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HUMAN ERROR IN MINING: A MULTIVARIABLE ANALYSIS OF MINING ACCIDENTS/INCIDENTS IN QUEENSLAND, AUSTRALIA AND THE UNITED STATES OF AMERICA USING THE HUMAN FACTORS ANALYSIS AND CLASSIFICATION SYSTEM FRAMEWORK

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HUMAN ERROR IN MINING: A MULTIVARIABLE ANALYSIS OF MINING
ACCIDENTS/INCIDENTS IN QUEENSLAND, AUSTRALIA AND THE UNITED
STATES OF AMERICA USING THE HUMAN FACTORS ANALYSIS AND
CLASSIFICATION SYSTEM FRAMEWORK

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Presented to
the Graduate School of
Clemson University

In Partial Fulfillment
of the Requirements for the Degree
Doctor of Philosophy
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by
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ABSTRACT

Historically, mining has been viewed as an inherently high-risk industry. Nevertheless, the introduction of new technology and a heightened concern for safety has yielded marked reductions in accident and injury rates over the last several decades. In an effort to further reduce these rates, the human factors associated with incidents/accidents need to be addressed. A modified version of the Human Factors Classification and Analysis System (HFCAS-MI) was used to analyze lost time accidents and high-potential incidents from across Queensland, Australia and fatal accidents from the United States of America (USA) to identify human factor trends and system deficiencies within mining. An analysis of the data revealed that skill-based errors (referred to as routine disruption errors by industry) were the most common unsafe act and showed no significant differences between accident types. Findings for unsafe acts were consistent across the time period examined. The percentages of cases associated with preconditions were also not significantly different between accident types.

Higher tiers of HFACS-MI were associated with a significantly higher percentage of fatal accidents than non-fatal accidents. These results suggest that there are differences in the underlying causal factors between fatal and non-fatal accidents. By illuminating human causal factors in a systematic fashion, this study has provided mine safety professionals the information necessary to reduce mine accidents/incidents further.

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EXECUTIVE SUMMARY

Mining has historically been viewed as a high-risk industry in which injuries are simply a part of the job. However, improvements in the mining industry have resulted in a decrease in injuries and fatalities. According to the Mine Safety and Health Administration, since 2000, the fatality rate per 200,000 hours worked has decreased 44%. Although the rate of fatalities has seen a dramatic drop over the last decade years, there are still a high number of mine workers killed or injured annually.

Technological advancements have successfully decreased the number of injuries and fatalities, but these numbers continue to remain unacceptably high. In an effort to further reduce fatality and injury rates, the role of human error in accidents and incidents was studied. Two distinct data sets have been used in this analysis. The first study looks at the role of human error in 508 high-potential incidents and lost time accidents in Queensland, Australia. The second study looks at 254 fatal accidents in the United States of America. A modified version of the human factors analysis and classification system (HFACS-MI) was used to classify errors and system deficiencies.

Results from the first study revealed causal factors at all tiers of HFACS-MI except for the fifth tier of outside factors. An unsafe act was identified in 94% of the cases analyzed. At this level, skill-based errors were most often identified. At the preconditions for unsafe acts tier, the technical and physical environments were the most often identified causal categories. With the adverse and rapidly changing conditions on mine sites, the physical environment was expected to be a highly identified contributing factor.

At the higher tiers of HFACS-MI, causal factors were associated with fewer cases. When codes were identified, they tended to center around a single category. Inadequate leadership is the most often cited causal factor at the leadership level. Organizational process was the most often cited causal factor at the organizational influences level; that category deals with the development and implementation of standard operating procedures (SOPs).

Results from the second study were similar to results from the first at the lower two tiers of HFACS-MI. An unsafe act was identified in about 80% of fatal accident cases. Like non-fatal incidents/accidents, skill-based errors were the most often identified error form. For fatal accidents, preconditions for an unsafe act were actually associated with a higher percentage of cases (81.9%). Within this category, the physical and technical environments were once again the most often identified causal categories.

For fatal accidents, the upper levels of HFACS-MI were associated with significantly more cases than non-fatal accidents. This implies that problems at the organizational and leadership levels are more likely to result in fatal accidents. In order to reduce the potential for fatal accidents, interventions need to be aimed at improving leadership and organizational deficiencies.

While the lower two layers of HFACS-MI had no significant differences between fatal and non-fatal accidents, there were differences at the specific exemplars identified. This suggests that while the error forms are similar, accident severity may vary on the specific error type that occurs.

Overall, the use of HFACS-MI proved to be a systematic process for identifying causal factors for fatal and non-fatal accidents. Results suggested the following: 1) differences exist between fatal and non-fatal accidents causal factors, 2) differences exist in the unsafe acts committed between mine sites, and 3) interventions introduced before or during the time span of this analysis aimed at reducing human error did not work. The use of HFACS-MI has established a baseline for measuring the success of future human factors interventions.

CHAPTER 1: INTRODUCTION

The mining industry has historically been viewed as a high-risk environment. While the industry has seen recent success in safety, it still remains one of the most high-risk professions worldwide (Mitchell et al., 1998). In Australia and the USA, the mining industry continues to have accident rates higher than that of any other industry (Bennet and Passmore, 1984; Hull et al., 1996). From July 2006 to June 2007, there were 367 reported mining accidents in Queensland, Australia with a frequency rate of five accidents for every million hours worked (DME, 2007). In 2005, the USA mining industry had an average lost time injury rate of 2.9 per 100 full time employees. Though these statistics point towards an improving industry, these rates suggest a system in which a continued focus on safety will result in still lower accident and injury rates.

Adverse working conditions lead miners to be exposed to hazards including flooding, explosive agents, the risk of asphyxia, etc (Mitchell et al., 1998). Although these hazards are present, the majority of accidents cannot solely be attributed to adverse working conditions. A study by the US Bureau of Mines found that almost 85% of all accidents can be attributed to at least one human error (Rushworth et al., 1999). In Australia, two out of every three occupational accidents can be attributed to human error (Williamson and Feyer, 1990). With the high percentage of incidents and accidents attributed to human error, it is vital that accident investigations begin to identify contributing factors attributed to human error and organizational or system deficiencies.

Although the majority of incidents and accidents that occur on mine sites do not result in either single or multiple fatalities, the cost to the organization for each incident is

significant. Even without a resulting injury, the organization encounters repair costs, downtime and the allotment of personnel for investigation. Unscheduled downtime has a negative impact on production and efficiency. True value can be added to the company by eliminating these additional costs by reducing incident and accident rates.

In 2007 at the annual Queensland Mining Industry Safety and Health Conference in Townsville, Australia, a request was put forth by the industry members present to the Department of Mines and Energy (DME) to start investigating the role of human error in mining accidents and incidents. To fulfill this request, DME initiated a project in which a human factors graduate student would begin a study to identify the leading causes of human error within the state of Queensland.

In order to identify trends in human error and organizational deficiencies, a modified version of the human factors analysis and classification system framework for use specifically within the mining industry (HFACS-MI) was developed to analyze incidents/accidents. The analysis covers 508 high-potential and lost time incidents that occurred in Queensland, Australia from 2004 to 2008 and 254 fatal accidents that occurred in the USA from 2004 to 2008. Data from Australia was supplied by the Queensland Government's Department of Mines and Energy. Data from the USA was gathered from fatal accident reports published on the Mines Safety and Health Administration's website. Together, these analyses will provide valuable information, such as error trends specific to a mining type/time of day/year and trends in system deficiencies helping the mining industry to mitigate risk by identifying the most significant areas of human error.

The first step in reducing human error related incidents and accidents is to identify the error forms and organizational problems that are culminating in adverse events. The primary goal in this research is to identify the causal and contributing factors for mining incidents and accidents. This research also aims to identify whether demographic differences will cause significant differences in causal factors. Finally, this research aims to identify the underlying differences between fatal and non-fatal accidents.

The second chapter of this dissertation describes the previous research into mining accidents, human error, and human error taxonomies and frameworks including the one used for the basis of the analytical framework used for this research. The methods chapter presents the modification to the original HFACS framework, data collection, coding, and the basic statistical analysis used. The results of this research are given in the fourth chapter along with a detailed description and discussion of the significance. The fifth chapter presents a comparison of the two studies and discusses potential reasons for these differences. The final chapter presents concluding remarks, the significance of the research and findings, and possible continuing research.

CHAPTER 2: LITERATURE REVIEW

2.1 Mining Regulations

In an effort to control the safety of workers, government organizations have been developed to regulate the safety and health of the mining industry. The safety and health of miners in the USA is regulated by the Mine Safety and Health Administration (MSHA) sector of the US Department of Labor. MSHA was created in 1978 as a result of the Federal Mine Safety and Health Act of 1977. MSHA is charged with developing and enforcing safety and health rules, helping mines comply with these rules and offers technical, educational and other types of assistance. The predecessor of MSHA was the Mining Enforcement and Safety Administration (MESA) which was created by the Federal Coal Mine Health and Safety Act of 1968, referred to as the Coal Act.

In Australia, mines are governed and regulated at the state level. In particular, the DME, a part of the Queensland government, regulates all mines, explosives, and petroleum and gas industries across Queensland. Within DME, there is a Mining Safety and Health division that oversees safety and health regulations, conducts audits and inspection across all industry sectors, issues licenses and authorizations, and provides advice and facilitates improved standards and practice. Both agencies also undertake investigations and provide emergency services when needed.

There are, in general, four main types of regulatory standards that are used to influence worker behavior. These four types are prescriptive, general duty of care, performance-based and systematic process-based (Gunningham, 2005). A prescriptive approach gives explicit information regarding how a hazard must be controlled and

leaves little to no room for independent interpretation of the standard. With a general duty of care approach, principles or goals are set out that must be met, but a way to achieve those principles is not identified. Performance standards specify what the outcome of safety measures must be, but leave the measures to ensure this outcome up to the individual mine. Finally, process based standards identify a series of steps that must be followed (Gunningham, 2005).

In the early years of mining legislation, Queensland's government relied most heavily on prescriptive standards (Hopkins and Wilkinson, 2005). This left little room for mines to develop their own safety measures and did not account for the vastly different needs of many mines. In an effort to overhaul outdated mining legislation and move from prescriptive standards to general duty of care standards, the Queensland's government—with the help of DME—developed new standards in the late 1990s. These standards included the *Coal Mining Safety and Health Act of 1999* (CMSHA) and *Mining and Quarrying Safety and Health Act of 1999* (MQSHA).

The USA mining industry also went through restructuring during the latter half of the 1900s. The first step at improving mining safety and health was through the *Coal Act of 1969*. This act was later amended by the *Federal Mine Safety and Health Amendments Act*, or *Mine Act of 1977*. These amendments renamed "MESA" to "MSHA" and expanded their enforcement power to include all mines (Nieto and Duerksen, 2008). The most recent mining legislation for the USA was the *Mine Improvement and New Emergency Response Act of 2006* (MINER). This act expanded the power of MSHA and created stricter legislation. The largest component of the MINER Act dealt with mine

rescue operations. Besides the acts stated above, mines in the USA are regulated by 30 codes of federal regulation (CFR).

