals to increased levels of risk Nasarwanji, Pollard & Porter, 2018; Ruff, Coleman & Martini, 2010). The data in this project demonstrates there is indeed an increased risk of injury with machinery usage, as light vehicle and drilling related machinery were within the top five incident types. With that, travel and transportation were within the top five activities that had the highest amount of incidents. The second similarity is in relation to age and experience and the associated risks. Literature has shown that age and experience levels heavily influence the likelihood of an incident occurring (Groves, Kecojevic & Komljenovic, 2007; Bahn, 2013). The data from the survey reports is aligned with these findings in that field work was the second highest activity with the most amounts of incidents. It is predicted that many workers in the field are assistants and students. Additionally, field work (not specified) and field assistant are within the top six occupations with the most reported incidents. In relation to safety models, the presented findings are consistent with the

safety pyramid and the HFACs models. The similarity regarding the safety pyramid is not related to the ratio that was generated, but is related to the notion that caution should be exercised when referring to this theory. The findings show a higher number of minor injuries, compared to near misses, which is opposite of what the pyramid states. This could possibly be due to either underreporting or that the nature of injuries is more severe. Nonetheless, the critiques of the safety pyramid align with the presented findings in that it should be used as a general concept in safety mitigation, opposed to interpreting the model too literally (Moore et al., 2020; Marshall, Hirmas & Singer, 2018Dunlap et al. 2019; Hudson, 2001). The similarities with the presented findings and literature supporting the HFACs model is that individuals completing the reports may be bias against higher order concerns (Patterson & Shappell, 2010). The findings showed the least amount of incidents to be reported as organisational contributory factors, aligned with previous studies demonstrating that possibly skilled individuals are great at identifying technical failures and not systemic or cultural.

8. The main difference between the presented findings and the high-risk industries the literature review was based on is the involvement of contract workers and how literature in related high-risk industries has shown an increase risk of incident occurrence, mainly related to safety culture concerns and experience levels (Clarke, 2003; Lippel & Walters, 2019; Blackley et al., 2014; Gpchfeld & Morh, 2007; Graham, 2010). The presented data showed employees to have higher incident occurrence compared to contract workers. This could be due to how the occupational status was filled out within the reports. Within the survey report there can be discrepancies on how the term contract worker is used between companies. For example, if an incident is reported by the drilling company and

they refer to the worker as a contract worker, that implies they are short term rather than a full-time employee. But if the drilling accident is reported by the mineral company, then they may refer to the worker as a contract worker because they work for the drilling company that is under contract; They could be an employee of the drill company though, not a contract worker from the drill companies' point of view. Additionally, the survey reports do not indicate experience level of the contract worker, nor evaluates perceptions of safety culture. For these reasons, it is unclear the main roles that could have played a role in the difference of findings.

CHAPTER 8

8.0 LIMITATIONS

While the study was plentiful in data, encompassing 14 years, covering a cumulative total of 105,408 individual data entries, there are limitations to the study. Although the dataset was plentiful in scope, it covers a niche within the mineral exploration field.

1. The data included was retrieved from Canadian incidents, therefore not representative of the global scale of mineral exploration. Although this data can be compared to other Canadian mineral exploration incidents, health and safety standards vary between countries, so discretion is to be advised when comparing findings to global incidents within the field. Also, the data was retrieved by companies who voluntarily submitted their yearly incidents, which could be seen as a limitation as it is not representative of all companies. Companies who submit their yearly incident reports could be seen as companies that value health and safety and are willing to utilize resources to adhere to health and safety initiatives and are more willing to find where gaps in safety standards may exist. That being said, the companies involved are working together to contribute to a safer working environment, and the details collected from the survey information is noteworthy.

2. The second limitation of this study was the use of secondary data. In this case, the data had been modestly cleaned prior to receipt; however, flaws existed within the set. There are a few problems with the use of this type of secondary data, particularly data that was collected in the field. Collecting data in the field subjects the data entry errors, for example notes written in short form or slang, have spelling and grammatical errors, and are written from the context of the individual. Terminology varies between companies

and even between workers on site; this opens the door to possibly describing the same incident in many ways. This resulted in a cluttered dataset that did not follow any streamlined or systematic processes and made data cleaning and coding a lengthy task.

3. The third limitation with using data that was collected in the field is that the data is handled by many people; workers are filling out the injury reports on the spot, to then be transmitted to the company's health and safety management for yearly reports, and then to be transmitted to PDAC's survey. Unintentional alteration of data can happen when files are moved around and handled so frequently. With this, another limitation can occur and is based on how individuals are interpreting the context of the categories when filling out the survey. The best example of this would be the selection of Contract Workers. There can be various instances in how this term is used and is left to the discrepancy of the individual filling out the form; there can be a contract worker, and an employee of a contractor. These terms can be used interchangeably within the survey and are not specified under the contract worker selection. Furthermore, if a drilling incident for example is reported by the drilling company and they refer to the worker as a contract worker, that implies they are short term and not a full-time employee. However, if the incident is reported by the mineral exploration company, they may refer to the worker as a contract worker because they work for the drilling company that is under contract. Meaning, they could be an employee of the drill company, not a contract worker from the drilling companies' point of view. Caution should be applied when interpreting these terms, and merits that either more research is needed, or modification of the survey questions would be appropriate.

4. The fourth limitation again relates to how the data was collected. Specifically, the nature of the individual completing the report could be bias against concerns categorized higher within the hierarchical systems of the HFACs model. Studies, such as that carried out by Patterson and Shappell (2010), note that very little reports were classified at the organisational level. The bias lies at the level of the individual doing the reporting and their capacity for identifying higher-level items. Individuals at the workforce level have skills to identify technical failures but often lack the ability to identify failures relating to systematic components, which can make it difficult to identify components related to safety culture. The heavy cleaning required of this data, specifically the blank entries or wrong entries relating to contributory factors, supports this limitation because it shows there was a lack of understanding where the failures might lie. This may point to an opportunity to better inform the workforce of the hierarchy of HFACs items that would help remove the bias in reporting.

5. The fifth limitation within this survey relates to the nature of the dataset and how it required heavy cleaning. The cleaning was conducted by an individual who is not familiar with terminology and slang within the domain of mineral exploration; Therefore, alterations were at the discretion of the researcher, allowing for the impact of subjectivity and biases associated with interpretation of textual entries. However, the research did access external, expert guidance to attempt to ensure slang was converted into proper terminology, and that the errors within the set were consistent with the actualities of events in the field. Lastly, French entries had to be translated to English, and this was

done using Google Translate, leaving a possibility for changes in terms and intent. More advanced language models may have better preserved the language intent.