In both Queensland and the USA, incidents and accidents must be reported to the respective regulator. In the USA, mine operators are required to contact MSHA within 15 minutes of an accident occurring (30 CFR 50.10). In Queensland, mine operators have to report accidents and high-potential incidents within 24 hours. The USA requires a follow-up form to be completed within 10 days of the accident for all reported accidents. DME inspectors are in charge of deciding whether an incident or accident needs to have a follow-up form completed.

2.2 Mining Techniques

Many mining methods exist for extracting minerals or other materials from underground ore bodies, veins, or seams. On the surface, open-pit mining, quarrying, strip mining, and placer mining are common. For subsurface mining, sites are distinguished by the extraction technique and access shafts. Extraction techniques include room and pillar, long wall, bore hole, drift and fill, and retreat mining. Underground mines are generally accessed through a horizontal access tunnel or vertical shafts (Hustrulid, 1982). The mining technique used depends largely on the geology of the area.

2.3 Mining Accidents

As a high-risk industry, the history of mining has been filled with large scale mining accidents. On March 6, 1906, the largest mining disaster in European history occurred when 1,099 miners were killed in a dust explosion at the Courrières mine in northern France ("French Mine Disaster", 1906). In 1921, 75 men were killed in northern

Queensland after an explosion at the Mount Mulligan mine (Barwick, 1999). Germany experienced a disaster when 299 men were killed at the Luisenthal mine in 1962 ("Six are found", 1988). More recent disasters include the Moura Mine explosion in 1994 that killed 11 men in Queensland (Hopkins, 2001), Nanshan Colliery explosion in northern China killing 24 men in 2006 ("25 dead in coal mine", 2006), and the 2006 Sago mine explosion in West Virginia killing 12 miners (Dao, 2006). Accidents of this magnitude attract enormous attention from the media but occur rarely, while on a daily basis, miners are continuously in situations that could lead to injuries or even death.

The definition of a mining accident differs slightly under USA and Australian legislation. In Australia, a mining accident is an "event, or series of events, at a mine causing injury to a person." A serious accident is an "accident at a mine that causes the death of a person, or a person to be admitted to a hospital as an in-patient for treatment of injury."¹ Under USA legislation, a mining accident includes "a death of an individual at a mine; an injury to an individual at a mine which has a reasonable potential to cause death; an entrapment of an individual for more than 30 minutes or which has a reasonable potential to cause death" (30 CFR 50.2)². Though similar, USA regulations identify a broader definition for accidents. However, the USA does not define a high-potential incident. A high-potential incident is an "event, or series of events, that causes or has the potential to cause a significant adverse effect on the safety and health of a person." A lost time injury is any incident or accident that results in an injury where the person misses work for more than the day the injury occurred.

¹ These definitions are supplied from the Queensland Government's *CMSHA* and *MQSHA*.

² Refer to the regulation for the complete list of accident definitions.

2.4 Injury Rate

According to statistics from MSHA, there have been recent improvements in the safety and health of miners. Since the early 1990s, the number of injuries per 100,000 miners working has steadily declined. This is true for both coal mining and metal/non-metal mining. Today, there are around 4,700 injuries per 100,000 workers in coal mines and 2,800 injuries per 100,000 workers in metal/non-metal mines yearly. This represents a 56% decrease in coal mining injuries since its peak in 1988 and a 66% decrease in metal/non-metal mining injuries since its peak in 1978.

Ural and Demirkol (2008) compared the occupational safety and health of surface mines across the world. They found that the non-fatal accident rate per 100,000 workers in Australia, Germany, Great Britain, New Zealand, and the USA is significantly lower than that of Turkey and South Africa. The analysis did not, however, determine if there were significant differences between the accident rates of Australia, Germany, Great Britain, New Zealand and the USA.

Similar trends exist with mining fatalities as well. There has been a decline in the number of fatalities per 100,000 workers since 1931. Since the peak in the early 1940s, the coal and metal/non-metal mining industries have seen a greater than 90% reduction in fatalities per 100,000 miners. The rate of fatalities for miners working in the coal industry is greater than that for other mining industries. One possible reason for this higher rate is the unstable nature of coal mines and the greater probability of gas ignitions and explosions. Underground coal mining represents the most dangerous mining environment (Karra, 2005).

When fatal accidents are looked at world-wide, the EU15 (Austria, Belgium, Denmark, Finland, France, Germany, Ireland, Italy, Luxembourg, Netherlands, Portugal, Spain, Sweden, and the United Kingdom), Australia, Germany, Great Britain, New Zealand and the USA have fatal accident rates that are significantly lower than the rates of Turkey and South Africa (Ural and Demirkol, 2008). Interestingly, the incidence rate per 100,000 workers for the EU15 is considerably higher than the rate for Great Britain and Germany. Because accident data for Germany and Great Britain are also included in the statistics for the EU15, this means that there are countries in the EU15 that have accident rates considerably higher than average.

Because of the adverse conditions in which miners work, they are exposed to a variety of potentially hazardous situations. High demands on operators, constantly changing road designs, the physical strength required to handle the mass of the trucks, long tedious drives, rough roads and loading impacts all contribute to the overall health and safety problems in the mining industry (Randolph and Boldt, 1996). Improvements in equipment and road designs over the years have helped to reduce injuries, but even with these improvements, the frequency rates for fatalities and injuries still remain at unacceptable levels. Coal mining operations continue to be the most dangerous for workers as injury frequency and severity rates are higher than the average for all industries (Bennet and Passmore, 1984). The probability of sustaining an injury resulting in 10 or more lost workdays was 0.52 for coal mine workers compared to 0.35 for metal/non-metal mine workers (Coleman and Kerkerling, 2007). While mining method was not related to the degree of injury, those miners that worked at a shaft or slope were

associated with lower injury severity than those miners working at the face (Bennet and Passmore, 1985b).

Much research has been conducted on the effect of job experience on injury severity. In general, injury severity is unrelated to total mining experience, job experience, and experience in the mine where the injury occurred (ex. Bennet and Passmore, 1985a, b; Lee et al., 1993; Maiti and Bhattacharjee, 1999; Maiti et al., 1999). When comparing worker age and experience level, it was found that injuries in coal mines are affected more by experience at the company than by age (Butani, 1988).

In a review of literature by Salminen (2004), 56% of studies showed that younger workers had a higher injury rate than older workers, 17% showed the opposite results, and 27% showed no difference between older and younger workers. When trying to link age and experience with accident rate, there are numerous other factors that must be taken into account, including job characteristics and the fact that physical and mental capabilities reduce with age.

Breslin and Smith (2005) found that some studies show similar or lower accident rates for younger workers simply because of the denominator used during comparison. The studies they looked at used number of injuries per number of workers in the age group instead of using injuries per hour worked. With younger workers, part-time and seasonal employment is more likely, so the risk of injury for younger workers was underestimated.

Interaction with electricity is a problem on mine sites. Cawley (2003) reports that from 1990-1999, electricity was the fourth leading cause of death and the fourteenth

leading cause of injuries on mine sites. Cawley also found that electrical shock accounted for 70 out of 75 fatal accidents, and burns were the leading cause of injuries. Over one fourth of electrical fatalities are attributed to accidental contact with live overhead wires (Homce et al., 2001). High-reaching mobile equipment often comes in contact with overhead power supplies and the metal frames become energized, sometimes without the operator noticing. From 1980-1997, in 57% of cases involving overhead power lines, operators were unaware of the contact until one or more workers touched the energized frames and were injured.

From 1995-2004 in the USA, 49% of incidents involved the use of mining equipment while 77% of fatalities resulted from the use of equipment (Groves et al., 2007). Haulage trucks were the most often cited machinery involved in these fatal accidents. Other mobile equipment frequently involved in mining injuries and death are front-end loaders, conveyors, dozers, and continuous miners. Continuous miners are associated with the highest injury severity (Groves et al., 2007) for all mobile equipment. The use of non-powered hand tools were a factor in 24% of incidents. These incidents often arise because industrial tools are larger and heavier than the household versions workers are used to and because of less than ideal working conditions on mine sites.

Keckojevic, Komljenovic et al. (2007) found that the most common types of accidents involving mobile equipment are collisions with pedestrians. Each year, an average of five pedestrians are killed at surface and underground metal/non-metal mines as a result of collisions with mobile equipment (Ruff and Hession-Kunz, 2001). Fatalities involving mobile equipment frequently are caused by a lack of visibility from the cab of

the truck (Ruff, 2001). Blind spots on the cab are caused by cab posts, vehicle lights and light brackets (Eger et al., 2004). Line of sight impairments are caused by objects such as buckets, booms, radio remote boxes, and fire extinguishers. Kecojevic Komljenovic et al. (2007) also found that the most common root causes of equipment related fatalities are failure of mechanical components, lack of and/or failure to obey warning signals and inadequate or substandard mechanical procedures. Contributing factors include inadequate training, poor haulage road and dump area designs and the failure to wear seatbelts.

At mines with higher accident rates, workers were more likely to report they were overworked and were troubled by the behavior of their co-workers (Gordon, 1988). These mines were also characterized by poor scheduling and planning and more misunderstandings over directions and assignments. Low accident rate mines have clearer instructions when compared to high accident mines and are characterized by the abundance of training and keeping good safety records.

2.5 Human Error

Human error is the “failure of planned actions to achieve the desired events without the intervention of unforeseeable events” (Reason, 1990). Only when judged on the basis of the outcome does the performer know that an error was committed (Rasmussen, 1982). Forms of human error are neither as varied nor abundant as would seem. Errors take on a similar pattern across different forms of mental activities (Reason, 1990). This pattern allows for the investigation of error at a global level.

Rasmussen (1982) categorized human error according to the level of cognition involved. Behavior is divided into three categories: skill-based, rule-based, and knowledge-based. Skill-based behaviors take place at an unconscious level and are often automated in nature. Rule-based behaviors deal with the application of learned rules such as policies and procedures through decision making. Errors occur when an individual uses the wrong rule or misapplies a good rule. The final category of human behavior is knowledge-based. This refers to novel instances where an individual must apply previous knowledge. These tasks require high mental demand which can cause problems in unusual emergency situations. Errors occur from a lack of training or information. The foundation that Rasmussen (1982) laid with his skills, rules, and knowledge behavior system lead to further classification of both errors and violations.

Reason (1990; 1995) uses the term “unsafe acts” to describe errors and violations committed by an individual or individuals that lead to an adverse event. Errors can be classified into two forms. First, the planned course of action is adequate, but the plan is not carried out as intended. These errors are commonly referred to as slips or lapses, and are errors of execution. Slips and lapses occurring during highly automated tasks and situations. Slips and lapses are associated with recognition, attention, memory, or selection failures. Second is when a plan is executed as intended, but the plan is inadequate for the situation. These error types are mistakes and generally arise from failures of intention.