6. The sixth limitation relates to subsetting the data in different ways for analysis. This study evaluated the reports by subsetting the data into time frames (analysis 1), activity (analysis 2), and personnel (analysis 3). The author recognizes that if the data was subsetted differently, for instance, breaking down into injury classifications or some other topic of interest may yield slightly different results. The limitation in regards to not subsetting the data into injury classification specifically, is that throughout the analysis conducted, all incidents were treated equally, meaning that a near miss was treated the same as a serious injury. Evaluating the data by injury classification could prove to be very useful, especially if a different outcome was presented. It is likely that there are numerous additional variations in which this data could be broken down, and this particular study only touches on a small piece of the potential these data hold.

7. The final limitation is how a different approach, namely using a temporal analysis model, might have resulted in different conclusions. Temporal analysis examines a specific variable and the behaviour of that variable over time. It is hypothesized that the results could have varied if using a temporal analysis approach, compared to the Leximancer findings. For example, following a temporal analysis with the variable of interest as 'gloves' might have shown the prevalence of gloves to be statistically significant over time, or not. Temporal analysis could show time dependencies and interrelationships that could be worth further investigation, findings that would not show up within the Leximancer analysis. Comparing it with the Leximancer analysis which outputs a visual

representation; In relation to figure 3 and the term ‘gloves’, the difference in position of the word between the three figures is dependent on how the term ‘gloves’ was used within the descriptions. For 2005-2009, PPE was the main theme (most highly ranked concept), with gloves just being a singular concept within that theme. The same goes for 2010-2014, work was the most highly ranked concept, hence why it is considered the theme, and gloves is a concept that is related to the theme work. Within the year 2015-2019, gloves were one of the most highly ranked concepts, therefore it created a full theme revolving around gloves and entries associated with that term. The year 2015-2019 shows gloves to be the most important over the three-time series. This shows the comparison of how Leximancer deemed the years 2015-2019 to have the most emphasis placed on glove use based on the textual entries, whereas a temporal analysis approach might have shown gloves to be more or less significant over time. A temporal approach has been shown to be useful in the health and safety field and could be used for future research when working with lots of data over time (Lingard et al., 2017).

CHAPTER 9

9.0 FUTURE RESEARCH AND IMPLICATIONS

There are numerous avenues of future research that can stem from the presented findings. Studying health and safety in the mineral exploration field is extremely scarce and could benefit from any type of further health and safety investigation. The findings of this study reiterate the importance of reviewing past incident reports by showing certain gaps, barriers, and safety hazards that exist, to ensure proper steps can be taken to mitigate risk within the field. The findings of such a study are systemic and should influence change through all levels of organisational systems from stakeholders right down to the front line.

Although distressing to see the level of incidents sustained in the field, research such as this is positive because it is forward thinking and can motivate organisations to make steps in the right direction towards a safer working environment. Health and safety is dynamic and involves many components such as safety culture, personal beliefs and attitudes and access to available resources; however, with proper education, like the findings of this research, which breaks down those dynamic influences, organisations can take these findings to help confidently implement change. This research has shown that mineral exploration shares many commonalities with other high-risk industries such as mining and construction, demonstrating that although the research specific to mineral exploration is limited, using findings from similar high-risk industries can prove to be beneficial.

Many avenues of future studies could be conducted based on these findings. Specifically speaking, organisations can take the methods used and apply it to the incidents within their company to see areas of importance. Organisations can gather a greater breakdown to show more detailed findings specific to the areas of interest, determined by the organisation. Broadly speaking, for the mineral exploration field in general, further research could address different variables associated with incident occurrence, like financial incentives, exploration budgets, hours worked per individual, and days in the field, to name a few. Lastly, this research has identified and utilized a novel approach to tackle large volumes of data, which can be used for continued research within the field.

9.1 PRACTICAL OUTCOMES

This next section will cover practical outcomes for the industry based on the findings of this report, to demonstrate how this work can be used to encourage knowledge transfer outcomes.

1. The findings of this research can guide the creation of deliverables, such as posters, infographics, and small papers. These deliverables can be targeted to workers within the field by highlighting areas of importance pertaining to specific job tasks, and health and

safety professionals to demonstrate and encourage how positive health and safety aspects, such as safety culture, can be managed and maintained. Additionally, knowledge transfer kits could be created based on the main areas of concern and distributed to health and safety professionals in the field. These knowledge transfer kits could include short presentations and discussion questions, a guide for the supervisors administering the educational pieces, potential for interactive technology components to foster engagement and posters to reinforce findings.

2. Secondly, variations of guidebooks, like those published by PDAC and the new code manual created by Bond, can stem from these findings. Honing in on particular aspects of the data analysis is a useful resource to pull information from when creating new guidebooks, whereby the data provides ample opportunity for new guidebooks to be created.

3. Thirdly, the creation of a database pertaining to “toolbox talks” could stem from this research. As the analysis continuously pulled communication between supervisors and workers to be important, having a structured format to follow and a designated database for these discussions could prove to be very useful to the industry and health and safety analysts.

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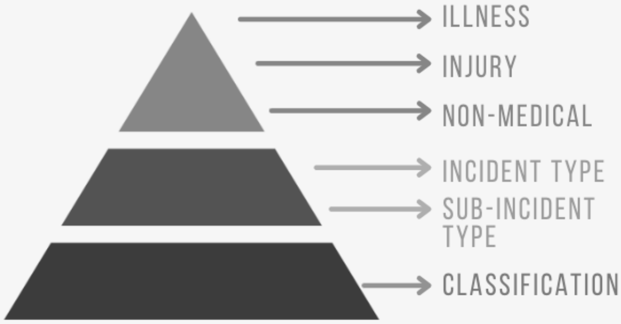
APPENDICES

Appendix A: Code Catalogue

The code catalogue that was created for the industry. The components within this catalogue are used for The Canadian Mineral Exploration Environment, Health & Safety Survey Incident Reports that are sent out to participating companies each year.

INCIDENT REPORTING SCHEME

FOR VISUAL REFERENCE, THIS SECTION BREAKS DOWN THE HIERARCHY OF THE CLASSIFICATIONS.