Mistakes are furthered categorized as rule-based or knowledge-based. Rule-based mistakes occur when a situation is similar in nature to previous events and the individual

uses information from those events to solve the situation at hand. The individual relies on previous knowledge and training. The mistake arises when the individual misapplies a good rule, fails to apply a good rule, or applies a bad rule. Knowledge-based mistakes occur during new situations in which an individual must form a solution without adequate knowledge of the problem. Without previous knowledge or information, the mind must develop a solution with inaccurate or inadequate knowledge of the problem. Knowledge-based mistakes are often subject to personal biases (Reason, 1995).

Violations are the willful disregard of established rules and regulations and can either be routine or exceptional. Violations can increase the probability of error and the likelihood that the error results in a negative outcome (Reason et al., 1998). Routine violations are the habitual “bending” of rules that are condoned by management. Exceptional violations are isolated departures from the rules and regulations that are neither condoned by management nor indicative to the individual’s behavior. These violations are highly uncommon and difficult to predict.

Errors can be viewed as a breakdown within an individual’s mental activity. These breakdowns can occur in attention, memory, retention, decision making, etc. When classifying error, it is also vital to discuss the intention of the individual. Intentional and unintentional behavior is an important distinction in classifying human error (Reason, 1990).

Sater and Alexander (2000) categorized human error as either errors of omission, commission, or substitution. Errors of omission occur when an individual fails to perform a required task. Errors of commission occur when the individual carries out an action in

either the incorrect manner or at the incorrect time. Substitution errors arise when an individual carries out the incorrect actions.

Human error has been described and categorized in numerous ways. Unfortunately, along with many ways to categorize human error comes a lack of common definitions and criteria of coding errors (O'Hare, 2000). This lack of consistency leads to an inability to share and compare data across industries and countries. According to O'Hare (2000), this “may be one of the reasons why the proportion of accidents considered due to human error has remained stubbornly high for several decades.”

2.6 Human Error Taxonomies

Human error models, taxonomies, and classification systems have been developed in attempts to understand the causes of human error. The perspectives of these models include: the cognitive perspective (Rasmussen, 1982; Wickens and Flach, 1988), the ergonomic perspective (Edwards, 1988), the behavioral perspective (Peterson, 1971), the epidemiological perspective (Suchman, 1961), and the psychosocial perspective (Helmreich and Foushee, 1993). Newer models tend to look at accidents as a result of a combination of causes that interact with each other. These models have moved from focusing on a single element of accident causation, to looking at the system as a whole. These models represent a systems or organizational approach to accident investigation.

2.6.1 SHEL Model

The SHEL model was originally developed by Edwards (1972; in Wiegmann and Shappell, 2003) to encompass human factors into system design. The model describes human-machine interactions and identifies where areas of failure can occur. The SHEL

model divides failures into four categories: software, hardware, environment conditions, and liveware (Figure 1). Software refers to the documents, policies, regulations, and standards upon which the system operates. Hardware is composed of the physical resources, such as machines, that are used within the system. Environmental condition refers to the physical environment in which the system operates. The final aspect of the SHEL model is liveware, or the people who are involved with the system. Failures occur in the system when any one of the components or the connections between components fails. This model puts primary focus on the man-machine interface when looking from a systems approach.

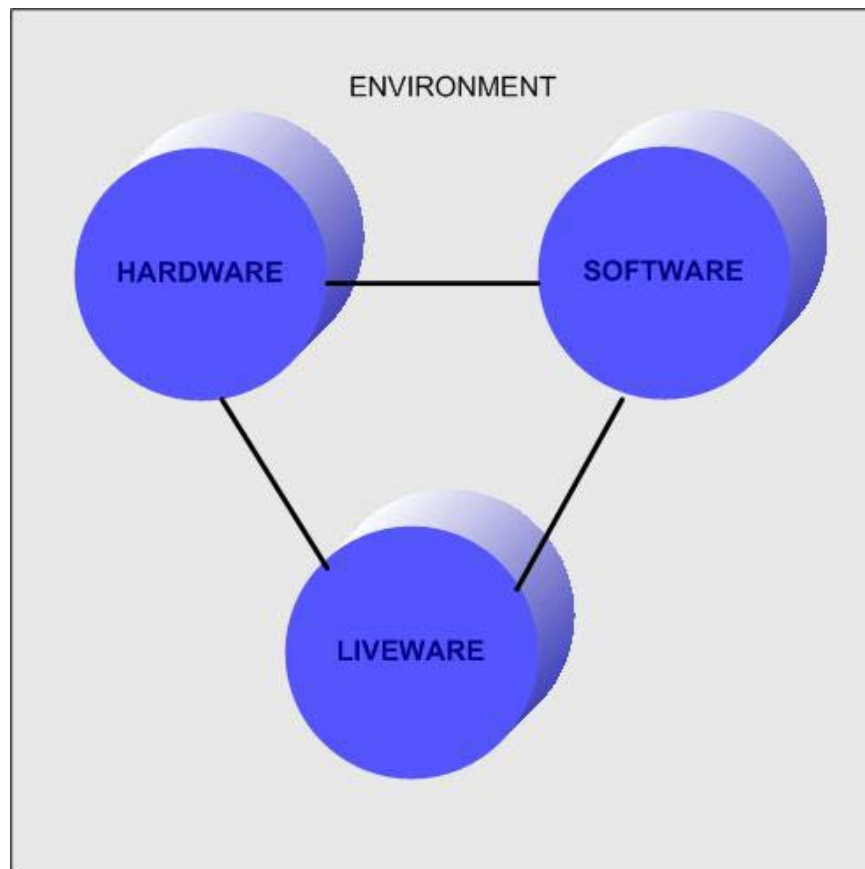


Figure 1: SHEL model adapted from Edwards (1972)

2.6.2 Incident Cause Analysis Method (ICAM)

The incident cause analysis method (ICAM) was developed by BHP Billiton and officially launched in April 2000 (Gibbs et al., 2001). The ICAM process (Figure 2) was developed with the help of James Reason, The Australian Transport Safety Bureau, and Dédale Asia Pacific. The ICAM philosophy most closely follows the work of James Reason. ICAM is based on three main beliefs: 1) the root causes of all accidents can be linked to organizational deficiencies, 2) human error is inevitable and must be accepted, and 3) if an organization is serious about accident reduction then new approaches must be used, and one must learn from past mistakes. ICAM is an investigation tool that aims to first identify the organizational deficiencies and failed defenses, then develop recommendations to address these deficiencies in the system defenses and organizational process. Together with the SCM and these beliefs, the ICAM process has been used to investigate accidents across many industries.

The objectives of an ICAM investigation are: establishing the facts, identifying contributing factors and latent conditions, reviewing the adequacies of existing controls and procedures, reporting the findings, recommending corrective actions, detecting organizational factors that can identify recurring problems, and establishing key learned facts that can be distributed across the company (De Landre and Bartlem, 2005). Strongly structured into the ICAM system is the belief that the purpose of accident investigations is not to apportion blame or liability. With the use of the ICAM process during accident investigations, deficiencies within an organization can be identified and recommendations derived to correct those deficiencies. Recommendations for corrective

measures are based on the findings of failures in the organizational level and on the absent or failed defenses.

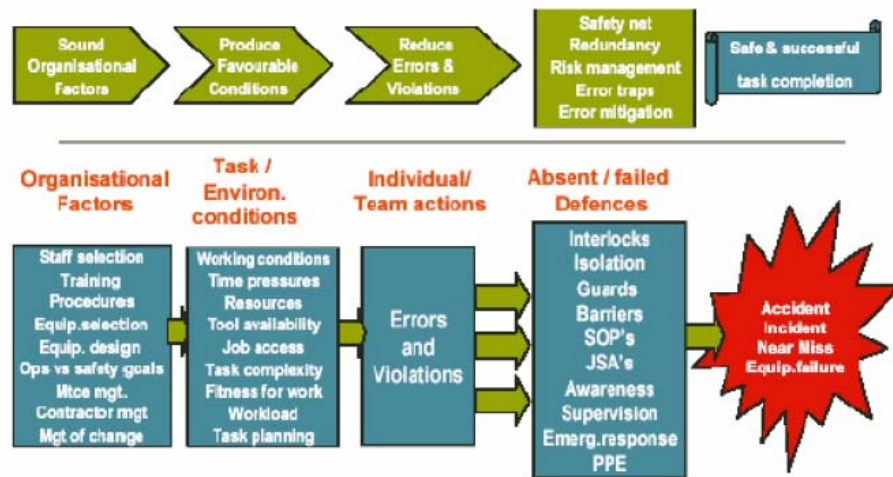


Figure 2: The ICAM model of incident causation (De Landre and Bartlem 2005)

2.6.3 Behavioral Safety (BeSafe) Method

The Behavioral Safety (BeSafe) method is an example of an accident investigation technique that attempts to identify the latent causes of accidents. The BeSafe method, previously known as the “potential human error audits,” was developed by ergonomists at British Coal (Simpson, 1994). The framework for BeSafe (Figure 3) is modeled after Reason’s Swiss-Cheese model and tries to systematically address latent failures of the system (Benedyk and Minister, 1998). The goal of BeSafe is to identify areas where human error is possible before any errors occur. This is done through the use of ergonomics tools such as checklists, task analysis, and questionnaires. Accident statistics from an organization are only used as a check in this system as the approach is based on finding errors before they occur (Benedyk and Minister, 1998).

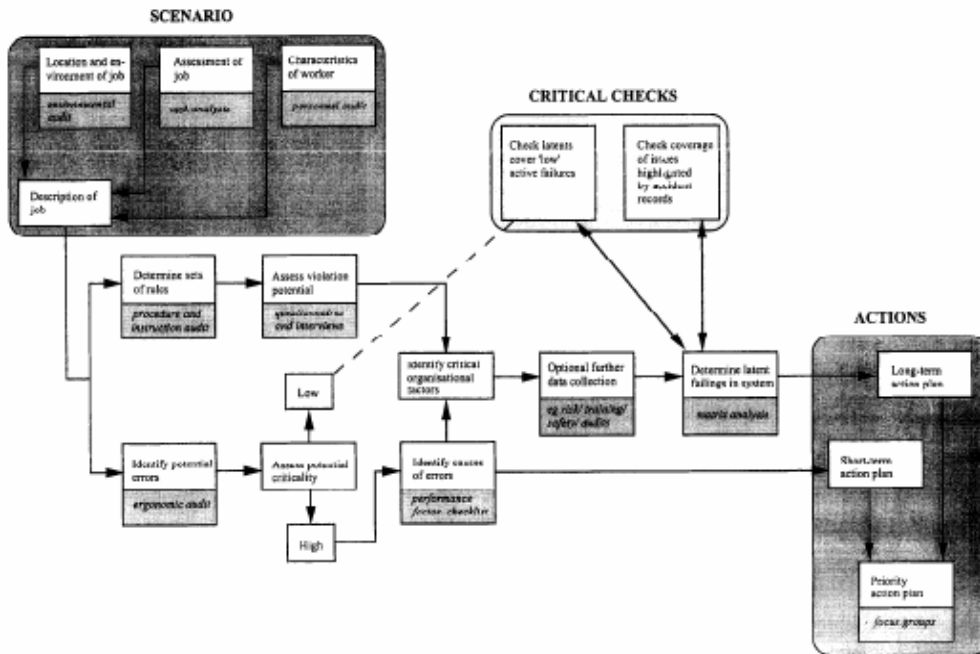


Figure 3: BeSafe Method (Benedyk and Minister 1998)

2.6.4 Wheel of Misfortune

In an attempt to analyze the role of human factors in accidents involving aviation or other complex systems, O'Hare (2000) developed a taxonomy called the "Wheel of Misfortune" (Figure 4). O'Hare's taxonomy draws on the works of Helmreich (1990; in O'Hare, 2000) and Reason (1990). The basic structure of the Wheel of Misfortune is three concentric spheres representing the actions of the front line operators, local conditions, and organizational conditions. The innermost sphere, "local actions," attempts to describe what happened. The second and third spheres aim to uncover why it happened.



Figure 4: The Wheel of Misfortune (O'Hare 2000)

2.6.5 Swiss-Cheese Model (SCM)

The SCM was developed by Professor James Reason (1990; 1997). In Reason's model, accidents result from a breakdown within the system. Breakdowns within the system are a combination of active failures and latent conditions. Active failures are the unsafe acts of those directly in contact with the system and are most often associated with incidents/accidents. These failures can be classified as errors or violations and intended or unintended actions. Unintended errors are classified as slips and lapses. These types of errors are generally associated with automatic actions and include result from memory or attention lapses. Intended errors are classified as mistakes. Mistakes occur when an the individual fails to carry out the action as intended or carries the action out as intended, but the action was the incorrect response for the situation. Violations are intended actions

that are carried out with willful disregard to the established rules and regulations. Latent conditions of a system often go unnoticed until an adverse event occurs. These latent conditions take two forms, those that create error provoking conditions and those that create weaknesses in system defenses (Reason, 2000). Reason’s SCM of human error defines the relationship between active failures and latent conditions.

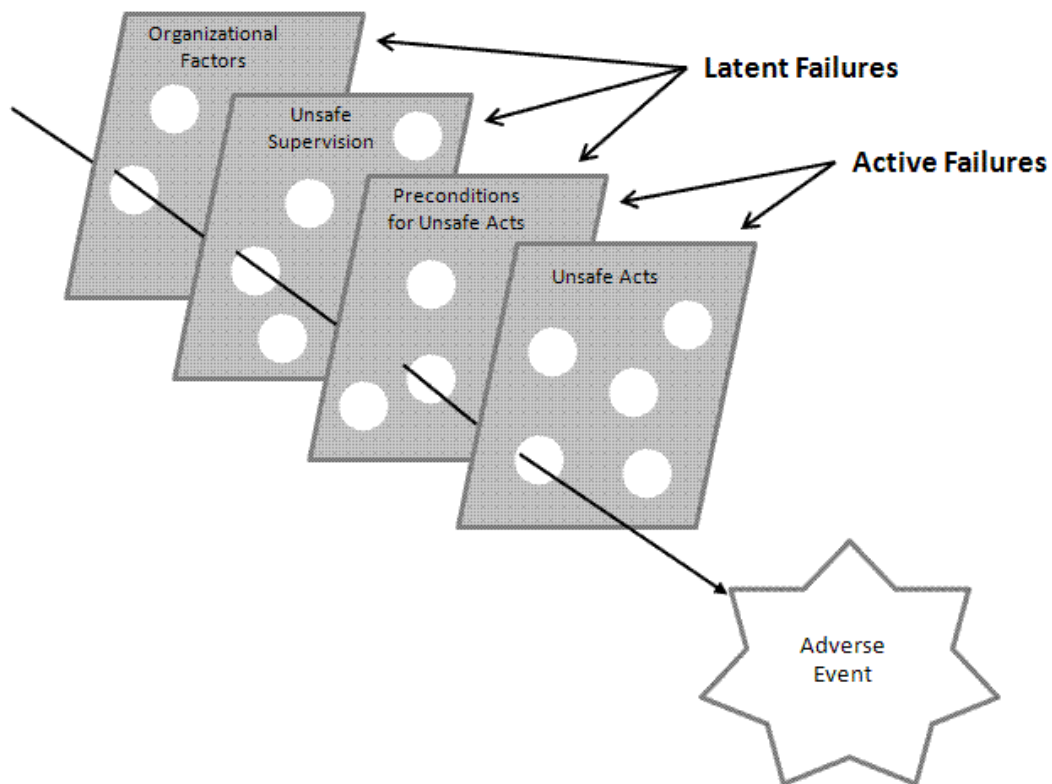


Figure 5: Reason’s SCM for Human Error Causation (adapted from Reason 1990)

Reason’s SCM is based on the assumption that there are fundamental components within an organization that must work together properly in order to achieve a safe and efficient system (Reason, 1990). In the model’s earliest version, Reason depicted a normal system as five “planes” lying behind each other. The five planes of the system are: top level decision makers, line management, preconditions, productive activities, and

defenses. The “Swiss cheese” part of the model is when “holes” develop within different planes of the system. These holes are latent and active failures. The defenses of the system are dynamic and change with regards to system characteristics. Adverse events are a result of breakdowns in the interactions between components—or the lining up of latent and active failures to breach the defenses of the system.

The second revision, Mark II, of the SCM reduced the number of planes to three, Organization, Task/Environment, and Individual, and extended the defenses’ plane into three layers. Also added to this version of the model was a latent failure path that led from the organization to the defenses to accommodate accidents in which no active failures were present (Reason et al., 2006).

In 1997, Reason developed a third version of the SCM, Mark III. In this version, the labels associated with the planes were removed. The planes represent the barriers, controls, defenses, and safeguards of the system. An explanation of how the holes arise in the system was added. Arrows to distinguish the directions in which an accident occurs and in which an accident is investigated were added. In all of the versions, accidents and incidents are a result of latent and active failures within the organization, environment, and individuals that breach the defenses of the system to cause a loss.

2.6.6 Human Factors Analysis and Classification System (HFACS)

The Human Factors Analysis and Classification System was developed by Dr. Scott Shappell and Dr. Douglas Wiegmann for use with the US Navy. During development, effort was made to ensure that the framework was useful not only as a data analysis tool, but also a structure for accident investigation. The HFACS framework was

developed to define the latent and active failures that were identified in Reason's SCM (Shappell and Wiegmann, 2001; Wiegmann and Shappell, 2003). HFACS is a four-level framework that addresses unsafe acts, preconditions for unsafe acts, unsafe supervision, and organizational influences. "Unsafe acts" refers to the actions that occur immediately before an incident/accident and directly result in an adverse event. "Unsafe acts" is further divided into three error categories (skill-based, decision, and perceptual) and two violation categories (routine and exceptional). The "preconditions for unsafe acts" level describes the environmental and psychological conditions that lead to an unsafe act. These conditions include the physical and technological environments, communication, fitness for duty, physical and mental limitations, adverse mental states, and adverse physiological states.

Unsafe supervision deals with the actions and decisions of the frontline management. Subcategories in this level include inadequate supervision, planned inappropriate operations, failure to correct known problems, and supervisory violation. Each of these tiers is divided into subcategories with a total of 19 causal categories in the original framework. Although developed for use within military aviation, HFACS has been shown to be effective in civil aviation (Wiegmann and Shappell, 2001b, a; Wiegmann et al., 2005; Shappell et al., 2007), aviation maintenance (HFACS-ME: Krulak, 2004), air traffic control (HFACS-ATC: Broach and Dollar, 2002), railroads (HFACS-RR: Reinach and Viale, 2006), medicine (EIBardissi et al., 2007), and remotely piloted aircrafts (Tvaryanas et al., 2006).

Though used in industry, the HFACS framework is also an academic tool. As such, HFACS has undergone a rigorous process to ensure validity of the framework. The criterion used to validate the HFACS framework were reliability, comprehensiveness, diagnosticity, and usability (Wiegmann and Shappell, 2003). Reliability refers to the framework's ability to gather the same results regardless of who carries out the investigation and analysis. For use with USA military aviation, the HFACS framework had an excellent reliability with a *Kappa* value of 0.94 (Wiegmann and Shappell, 2003). According to Fleiss (1981), a *Kappa* value of 0.60 to 0.74 is good and values over 0.75 are considered excellent. The minimum value for any classification system should be 0.60 or better. When used outside of military aviation in commercial aviation, the HFACS framework was found to have a *Kappa* value of 0.75 (Wiegmann and Shappell, 2001b) showing that the HFACS framework was applicable outside of military aviation with slight modifications to terminology.

Comprehensiveness refers to the framework's ability to identify all key information surrounding an accident/incident. When using the HFACS framework to investigate aviation accidents, the developers found that they were able to capture all the current human error causal factors used in USA civil and military aviation databases, thus assessing the comprehensiveness of the system to be good.

Diagnosticity refers to the framework's ability to identify the relationships between errors along with trends and causes (Wiegmann and Shappell, 2003). The diagnosticity of the HFACS framework has recently been statistically proven by Li and Harris (2008) with use in aviation.

Finally, usability refers to the framework's ability to be transferred from theoretical and academic uses to practical use within industry. The usability of HFACS has been proven by the successful application of HFACS into accident investigation within industries and organizations, such as the Federal Aviation Administration.