CLASSIFICATION

The classification refers to the incident class in which an injury or near miss was sustained. These are the broad, overarching categories that represent the first component of analyzing an event.

These classifications fall under the idea of the injury severity matrix, by chronologically ordering injuries from most severe to less severe (lost time injuries/serious, minor injuries/reportable/first aid, near misses and unsafe acts). Other applicable components have also been added.

The classifications have been simplified from the original survey report.

The classifications have been ordered from least severe to most severe.

- Near Miss / Near Hit
- Illness
- First Aid
- Medical Aid
- Non-Medical
- Restricted Work
- Lost Time
- Property Damage
- Environmental
- Fatality

CLASSIFICATION QUALIFIERS

Near Miss / Near Hit	A event that has the potential to cause, but does not actually result in an incident
Illness	A sickness affecting the body or mind
First Aid	A minor incident requiring immediate attention at the location of injury. Aid may either be self-administered or provided by another person (not medical professional)
Medical Aid	Medical treatment administered by a medical professional (e.g. nurse or doctor)
Non-Medical	An incident that does not require medical attention or first aid (see p. 15 for details)
Restricted Work	Modified work duties as a result of a work-related injury
Lost Time	A work-related injury that results in the individual being off work past the day of the incident
Property Damage	Damage done to tangible property
Environmental	Any damage or degradation sustained to the air, water, or land surrounding working environment
Fatality	The occurrence of death as a result of an incident

INCIDENT TYPE

The incident types have been broken down into two parts: incident type and sub-incident type.

The incident type is the second category within the overall incident reporting scheme and refers to the mechanism of injury.

These mechanisms of injury are the general action or event that best describes the circumstances that resulted in the injury or near miss.

Airplane	Helicopter
Animal	Improper Lifting
ATV / UTV	Improper Operation
Boat	Light Vehicle
Camp Equipment Related	Medical Condition
Chemicals	Other
Drill Machinery Realted	Preventable with PPE
Environmental Conditions	Repetitive Activity
Falling Objects	Slip / Fall
Field Work	Snowmobile
Harassment	Tool Use
Heavy Equipment	Water Realted

SUB-INCIDENT TYPE

This section refers to the secondary factors present within an injury or event. A sub-incident will not be relevant for every documented event. Recording the sub-incident will help clarify the main contributing factors and the secondary factors, and enhance data analysis by narrowing down the main factors involved within an event. This will also limit confusion and user error when selecting appropriate entries while filling out the report.

Adding the sub-incident will place emphasis on the specific factor, rather than classifying events broadly.

Airplane	Helicopter
Animal	Improper Lifting
ATV / UTV	Improper Operation
Boat	Light Vehicle
Camp Equipment Related	Medical Condition
Chemicals	Other
Drill Machinery Realted	Preventable with PPE
Environmental Conditions	Repetitive Activity
Falling Objects	Slip / Fall
Field Work	Snowmobile
Harassment	Tool Use
Heavy Equipment	Water Realted

NATURE OF: INJURY & ILLNESS

The nature of injury & illness are the most specific categories within incident reporting schemes.

These are the primary physical/psychological characteristics. The nature of illness refers to a sickness affecting the body or mind, whereas the nature of injury refers to physical damage done to the body.

Nature of Illness
Allergic Reaction
Cardiac
Dehydration
Heat Realted
Hypothermia
Mental Health
Other
Pre-existing Condition
Respiratory
Tick Fever
Virus

Nature of Injury	
Anaphylaxis	Fatality
Bleeding	Fracture
Blister	Frostbite
Bruise	Infection
Burn	Muscular
Chemical	Overexertion
Cut	Sprain
Dental	Strain
Electric Shock	Tendonitis

NATURE OF: NON-MEDICAL

Non-medical classification are two fold; events that occur that do not require any medical attention, or events that damage the body or mind external to the working environment.

Examples of non-medical situations could be abuse of alcohol or drugs, a physical fitness limitation, verbal or physical abuse, or a soft tissue injury that was sustained where no medical attention was required.

Nature of Non-Medical
Behavioural
Fitness - Mental
Fitness - Physical
Substance Abuse

ANATOMICAL LOCATION

Anatomical location refers to any region or part of the body that the injury was sustained or involved in a near-miss incident.

Anatomical Location	
Abdomen	Knee
Ankle	Lower Back
Buttock	Lower Leg
Chest	Mouth
Ear	Neck
Elbow	Other
Eye	Pelvis
Face	Shoulder
Finger(s)	Thigh
Foot	Toe(s)
Forearm	Upper Arm
Hand	Upper Back
Head	Wrist
Hip	N/A

CONTRIBUTORY FACTORS

Contributory factors within injury and incident causation are one element within the situation that caused the incident to occur.

Personnel: individual psychology and physiology; motivation, fatigue, stress & deviation of protocols

Task: components that influence how tasks are performed; workload, teamwork, job hazard assessment

Workplace: physical working environment; sub-standard environment & equipment

Contributory Factors
Personnel Factor
Task Factor
Workplace Factor

LOCATION

The location has been edited from the original survey report to provide a more streamlined approach. The original reporting system allowed users to manually enter in the location of the event. This added confusion, increased errors and made data cleaning more involved. The intent of the location was not specified and was left to the discretion of the user.

Moving forward, location will not refer to city, town or street name, but will refer to the geographical location or site in which the mineral exploration activities were carried out.

Location	
Core Logging Facility	Laydown / Laydown Storage
Core Sample Preparation	Line or Trail Cutting
Drill Machine	Mine - Open Pit / Quarry
Drill Pump and/or Shack	Mine - Underground
Drill Site (Outside Drill Machine)	Off Project Site
Exploration Warehouse	Office
Field Camp	Parking Lot
Field Camp - Dining Facility	Shop - Maintenance / Repair Facility
Field Camp - Field Office	Shop Yard
Field Camp - Kitchen	Staging / Mob / Demob
Field Work	Trail - Off Road
Flying - Airport / Airstrip	Trail
Flying - Fixed Wing	Travel on Highway
Flying - Helicopter	Travel on Site Access Road
Flying - Helicopter Landing Site/Pad	

ACTIVITY

BELOW ARE THE OPTIONS USERS CAN SELECT WHEN CATEGORIZING THE ACTIVITY THAT WAS INVOLVED WHEN THE INJURY OR NEAR MISS WAS SUSTAINED. THESE SELECTIONS ARE ALL ENCOMPASSING AND FAIRLY BROAD, AND AS SUCH, USERS SHOULD MATCH ACTIVITY AS CLOSE AS POSSIBLE TO THE OPTIONS PROVIDED.