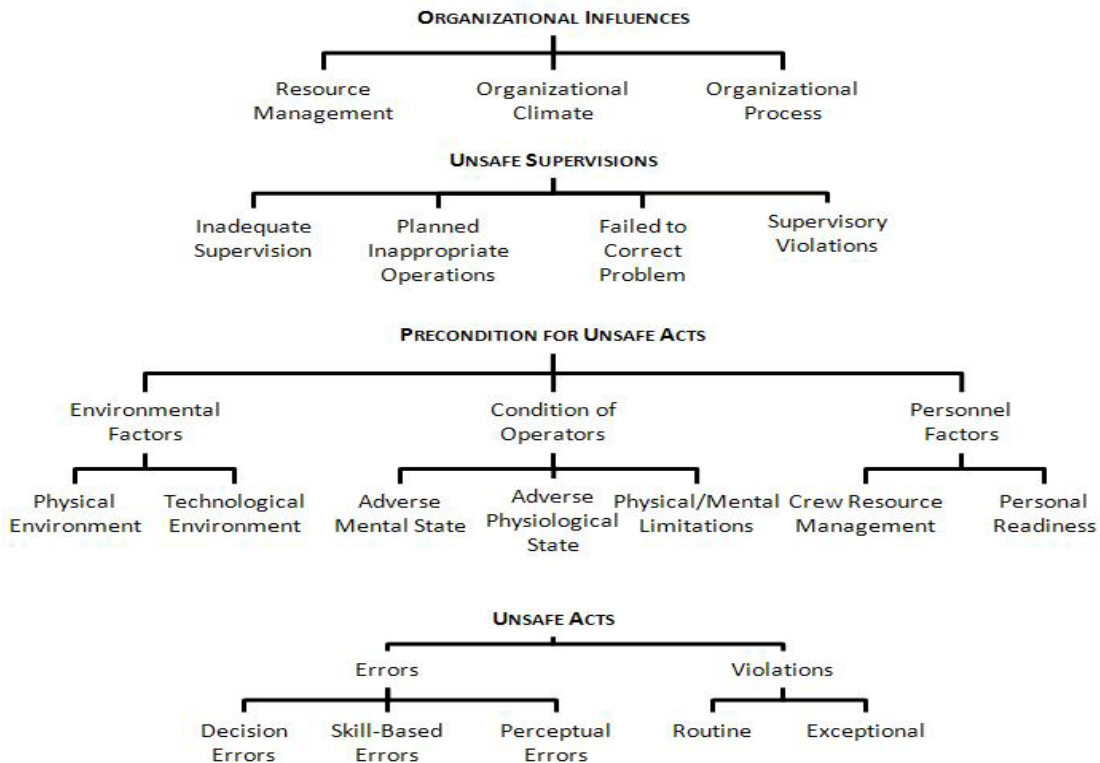


Figure 6: HFACS framework (adapted from Wiegmann and Shappell 2003)

2.7 Criticism to Error Classification Systems

Although widely used as an investigation and analysis tool, criticisms of HFACS have emerged. Dekker (2001) has suggested that HFACS is not identifying why an individual erred, but merely shifting blame for the error farther up the organizational chain. This argument stems from there being little evidence that causal factors in the higher levels of HFACS did contribute to operator error. However, recent studies (Li and

Harris, 2006; Tvaryanas et al., 2006) have found statistical relationships between various levels of the HFACS framework. This shows that HFACS is not merely shifting the blame, but uncovering latent conditions that have proven effects on operator performance.

Early criticism of HFACS questioned the validity of the framework since the validity was established by the developers (Beaubien and Baker, 2002). Since this time, the HFACS framework has been validated by other authors (ex. Gaur, 2005; Li et al., 2007). Reason's SCM, upon which HFACS was developed, has recently been validated as well (Li and Harris, 2006; Tvaryanas et al., 2006; Li et al., 2008).

2.8 Findings from HFACS Analysis

As previously stated, HFACS has been adapted and used in a variety of industrial settings including aviation, medicine, and railroads. In military, commercial, and general aviation industries, skill-based errors have routinely been found to be the leading type of unsafe acts (ex. Wiegmann and Shappell, 1997, 2001c; Shappell and Wiegmann, 2003; Detwiler et al., 2006; Shappell et al., 2007; Li et al., 2008). In recent research into railroad yard accidents, skill-based errors were also the most identified unsafe act committed (Reinach and Viale, 2006; Baysari et al., 2008). Skill-based errors have also been found to be the most common error form for air traffic controllers (Pape et al., 2001). When workers in a cardiovascular surgery operating room were interviewed, they identified skill-based errors as the most common type of unsafe acts (ElBardissi et al., 2007).

Guar (2005) in a study on civil aviation in India found that over half (52.1%) of the accidents examined had at least one contributing factor at the organizational level. The most often cited organizational factor was “organizational processes.” Li and Harris et al. (2008) also found a substantial number of causal factors at the organizational and supervisory levels. In their study on the Republic of China Air Force, “resource management” was identified as a causal factor in 35.2% of cases and “organizational process” in 14.5% of cases. At the supervisory level, “inadequate supervision” was identified in 33.8% of cases. Baysari et al. (2008) found that 44% of all error codes identified in rail yard accidents were at the organizational level. These numbers show differences from other HFACS studies in which causal factors at the top two levels were relatively rare (ex. Wiegmann and Shappell, 2001a; Shappell et al., 2007).

CHAPTER 3: METHODS

3.1 HFACS Framework

3.1.1 Construction of HFACS-MI

The framework developed for this study was based off of the version of HFACS described by Wiegmann and Shappell (2003). This framework was modified by the author with the input of end users to better correlate to the mining industry. The modified framework is called human factors analysis and classification system-mining industry (HFACS-MI). During training and testing with future HFACS-MI lead users, the term “skill-based” error continually caused confusion during coding. To reduce confusion and improve performance, the group of future users along with the author renamed the category “skill-based errors.” For the preconditions for unsafe acts level, “personal readiness” was changed to “fitness for duty” and “crew resource management” was changed to “communication and coordination” to keep with terminology familiar throughout the mining industry.

For the unsafe supervision level, all references to “supervision” were changed to “leadership.” This change was made due to the vast hierarchy of management at each mine site. It was believed that using the word “supervision” would lead users to only think about those latent conditions which could be attributed to the operator’s immediate supervisor. On large mine sites, there are a number of people who are not direct supervisors for operators that make decisions at the supervisor level, such as the Site Senior Executive (SSE). These higher-up decisions are not always at the organizational level as a single company can control multiple mines across the state and world. The

organizational level was left unchanged, but emphasis was made to raters that the organizational structure could be global and to remember that decisions at this level are not always made at the mine site. A fifth level was added to incorporate influences outside of the organization and is based off of the work of Reinach and Viale (2008) with the railroads. This level includes regulatory, social, political, environmental, and economic influences. The final HFACS-MI framework can be seen in Figure 7.

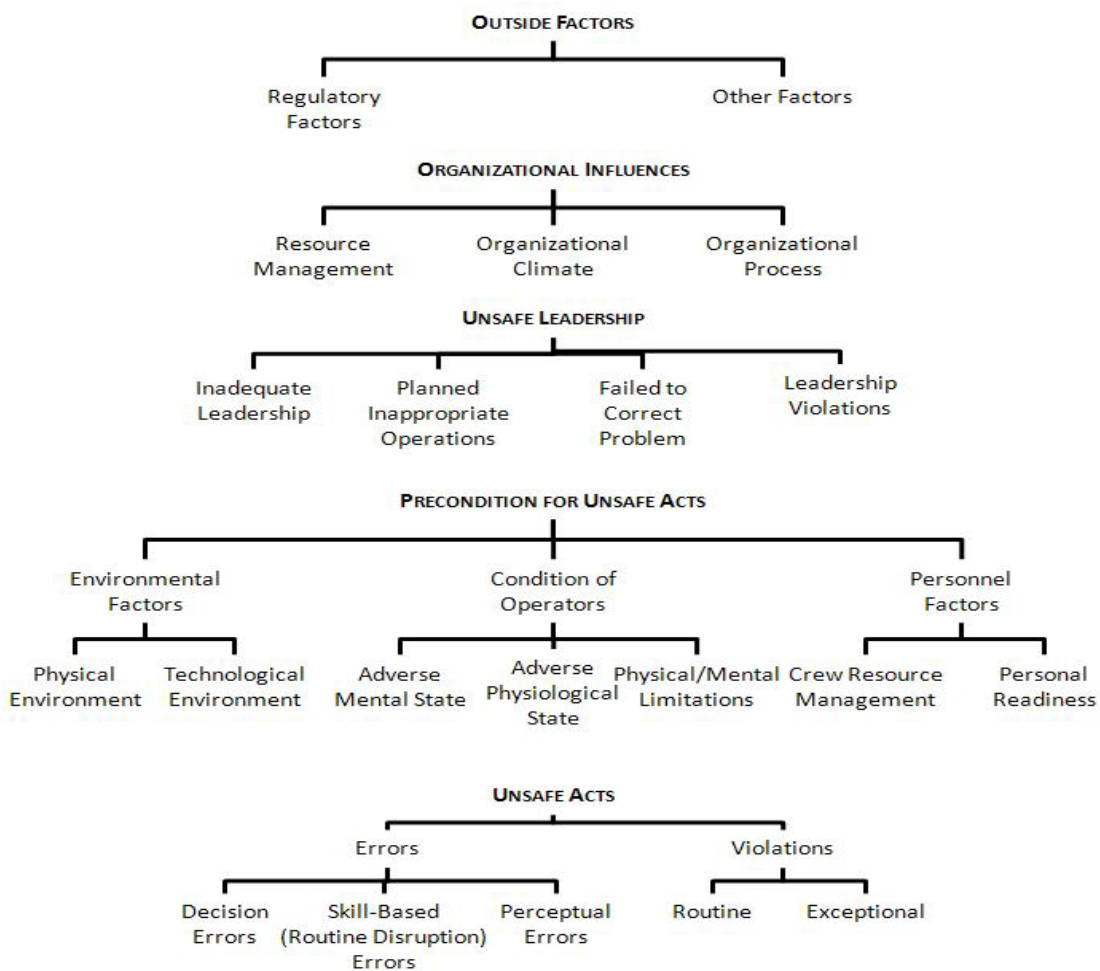


Figure 7: Human factors analysis and classification system-mining industry (HFACS-MI) framework

3.1.2 Description of HFACS-MI Categories

Unsafe Acts of Operators

This first level of HFACS-MI describes the unsafe acts of the operator that directly lead to an incident/accident. This level is typically referred to as operator error and is where most accident investigations are focused. Unsafe acts typically dominate accident databases as they are easy to identify and place the blame on a select few people. Unsafe acts of the operator are classified into two categories, errors and violations. Errors are activities that fail to achieve the desired outcomes whereas violations are activities that consciously disregard established rules and regulations. In the HFACS-MI framework, errors are divided into three basic types (decision, routine disruption, and perceptual) while and violations are divided into two (routine and exceptional).

Decision Errors. Decision errors represent intentional actions that proceed as intended, but the plan proves inadequate or inappropriate for the situation. Decision errors occur during highly structured tasks and are divided into three types: rule-based, knowledge-based, and problem-solving. Rule-based errors occur when a situation is either not recognized or is misdiagnosed, and the wrong procedure is applied. Knowledge-based errors occur when an operator chooses between various action plans but selects the incorrect procedure for the situation; this can be exacerbated by time pressure, inexperience, stress, etc. Problem-solving errors occur when an individual is put in a situation where the problem is not well understood, and no formal procedure exists; instead, a novel solution is required. During these situations an individual must resort to reasoning and thought-processing which is often time consuming and mentally taxing.

Skill-based Errors (Routine Disruption Errors). Unlike decision errors, skill-based errors occur with little conscious effort during highly automated tasks. As tasks become more familiar to an individual, they also become more automated. After some time, it does not take much conscious thought for an individual to navigate a car home following the same route every day. The skill-based error would arise when the person simply drives past his desired turn without noticing. Skill-based errors are due to failures of memory or attention. In the example given above, a loss of attention to where the individual was going could have led to the error. Failures of attention have been linked to breakdowns in visual scanning, task fixation, and inadvertent activation of controls. Consider an operator who is busy checking the status of the ground support and activates the incorrect control.

Memory failures often appear as missed steps in a checklist, forgetting intentions, or losing one's place in a sequence of events. Most people can relate to others that go to get something only to forget what they went to get. In everyday situations, these failures have minimal consequences. In comparison, consider the pedestrian on a mine site who forgets to wait for radio confirmation before proceeding into an area with heavy vehicles. The consequence of this action could quite literally lead to death. These errors increase during emergency situations when stress levels increase.

Skill-based errors are also caused by the technique employed to carry out a task. Even with similar backgrounds in training and experience, the way an individual operates equipment can cause an increased likelihood of committing an error. An operator may move controls using tactile clues only when deciding which lever to move. When

compared with other techniques for operation, such as the added use of visual clues, this way could lead to more unintentional errors being committed.

Perception Errors. Perception errors occur when sensory input is degraded, usually in impoverished environments. The error is not the degraded input being used, but the misinterpretation of the input itself. In the mining industry, the effect of a degraded physical environment has seen very little research. Operators, especially those working underground, are often in areas with limited lighting and constantly changing ground and rib conditions.

Routine Violations. Routine violations refer to the willful disregard of rules and regulations that are condoned by persons in positions of authority. These violations tend to be habitual and accepted as part of what goes on in the organization. Consider, for example, the operator who continually drives above the posted speed limit on the haulage roads. As this is normal on city roads, many people do not think anything of driving 5-10 kph over the posted speed. Since this act occurs frequently and there are few adverse events as a result, the enforcement of the rule is not a priority. In order to prevent routine violations from occurring, one must look to the members of authority to begin enforcing all of the rules.

Exceptional Violations. Exceptional violations are isolated departures from rules and regulations. These departures are not condoned by management, nor are they indicative of an individual's behavior. For example, imagine an operator who violated regulations by operating a piece of equipment that he or she is not authorized to use.

Exceptional violations are difficult to correct because they are unpredictable due to their departure from normal behavior.

Preconditions for Unsafe Acts

While the unsafe acts of the operator have continually been linked to accidents, the preconditions to the unsafe acts must also be understood in order to reduce incidents/accidents. Preconditions are generally latent system failures that lay dormant for long periods of time before ever contributing to an accident. Understanding the preconditions that an individual is placed under will help identify other areas for organizational improvements. Preconditions for unsafe acts include environmental factors, conditions of the operator, and personnel factors.

Physical Environment. The physical environment is often looked at and cited in accident databases. The physical environment refers to both the operational (tools, machinery, etc.) and ambient (temperature, weather, etc.) environments. Mining operations, especially those underground, take place in adverse environmental conditions. Miners are often exposed to high temperatures which can lead to a decrease in attention, dusty conditions that reduce visibility, and dehydration—all of which can contribute to unsafe acts.

Technological Environment. The technological environment deals with the design of equipment and the interaction between operators and equipment. The displays and control designs within equipment play a critical part in human error. Within Australia, differences in control locations may become a major issue. Most equipment is designed and manufactured overseas where standards are different. Even the side on which an

operator sits in the truck will change depending on whether the truck was designed based on the American standard of drivers sitting on the left, or if the design was modified to be driven from the right, as is standard in Australia. This change in seat position can have an effect on operators who are inexperienced and unfamiliar with the new layout or who are constantly switching between left- and right-hand drive vehicles.

Adverse Mental State. The adverse mental state of the operator covers a broad range of mental conditions that can affect the performance of an operator. These conditions include mental fatigue, monotony, distraction, inattention, inherent personality traits, and attitudinal issues such as overconfidence, frustration, and misplaced motivation.

Adverse Physiological State. Adverse physiological state refers to medical and physiological conditions that affect performance. Physiology refers to the normal functioning of an organism—in this case, of an individual person. It may be part of an individual's normal body function to have an overactive sweat gland. While this in itself will not preclude safe operation, combined with a hot humid environment and restricted water access, dehydration could be a major problem. It is important to identify these conditions in order to ensure that actions are taken to ensure individuals are not at an increased risk of harm due to medical or physiological conditions. This category also covers temporary medical conditions such as colds, headaches, et cetera, and the effects of the over-the-counter medications that people take to relieve these conditions.

Physical/Mental Limitations. While many people are unwilling to admit it, there are occupations simply beyond the capabilities of some individuals. All of us cannot

aspire to be test cricket players in a week, and similarly may not have the physical or mental capabilities to operate complex, heavy-duty machines in often adverse environments with limited experience. This category refers to situations when individuals' capabilities are exceeded by the demands of the job.

This category takes into account many different forms of incompatibility. Some of these incompatibilities are possessed by all humans. The human visual system is known to be limited in dark environments so precautions must be taken to account for this decrease in visual acuity. Other areas of incompatibility are often overlooked simply because people do not want to offend others. These incompatibilities are those referring to physical and mental aptitude. Some people do not possess the mental aptitude to correctly react to novel situations or to memorize different procedures. Some individuals lack the physical ability to safely perform a job. This includes not having the physical strength to operate the controls, having incompatible anthropometric measurements for machines and poor physical health to complete strenuous aerobic tasks.

Communication and Coordination. Communication and coordination within an organization is vital for safe operations. Poor coordination between personnel, management, and contractors leads to confusion in responsibilities and overall breakdowns in organizational pathways. Communication breakdowns can occur between varieties of people within the work site—within workgroups, between workgroups, between management and personnel, and between management and contractor.

Fitness for Duty. It is the responsibility of an employee to arrive for work in a condition which allows him or her to work safely. To a large extent, mine sites have

taken measures to ensure that workers show up not under the influence of drugs and/or alcohol. Unfortunately, other factors play a significant part of being fit for duty. These factors include showing up to work with adequate sleep, avoiding physical overexertion during free hours, and maintaining a healthy diet. Within the mining industry, shift work is very common. Engaging in shift work can lead to poorer sleep patterns and nutrition which can negatively affect circadian rhythms and result in lack of fitness for duty.

Unsafe Leadership

According to Reason (1990), the actions of people in leadership positions can influence the performance and actions of operators. As such, the causal chain in accident investigation should include factors at this level. Unsafe leadership is divided into four categories: inadequate leadership, planned inappropriate operations, failure to correct known problems, and leadership violations.

Inadequate Leadership. Leadership is responsible for providing personnel with the opportunity for safe operation. This is done through adequate training, oversight, incentives, guidance, etc. While leadership has the responsibility to provide these things, they do not always do so. With training issues, it is up to leadership to arrange and authorize training programs. When employees are not given the opportunity to attend training sessions, decision making abilities are not developed, potentially leading to an increase in decision errors. Oversight is also an important part of leadership responsibilities. While it is important to trust the competency of operators, leadership must still be present to prevent the breeding of violations within the system.

Planned Inappropriate Operations. The category of planned inappropriate operations refers to situations where actions are initiated that put personnel at an unacceptable level of risk. While these actions may be acceptable during emergency situations, they are unacceptable during normal operation. Consider, for example, leadership that allows a worker to pick up extra shifts in order to cover poor shift scheduling. However, allowing an operator to continue to work after completing a 12-hour shift will possibly lead to drowsiness and increase the potential for human error.

Failure to Correct Known Problems. The third category, failure to correct known problems, refers to instances where unacceptable conditions or behaviors are identified, but actions are not taken to correct them. While most correction measures are left to those in authority, instances of unacceptable behaviors are more likely to surface when authority figures are not present. It is therefore vital that everyone in the organization take an active role in correcting known problems. Inconsistent actions or discipline promotes violation of rules and regulations.

Leadership Violations. The final category, leadership violations, is reserved for situations in which established rules and regulations are willfully disregarded by those in positions of leadership. Leadership violations are rare in nature, but their effects can permeate throughout the organization. When employees witness the mine leadership disregarding rules and regulations, a culture is created where following the rules is not a priority.

Organizational Influences

Organizational failures can be further traced to deficiencies within the highest levels. Latent conditions within the organizational level often go unnoticed during accident investigations. These factors are difficult to find unless a clear understanding of the organization's framework is understood, and a consistent accident investigation framework is used. Identification of causal factors at this level can also be hindered by the unwillingness to apportion blame to the company for fear of liability. Organizational influences are divided into three categories: resource management, organizational climate, and organizational process.

Resource Management. The most obvious corporate decisions are those that related to the allocation of resources. Organizational resources include equipment, facilities, money, and humans. The allocations of these assets are often based on two conflicting objectives: safety and profit. Part of resource management deals with the allocation and availability of personnel. Failures of resource management can occur when an unfavorable ratio of leadership to workers exists.

Organizational Climate. An organization's climate refers to a range of variables that affect performance, including the organizational structure, culture, and policies. Organizational structure is most often viewed as the chain of command that is employed within the company. The way that different levels of management and employees interact with and relate to one another is all part of the organization's climate. "Culture" refers to the attitude, values, beliefs, and customs that are used as guidance. In many organizations, the culture reflects the manner in which tasks are carried out regardless of

the rules and policies that should be followed. A company's policies refer to both the written procedures that are used and the unwritten policies that are embedded in the organization.

Organizational Process. The final category of organizational influences, organizational process, refers to the decision making that governs the day-to-day operations of an organization. Organizational process includes the creation and dissemination of SOPs, roster selections, and the establishment of safety programs.

Outside Factors

Rarely, if ever, do organizations operate in isolation. Depending on the type of work being conducted, an organization will be regulated by a government body. Even those that do not have a specific government entity oversight are still required to comply with safety and health regulations. Additionally, an organization must answer to the community. This fifth and final level of the HFACS-MI framework is not part of the original framework developed by Wiegmann and Shappell (2003). It was modeled after the work of Reinach and Viale (2006) on problems within the rail industry.

Regulatory Factors. As a government entity, DME has a responsibility to the industry it oversees, as well as workers in the industry. DME is split into many groups, but the two main groups dealing with mining are Safety and Health and the inspectorate. The inspectorate regulates industry and provides advice and guidance but is not responsible for safety. Safety and Health is there primarily for the worker. DME must ensure that inspectors and others who interact with industry and unions are seen as unbiased, knowledgeable, adequately trained, and competent in their positions.

Deficiencies in any of these areas could lead to suboptimal enforcement of legislation and inadequate guidance on safety issues and concerns. It is this level of the HFACS-MI framework that will allow DME to ensure that its actions do not adversely affect safety and health.