Activity	
Core Logging	Mine - Surface
Core Sample Preparation	Mine - Underground
Drilling Related	Field Office Related
Field Camp Related	Storage
Field Work / Traversing	Training
Geophysics Surveying	Travel - Business
Infrastructure Construction	Travel - Transportation

OCCUPATION

After closely analysing 34 years of accident data, changes have been made to address the dynamic working environment within the mineral exploration field. Adding more options for users to select will enhance the validity of the report through selection of the most specific and accurate job titles. Although sufficient, the previous survey report was broad and lacked specifics in terms of occupations. This in turn could result in users selecting occupational titles that 'accurately depict' the job title rather than 'best suited'.

Existing Occupations

COOK
DRILL - NOT SPECIFIC
DRILLER
DRILLER HELPER
FIELD ASSISTANT
MINER
GEOLOGIST
GEOPHYSICIST
HEAVY EQUIPMENT OPERATOR
LABOURER
LINE CUTTER
MINER
OTHER

Added Occupations

AUDITOR
BIOLOGIST
CAMP MANAGER
CAMP WORKER
ENGINEER
FIELD WORKER - NOT SPECIFIC
MEDIC
MOTOR VEHICLE OPERATOR
PILOT
TECHNICIAN

Appendix B: Incident Template

The categories within the excel file, 'The Canadian Mineral Exploration Environment, Health & Safety Survey Incident Report', that is sent to the companies who submit their health and safety reports to be analysed by PDAC. Each company fills out this excel spreadsheet by selecting associated drop down choices within each category. The items within the drop down menu are those detailed within the code catalogue and shown below with their associated values for the purpose of analysing.

Canadian Mineral Exploration Environment, Health & Safety Survey Incident Report (include all reportable incidents - either with or without lost time)																			
Date (DD/MM/YYYY)	Site Location	Province/Territory	Occupation	Employment Status	Gender	Day vs Night	Activity	Location	Classification	Nature of Injury	Nature of Illness	Nature of Non-Medical	Incident Type	Sub-Incident Type	Contributory Factors	Anatomical Location	Incident Description	Description	Action Taken

A component of the of 'The Canadian Mineral Exploration Environment, Health & Safety Survey Incident Report'; the excel spreadsheet showing the codes and associated values.

Location	Value	Classification	Value	Nature of Injury	Value	Nature of Illness	Value	Nature of Non-Medical	Value
Core Logging Facility	1	Near Miss / Near Hit	5	Anaphlyaxis	26	Allergic Reaction	1	Behavioural	1
Core Sample Preparation	2	Illness	8	Bleeding	27	Cardiac	2	Fitness - Mental	2
Drill Machine	3	First Aid	2	Blister	28	Dehydration	3	Fitness - Physical	3
Drill Pump and/or Shack	4	Medical Aid	4	Bruise	29	Heat Related	4	Substance Abuse	4
Drill Site (Outside Drill Machine)	5	Non-Medical	9	Burn	30	Hypothermia	5	N/A	5
Exploration Warehouse	6	Restricted Work	10	Cut	32	Mental Health	6		
Field Camp	7	Lost Time	11	Chemical	31	Pre-existing Condition	7		
Field Camp - Dining Facility	8	Property Damage	6	Dental	33	Respiratory	8		
Field Camp - Field Office	9	Environmental	1	Electric Shock	34	Tick Fever	9		
Field Camp - Kitchen	10	Fatality	12	Fatality	23	Virus	10		
Field Work	11			Fracture	35	Other	11		
Flying - Fixed Wing	12			Frostbite	11	N/A	12		
Flying - Helicopter	13			Infection	36				
Flying - Helicopter Landing Site / Pad	14			Muscular	37				
Flyng Airport / Airstrip	15			Overexertion	38				
Laydown / Laydown Storage	16			Sprain	39				
Line or Trail Cutting	17			Strain	40				
Mine - Open Pit / Quarry	18			Tendonitis	41				
Mine - Underground	19			N/A	25				
Off Project Site	20								
Office	21								
Parking Lot	22								
Shop - Maintenance / Repair Facility	23								
Shop Yard	24								
Staging / Mob / Demob	25								
Trail - Off Road	26								
Trail	27								
Travel on Highway	28								
Travel on Site Access Road	29								

Incident type	Value	Sub-Incident type	Value	Contributory Factor	Value	Anatomical Location	Value
Airplane	28	Airplane	1	Organizational factor	1	Abdomen	1
Animal	1	Animal	2	Personnel factor	2	Ankle	17
ATV/UTV	29	ATV/UTV	3	Task factor	3	Buttock	18
Boat	30	Boat	4	Workplace factor	4	Chest	4
Camp Equipment Related	4	Camp Equipment Related	5	Unknown	5	Ear	19
Chemicals	6	Chemicals	6			Elbow	20
Drilling Machinery Related	31	Drilling Machinery Related	7			Eye	5
Environmental Conditions	39	Environmental Conditions	8			Face	6
Falling Objects	9	Falling Objects	9			Finger(s)	7
Field Work	10	Field Work	10			Foot	21
Harassment	11	Harassment	11			Forearm	22
Heavy Equipment	32	Heavy Equipment	12			Hand	23
Helicopter	33	Helicopter	13			Head	24
Improper Lifting	12	Improper Lifting	14			Hip	25
Improper Operation	34	Improper Operation	15			Knee	26
Light Vehicle	35	Light Vehicle	16			Lower Back	27
Medical Condition	14	Medical Condition	17			Lower Leg	28
Preventable with PPE	22	Preventable with PPE	18			Mouth	29
Repetitive Activity	23	Repetitive Activity	19			Neck	30
Slip/Fall	24	Slip/Fall	20			Pelvis	31
Snowmobile Use	36	Snowmobile Use	21			Shoulder	13
Tool Use	25	Tool Use	22			Thigh	32
Water Related	37	Water Related	23			Toe(s)	14
Other	38	Other	24			Upper Arm	33
		N/A	25			Upper Back	34
						Wrist	36
						Other	15
						N/A	16

Incident Description	Value
3rd party cause	1
Altitude sickness	2
Bear	3
Bee sting	4
Broken safety measure	5
Casing	6
Chain saw	7
Crash	8
Cutting core	9
Dangerous landing/takeoff	10
Distance between vehicles	11
Drill rod	12
Drill rod fall	13
Drill tube	14
Dropped tool from height	15
Dust in eye	16
Electric shock	17
Fainted	18
Falling boulder	19
Falling tree	20
Fatigue	21
Fire	22
Flat tire	23
Food allergy	24
Gasoline splash	25
Generator incident	26
Grease in eye	27
Hammered finger	28
Heavy lifting	29
Height fall	30
Hit head on drill	31
Hobble	32
Improper disposal	33
Improperly stored propane	34
Improperly stored core boxes	37
Improperly stored drill rod	38
Improperly stored fuel	40
Improperly stored object	46
Insect bite	47
Lack of 3-point contact	48
Lack of awareness	49
Lack of communications	50
Lack of equipment availability	51
Lack of experience/training	52
Lack of experience/training	52
Lack of preventative measures	53
Ladder	54
Metal in eye	55
Moose in road	56
Mud in eye	57
N/A	90
No PPE	58
Off trail	59
Office drawer	60
Oil stove	61
Overshot	62
Pipe wrench	63
Pull-start	64
Rash	65
Repetitive lifting	66
Repetitive strain	67
Reversing incident	68
Rig construction	69
Rod handler	70
Rubber allergy	71
Rushing	72
Scrambling	73
Shovel	74
Slick snow/ice/ground	75
Slinging incident	76
Smoke inhalation	77
Snow blindness	78
Snowed in	79
Soft ice	80
Spider bite	81
Splinter	82
Staircase	83
Tripped on obstacle	84
Unknown	89
V-door	85
Vehicle flip	86
Wireline	87
Wolf	88

Appendix C: NOLS Incident Data Fields and Menus

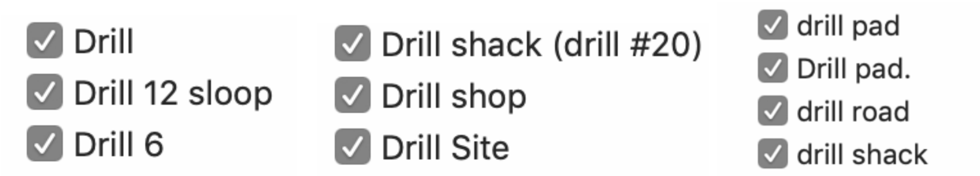
Incident Type
Fatality Illness Injury Near miss Non medical

Sub Type: Illness	Sub Type Injury	Sub Type Nonmedical	Anatomical Location (Injury)
Abdominal pain	Athletic	Alcohol	Abdomen
Allergy	Dental	Drugs	Ankle
AMS	Dislocation	Family Emergency	Butt
Anaphylaxis	Fracture	Fitness	Chest
Appendicitis	Frostbite	Misbehavior-physical	Ear
Asthma	Head w loss of conc	Misbehavior-verbal	Elbow
Cardiac	Head w/o loss of conc	Motivation	Eye
Constipation	Immersion foot	Nicotine	Face
Dehydration	Near drown/submersion	Poor Performance	Fingers
Diabetes	Other	Safety/Judgment	Foot
Flu symptoms	Snow blindness		Forearm
Headache	Soft tissue		Hand
Heat exhaustion	Soft tissue – blister		Head
Heat stroke	Soft tissue – burn		Hip
Hypothermia	Soft tissue – infection		Knee
Infection	Soft tissue – mrsa		Lower back
Infection – ear	Soft tissue – poison ivy		Lower leg
Infection – eye	Soft tissue - sunbumps		Mouth
Mental health	Soft tissue - wound		Neck
Motion (sea) sickness			Other
Nausea/vomiting/diarrhea			Pelvis
Other			Shoulder
Pulmonary edema			Thigh
Respiratory symptoms			Toe
Seizure			Upper arm
Testicular pain			Upper back
Tick fever			Wrist
UTI			NA
vaginitis			

Act	Objective Factor	Subjective Factor

Animal encounter Avalanche Bite/sting Broach/pin/wrap/strainer/swamp Capsize Cooking Crevasse fall Crew overboard Diving (snorkel/swim) Driving Eating Exertion/stress Fall from horse Fall on rock Fall on snow Fall while climbing Fall while skiing/riding Fall/slip Fall/slip off trail Flash flood Hit/miss by falling object Immersion Jump from height Knife cut Lack of self-care Lost Non-specific Not meeting expectations Other Overuse Policy infraction Poor performance Runaway Shortness of breath Spilled hot water Stepped on object Stove fire Technical system failure Technical system misuse Unexpected swim Unprotected climb Unknown NA	Altitude Animal/insect/plant Avalanche Equipment Falling object Flashflood Ice Immersion in water Lightning Loose rock/boulders Rockfall Sea state Snow Terrain (steep, wet, etc) Vegetation Visibility Water (deep, cold, moving) Weather Other Unknown NA	Carelessness Communication Distraction Exceeded ability Failed to follow instructions Fatigue Food/water intake Haste Hygiene Improper procedure Inexperience Instruction Judgment Lack of fitness Misbehavior Misperception Motivation Other Over confidence Peer pressure Physical profile Position Previous history Psychological profile Screening Supervision Technique Unexpected situation Unsafe speed Unknown NA

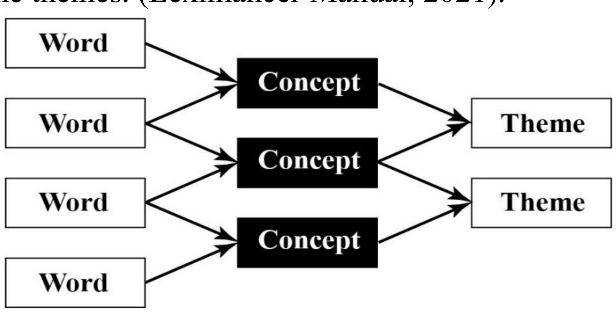
Appendix D: Example of Location Column within original Survey Report Excel Dataset