Other Factors. Besides government influences, organizations are faced with a myriad of other outside influences as they are pressured by different sources to ensure safety and health. The community in which an organization is located might pressure the organization to hire locally which could lead to an increase need for training. Legal pressure is always a concern as many organizations become fearful of prosecution for their actions. Economic pressures could force an organization to increase production, and in turn, potentially overwork employees. Pressure from environmental groups could lead to changes in procedures and policies which would have to be effectively communicated throughout the organization. Changes in the overall surrounding population may have an effect on safety and health. Australia, as in other parts of the world, is seeing an overall aging of the work force and a decrease of younger workers entering into high-risk industries. All of these outside influences have the ability to adversely affect the safety and health performance of an organization unless the organization recognizes them and takes steps to mitigate their impact.

3.1.3 Exemplar Development

Examples of each causal factor were generated to use as a guide during accident investigation. The first step involved in developing these examples, or “exemplars,” was a brainstorming session with a focus group. The focus group totaled seven people and

included inspection officers, mines inspectors, and regional inspectors of mines. All members of the focus group worked for the DME and had at least five years of experience within the mining industry. Individual and small group non-structured interviews were then held between mine operators and a human factors specialist to gain more firsthand knowledge of active and latent failures. Mine workers interviewed had between less than one year and 20 years experience in the industry. After this list of examples was compiled, it was reviewed and categorized by a group of seven people with mining experience and a group of four with HFACS experience. Where disagreements existed, discussions were held until a consensus agreement was reached. A complete listing of exemplars can be found in Appendix A.

3.2 Data Collection

3.2.1 Study One- Australia

Data was collected from mining incident/accident reports obtained from the DME in Queensland, Australia. The author collected the data personally at five regional offices throughout Queensland, Australia. Mines and quarries in Queensland are divided into three separate regions; northern, central, and southern.

All mines and quarries in Queensland are required to report lost time accidents and high-potential incidents to DME within 24 hours of the event. Because of the large number of incidents/accidents reported, investigation reports were selected based on the following criteria: an initial report was made to DME, a follow up report was submitted by the mine, and an accident investigation was conducted by either the mine or DME. In total, 508 incident/accident cases occurring from January 2004 to June 2008 were used in

the analysis. This represents approximately 10% of the total number of reported events during this time frame. Mines involved in the analysis included open cut and underground coal mines; open cut and underground metal/non-metal mines; and quarries.

3.2.2 Study Two- USA

Data was collected from fatal mining accidents on the MSHA website (<http://msha.gov/>). As these reports are up for public access, no de-identification of information was done. As a federal government agency, accidents gathered were from mines across the USA. Mines included coal mine facilities and metal/nonmetal mine facilities. In total, 254 fatal accident cases were included from 2004-2008.

3.3 Causal Factor Classification using HFACS-MI

3.3.1 Study One

Groups of two human factors specialists were used to code each case by consensus. Given the high inter-rater reliability found in previous HFACS analysis (ex. Pape et al., 2001; Wiegmann and Shappell, 2003; Gaur, 2005; Reinach and Viale, 2006; Li et al., 2008), consensus coding was deemed appropriate for analysis. All human factors specialists possessed a minimum of a Master's degree in industrial engineering with an emphasis on human factors. All coders were previously trained and certified in the use of the HFACS framework and had experience with the application of HFACS in accident analysis.

HFACS-MI codes were identified using the incident narrative, sequence of events, recommendations and/or findings. Each HFACS-MI category was counted a maximum of one time per case. This count acted as an indication of the presence or absence of a given

category for each incident/accident. Subsequent category codes were also classified for further analysis. During the coding process, each rater was supplied with copies of the HFACS-MI framework and corresponding exemplars. All raters had electronic access to incident reports.

3.3.2 Study Two

Groups of two human factors specialists were used to code each case by consensus. Given the high inter-rater reliability found in previous HFACS analysis (ex. Pape et al., 2001; Wiegmann and Shappell, 2003; Gaur, 2005; Reinach and Viale, 2006; Li et al., 2008), consensus coding was deemed appropriate for analysis. All human factors specialists possessed a minimum of a Master's degree in industrial engineering with an emphasis on human factors. All coders were previously trained and certified in the use of the HFACS framework and had experience with the application of HFACS in accident analysis.

HFACS-MI codes were identified using the overview, accident description, and root cause analysis. Each HFACS-MI category was counted a maximum of one time per case. This count acted as an indication of the presence or absence of a given category for each incident/accident. Subsequent category codes were also classified for further analysis. During the coding process, each rater was supplied with copies of the HFACS-MI framework and corresponding exemplars. All raters had electronic access to incident reports.

3.5 Analysis

Coded data was organized and analyzed using a MICROSOFT ACCESS database and MICROSOFT EXCEL. Hypothesis testing was used to compare proportion of errors and organizational deficiencies. The following is the general hypothesis that will be tested

$H_0 : o_i = \varepsilon_i$ for all populations

$H_1 : o_i \neq \varepsilon_i$ for at least one population

where:

o_i = observed value

ε_i = expected value

To test for significance, the chi-squared statistic will be used. The test statistic value for testing the hypothesis $p_1 = p_2$ is determined from the formula

$$\chi^2 = \sum_{i=1}^n \frac{(O_i - E_i)^2}{E_i} \quad (1)$$

A *p-value* of 0.05 was used to identify significance. This study looked to minimize Type II errors. Type II errors will be minimized to ensure that all significant differences are identified. This will be done to increase the chances of finding areas for future improvement and to better protect the worker.

If the results of the chi-square goodness-of-fit test is significant, it can be concluded that in the underlying population represented by the sample, there is a high likelihood that the observed frequency for at least one of the sub-population is not equal to the expected frequency. The chi-square goodness-of-fit test provides an approximate of the multinomial distributions. The following are the assumptions that must be met to use the chi-square goodness-of-fit test on population frequencies:

- a. Categorical/nominal data are employed
- b. The data that are evaluated consist of a random sample of n independent observations
- c. The expected frequency of each cell is 5 or greater.

Instances where the third assumption was violated resulted in no statistical test being performed. This was due to the extremely small sample sizes. It was believed that no meaningful results could be derived from sample sizes that were very small.

3.6 Case Study

To clarify the coding process that took place during both studies, an example case study will be reviewed. The accident took place at an open pit coal mine on May 23, 2006 in Kentucky and resulted in the death of a 23-year-old miner with less than one year of mining experience. The accident occurred because the service brakes were not adequate, the engine brake was inoperative, and the victim was not tasked trained. The approved training plan was not followed, and effective procedures were lacking to ensure adequate braking systems. Using the overview, the accident description and the root cause analysis, HFACS-MI codes were identified for contributing factors for this accident.

The first step in the analysis process was to code the root causes identified by MSHA investigators. The first root cause was that management failed to task train the victim, and the approved mine training plan was not followed. This was coded at the leadership level and fell under the category **inadequate leadership**. Although the victim had training on the operation of a Mack truck, the training he had received was on a truck

specifically used to carry explosives. The two trucks, although the same brand, had different transmissions; and therefore, the operation of the braking system was slightly different. Therefore, the incorrect application of the braking system when the truck started to slide down the embankment was coded as a **decision error**, or more specifically, as the incorrect use of equipment. The assignment of an untrained, inexperienced driver to operate the water truck by members of leadership was coded as **planned inappropriate operations**.

The engine brake on the water truck was inoperable at the time of the accident. When the victim was given the task of driving the water truck, he was told by his supervisor that the engine brake did not work. He was also told to inform the mechanic of the problem so that the mechanic might fix it. The problem with the brake not being operational had been reported to the supervisor on two previous occasions before the accident occurred. Because the problem was known and management failed to see the problem corrected, the causal factor was coded as **failure to correct known problem**. There was also a **technical environment** code as the brakes failed to prevent the water truck from sliding down the incline. MSHA investigators also discovered that the organization lacked a policy for ensuring that maintenance checks were carried out. This lack of procedure was coded at the organizational level and was identified as a failure of the **organizational process**. The final contributing factor to this accident was the gradient of the road. The truck began to gain speed while driving down a 9% gradient. This contributing factor was coded as a **physical environment** factor, or more

specifically, a surface/road condition. All incidents and accidents were coded in a similar manner.

CHAPTER 4: RESULTS

4.1 Study One: High-potential and Lost Time Accidents/Incidents, Australia

The results for this analysis identified causal factors at all tiers except for outside factors. For both the organizational influence and unsafe leadership tiers, causal factors tended to concentrate within a single category. Causal factors at the lowest two tiers were dispersed over multiple categories. Table 1 shows the frequency and percentage of incident/accidents cases associated with each HFACS-MI category. The percentages at each level can add up to more than 100% as more than one category could be associated with an individual case. A more detailed analysis of each level is provided in the following sections.

Table 1: Frequency and percentage of cases- Study One

HFACS Category	N* (%)
Outside Factors	
Regulatory Influences	0 (0.0)
Other Influences	0 (0.0)
Organizational Influences	
Organizational Climate	7 (1.4)
Organizational Process	42 (8.3)
Resource Management	5 (1.0)
Unsafe Leadership	
Inadequate Leadership	144 (28.3)
Planned Inappropriate Operations	60 (11.8)
Failed to Correct Known Problems	20 (3.9)
Leadership Violations	7 (1.4)
Preconditions for Unsafe Acts	
Environmental Conditions	
Technical Environment	179 (35.2)
Physical Environment	198 (39.0)
Conditions of the Operator	
Adverse Mental State	64 (12.6)
Adverse Physiological State	32 (6.3)
Physical/Mental Limitations	55 (10.8)
Personnel Factors	
Coordination and Communication	138 (27.2)
Fitness for Duty	2 (0.4)
Unsafe Acts of the Operator	
Skill-based errors	299 (58.9)
Decision Errors	249 (49.0)
Perceptual Errors	25 (4.9)
Violations	28 (5.5)

* N = 508

4.1.1 Unsafe Acts of the Operator

A large amount of data was gathered at the unsafe acts tier. Nearly all cases analyzed identified at least one causal factor at this tier (94.7%). The large number of

unsafe acts found in the incident/accident reports was not surprising as most reports gave a fairly descriptive account of events.

The following section presents a general analysis of the unsafe acts identified. It also provides an analysis differentiating unsafe acts based on mine type, mine material, time of day, and year. Age and experience data could not be analyzed as this information was only available for a small percentage of cases.

The most often identified unsafe act was skill-based errors, followed by decision errors, and violations. Perceptual errors were identified in less than 5% of cases analyzed. At least one skill-based error was identified in 58.9% of cases analyzed. From Figure 8 it can be seen that 50% of unsafe act codes identified are associated with skill-based errors. Decision errors also account for a large percentage of codes identified. Perceptual errors and violations are nearly similar in frequency and when combined account for less than 9% of codes.