Appendix E: Interpreting Leximancer Concept Maps

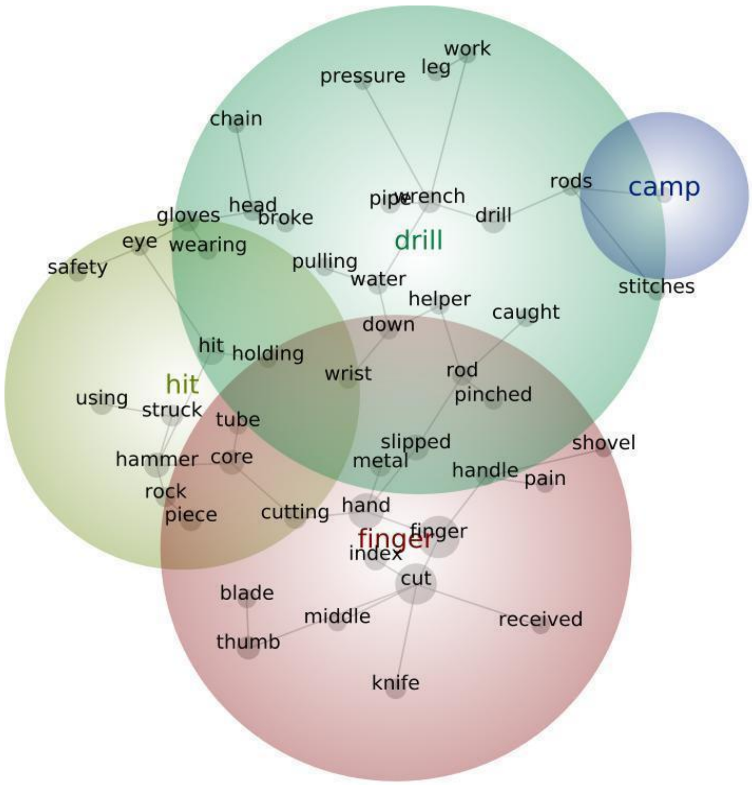
To correctly interpret the concept map output by Leximancer, there are various elements that should be considered:

1. **Theme**:
2. **Concept**: Concepts are labelled and color-coded. The labels represent the concept name which are single-word descriptors pulled from the collection of words within the data being analysed (Indulska, Hovorka & Recker, 2012).
3. **Size of a Theme Circle**: The size of the circles have no bearing as to its prevalence or importance on the text. The circle outlines act merely as boundaries (Leximancer Manual, 2021).
4. **Colour of Theme**: The colour scheme within the concept map is based on heat mapping techniques. The hot colours (red and orange) denote the most important themes, whereas cooler tones (blue and green) indicate the least important themes (Leximancer Manual, 2021).
5. **Concepts clustered**: Concepts will be clustered based on their co-occurrence and represent themes within the analyzed text with similar contexts. The concepts that appear closer together co-occur more frequently, and concepts displaced further co-occur less frequently (Indulska, Hovorka & Recker, 2012).
6. **Thickness and brightness of connection lines**: As per the co-occurrence matrix, the thickness and brightness of the line that connects the concepts is indicative of the frequency of co-occurance. A thick and bright line indicates two concepts that occur together frequently (Indulska, Hovorka & Recker, 2012).
7. **Centrality of concepts**: Concepts that are overlapping or close together indicate those two concepts appear close together in the text. Concepts that are not semantically linked will appear farther apart on the map (Leximancer Manual, 2021).
8. **Analyst Synopsis**: Presents the main themes, the associated concepts within, and the amount of times the concepts within the themes are present. The bars indicate the colour associated with the themes. (Leximancer Manual, 2021).



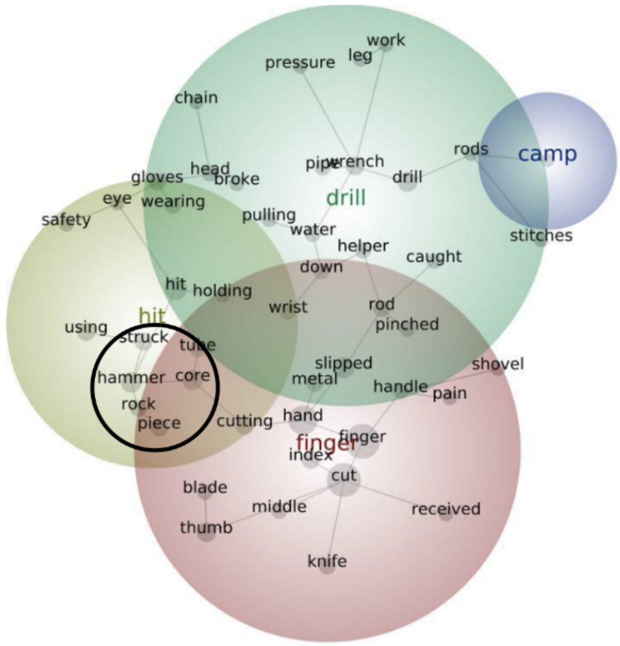
Retrieved from (Byun et al., 2023)

Appendix F: Visual Representation of Leximancer Concept Map for Interpreting
Example pulled from Figure 9. The concept map of seeded terms within the four major themes. This concept map is generated from the data consisting of the incident type, tool use.

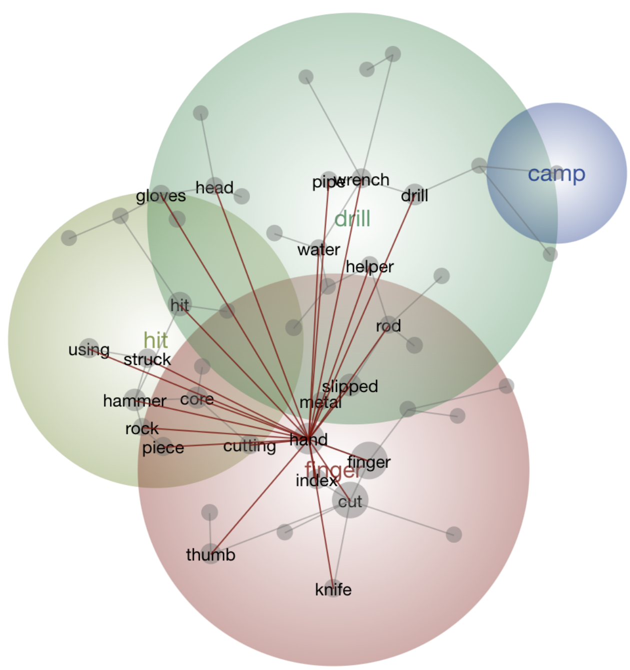


1. **Theme**: Hit, Drill, Finger, and Camp
2. **Concepts**:
    a. Finger: Down, wrist, rod, pinched, slipped, metal, handle, pain, shovel, tube, core, cutting, hand, finger, blade, middle, thumb, knife, received, cut, index
    b. Hit: Safety, eye, gloves, wearing, hit, holding, using, struck, tube, hammer, core, rock, piece, cutting
    c. Drill: Chain, pressure, leg, work, head, gloves, broke, wearing, pulling, water, hit, holding, wrist, down, helper, caught, rod, pinched, slipped, metal, handle, stitches, drill, rods
    d. Camp: Camp
3. **Size of a Theme circle:** The largest theme circle is drill, however, the size of the circle is not indicative of the most important theme. The size is simply due to the greatest amount of concepts within the theme.
4. **Colour of a Theme**: Hot colours (red) denote the most important themes, and cool colours (blue) denote less importance. Therefore, in order of most important to least important is: Finger (red), Hit (yellow), Drill (green), and Camp (Blue).
5. **Concepts clustered**: The concepts that appear closer together co-occur more frequently, and concepts displaced further co-occur less frequently. An example of concepts that

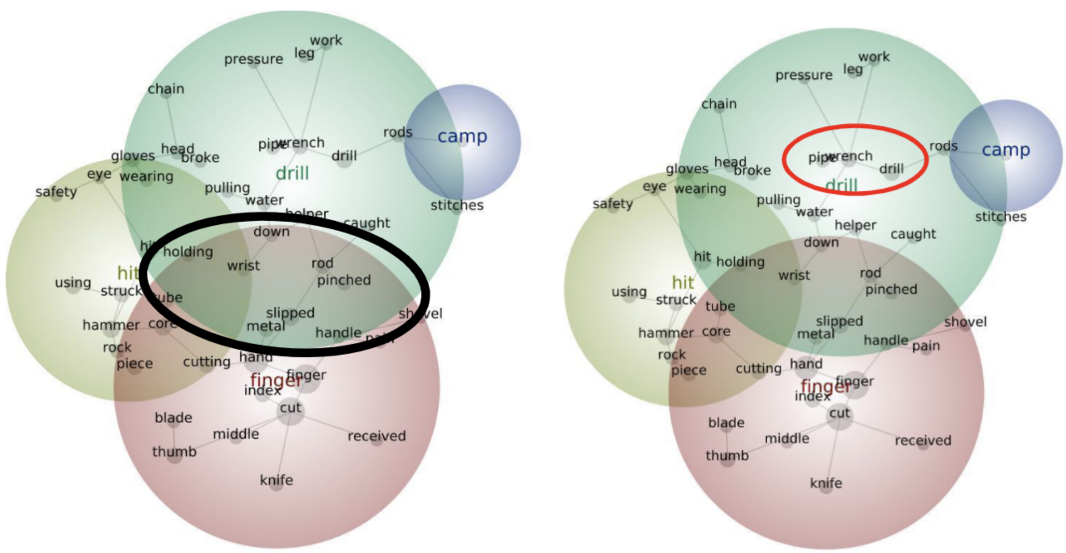
co-occur more frequently would be hammer, tube, core, rock and piece within the theme Hit.



6. **Thickness and brightness of connection lines**: The concept ‘hand’ was chosen within the theme Finger. The bright red lines show the two concepts that occur together frequently within the text. As an example, hand is connected to the concepts hammer, core, rock, piece, using and gloves within the theme Hit.



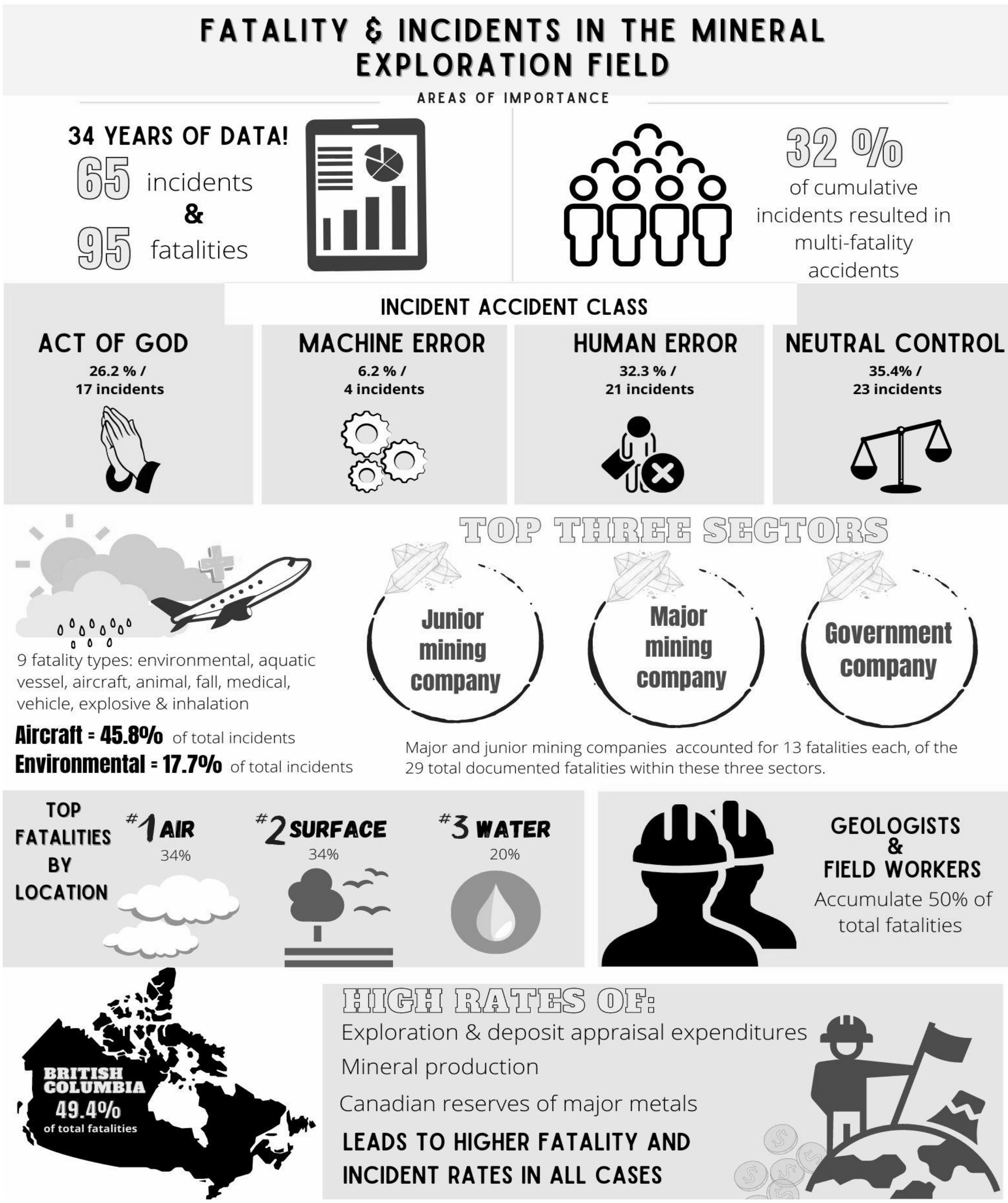
7. **Centrality of concepts**: Concepts that are close together or overlap circles in the map, mean they appear close together in the textual descriptions. Concepts that are further apart within the circles are directly related to the theme, but are not strongly linked within the text. The concepts overlapping, as highlighted by the black circle on the image below indicate the concepts that appear within two different themes. Additionally, the words enclosed by the red circle on the image below show concepts that appear close together in the text. The positioning of the words (concepts) in the circles has to do with the closeness of related concepts in the text.



8. **Analyst Synopsis:** Simple visual of the themes, the number of times the concepts within occurred, and their associated colour as per the heat mapping scheme.

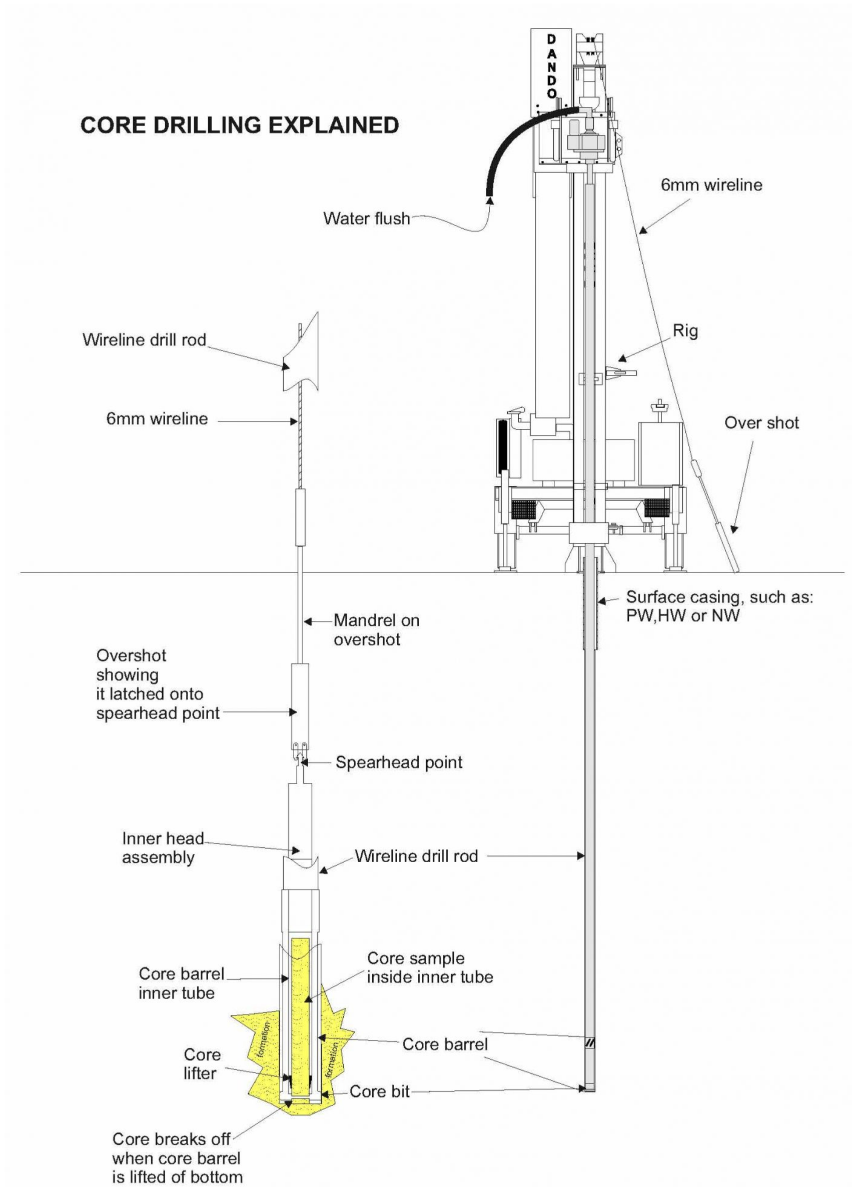
Theme	Hits
finger	347
hit	262
drill	175
camp	17

Appendix G: Fatalities Within the Mineral Exploration Field: 34 Year Review



Created by R.Bond 2022

Appendix H: Drilling Rig Diagram and Explanation



Retrieved from https://dando.co.uk/drilling-techniques-for-mineral-exploration/

Drilling Components Explained:

The reaming shell is attached to the **core barrel**, the part of the equipment that will collect the core sample. A wireline core barrel includes three components: **an inner tube assembly, and outer tube assembly** and the **overshot**. The inner tube assembly includes the **head assembly** and the inner tube, the piece that will hold the core sample during the drilling process. The inner tube does not rotate.

The core barrel is connected to the drill rig by **drill rods**. The further into the bore hole we drill, the more drill rods that are needed. Drill rods transfer the torque, feed, force, and rotation speed required to drill into the rock, from the drill rig to the drill bit. The more drill rods that are attached, the greater the chance of the **bore hole deviating**.

Casing is used to hold back overburden and prevent it from entering the borehole. This is common when you are drilling in fractured, unconsolidated ground.

A drill's pressure pump is used to pump drilling fluids into the drill string. The fluids will flush the rock cuttings and carry them to the surface and will cool the bit at the same time.

The list of components above includes what you would find in any core driller's toolbox. Each is a vital component in the drilling cycle. The 'cycle' consists of:

1. Advancing the core bit into the rock and filling the core barrel
2. Retrieving the core tube and filing the core
3. Cleaning, inspecting, and lubricating the inner barrel then adding a drill rod

And the cycle continues.

Retrieved from https://blog.fordia.com/blog/abcs-diamond-drilling-drilling-components