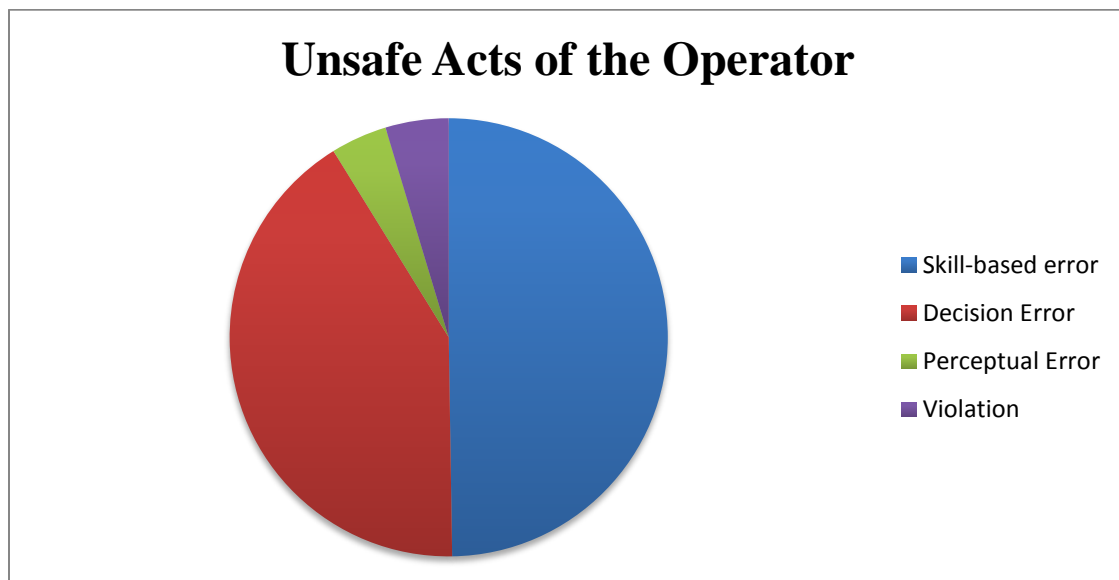


Figure 8: Unsafe acts of the operator percentages of codes

In order to standardize the analysis process, examples were created at each HFACS-MI category level of typical actions or issues that might occur. These examples were then clustered within each category based on underlying similarities. For example, “working at heights without fall protection” was grouped with other codes involving the misuse or inadequate use of personal protection equipment (PPE). The top three skill-based errors and decision errors can be seen in Table 2. Violations and perceptual errors represented a small percentage of unsafe acts and therefore are not shown here. A complete list of the groupings can be found in Appendix A. The percentages of incident/accident cases associated with each unsafe act exemplar are displayed in Figure 9.

Table 2: Top three routine disruption and decision errors

Skill-based errors	Decision Errors
Inadvertent or missed operations	Procedural errors
Technique errors	Situational assessment errors
PPE/tools/equipment errors	Risk assessment errors

Exemplars associated with violations and perceptual errors combined represent only 10.2% of all exemplars identified.

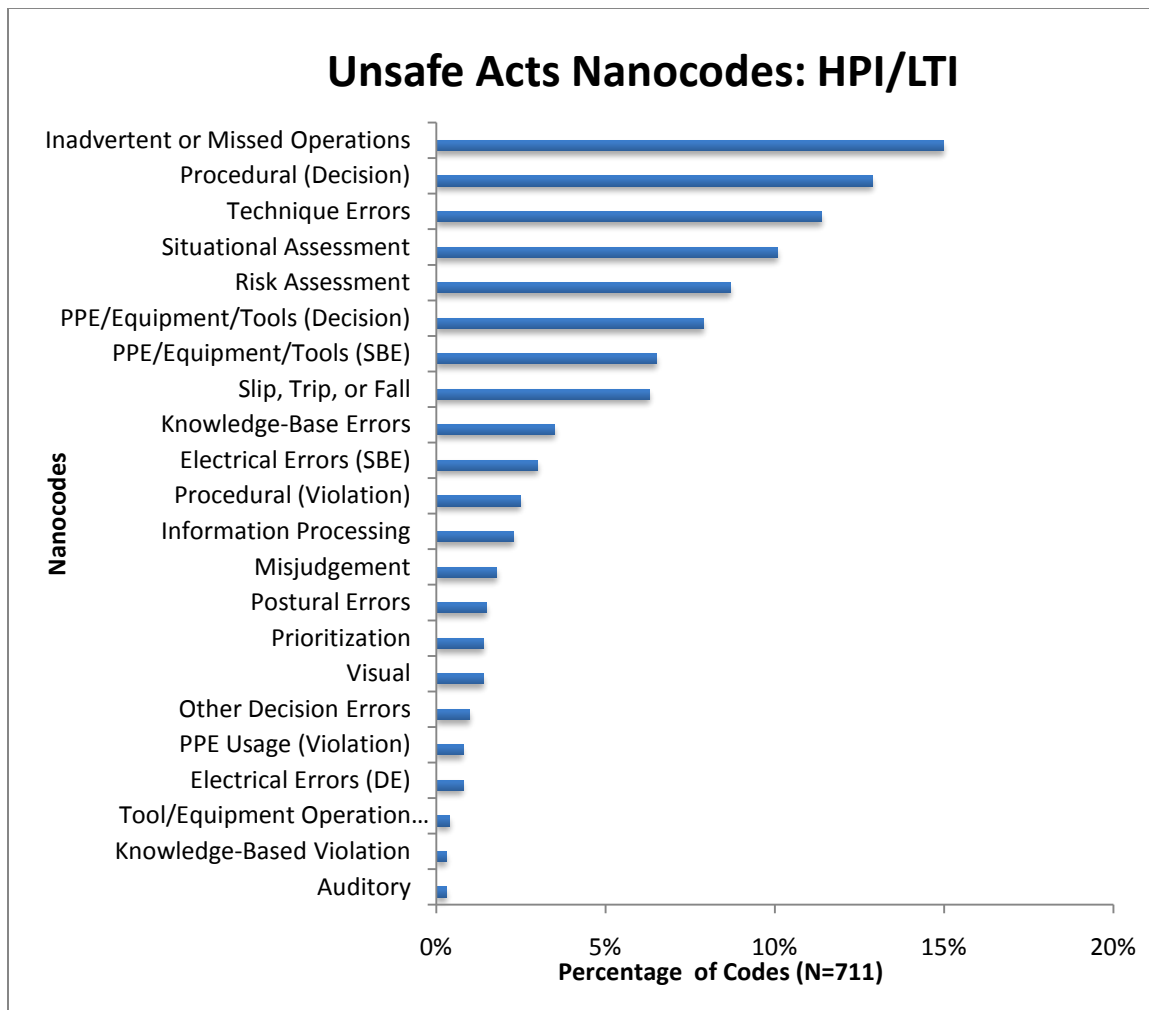


Figure 9: Unsafe acts of the operator exemplars

A closer examination of skill-based errors revealed that the most common types of errors were inadvertent/missed operations, technique errors, and PPE/tools/equipment errors. Inadvertent/missed operations mainly occurred in the form of a breakdown in visual scan or the inadvertent activation of a control. A breakdown in visual scan can occur for a number of reasons including distractions and interruptions. However, with the large amount of activity on site being conducted at any one time, the visual environment can often be overburdened. One intervention aimed at reducing this specific error form is

the use of proximity detection units on mobile equipment. The use of proximity detection devices may help with reducing instances of vehicle-vehicle interaction especially when both heavy and light vehicles are used in close vicinity of each other. One might also examine ways to improve vigilance—particularly during times when fatigue and boredom may set in, like night-time operations or during repetitive and mundane tasks.

With inadvertent activation of a control, problems arose from the placement of the control and differences in layouts between mobile equipment. To reduce these errors, it makes sense to standardize controls and/or reduce the variety of vehicles with different control layouts so that switching between vehicles no longer poses a threat. Another option would be to introduce warnings or back-up automation that prevents the inadvertent/incorrect activation of critical controls.

An operator's technique refers to the way in which an operator typically completes a task. This technique can cause an increase in an operator's likelihood of committing an error. For example, an operator may get into a practice of calling out when entering into an area and not coming to a complete stop while waiting for a response. The operator typically gets a response directly after his call out and therefore continues to move into the area assuming that the response will come. This "technique," similar to an automobile driver rolling through a stop sign, may increase the likelihood of an adverse event occurring.

Problems with the use of PPE/tools/equipment dealt with the operation of tools or equipment and the use of correct PPE. The most frequent activity being performed when this type of skill-based error was with the parking of vehicles. When parking either a

heavy or light vehicle on site, the engine must be shut off, the parking brake applied, and the wheels turned correctly before exiting the cab. It was found that operators often exited the cab without completing one of these duties.

Procedural errors generally refer to the incorrect or misapplication of a given procedure for a job. Like any decision making task, it also assumes that the individual has knowledge of the procedure. However, an operator may carry out a procedure incorrectly simple because he or she does not know the correct steps in the procedure either due to lack of training or lack of retention of information. Regardless, these types of errors suggest that additional training or procedural aids like checklists or other memory aids may prove useful.

Another common form of decision error observed involved situational assessment. That is, assessing whether or not the individual identified the hazard and took appropriate action. To increase the likelihood of operators correctly identifying hazards, scenario based training that includes visual images of potential hazards has proven useful in other high-risk industries, like aviation. A similar training program could be developed in mining, albeit at a broader scope. Alternatively, making potential hazards more easily identifiable with the use of warnings, barriers, etc. might decrease the occurrence of this specific error form.

Typically, operators are expected to carry out a complete and thorough risk assessment and/or job safety analysis before commencing tasks. This includes the identification of the necessary controls to either eliminate or mitigate any potential hazards that may arise. Unfortunately, the data examined here suggest that many

operators did not conduct an adequate risk assessment leading to incidents and accidents. While there may be many reasons for this, it is possible that operators have become so accustomed to the risk analysis that they have lost sight of its purpose. Consequently, they either underestimate the risk or simply fill out the form without giving it sufficient thought. This may lead to potentially threatening or unusual (albeit rare) risks to be overlooked during the risk assessment process. This is a particularly vexing problem for many industrial settings. After all, how does one motivate a person on the front line to fill out yet another form when the risks are not necessarily evident or probability of injury may not be understood?

When looking at just skill-based errors, the exemplars “inadvertent or missed operation” and “technique errors” appear to be the major contributors as they make up 32% and 24% of the codes, respectively (see Figure 10). “Postural errors,” which deal more with manual handling tasks, represent a very small percentage of skill-based error codes. This result may seem to contradict popular belief that manual handling injuries are highly associated with industrial tasks. A possible reason for manual handling representing a small proportion of HPI and lost time accidents may be that these types of injuries are gradual; therefore, they do not necessarily occur as a single accident but rather as the result of years of work. That being said, there might not be an “accident” or “incident” as defined within regulations to report. Another possible reason for few manual handling accidents/incidents is the decrease of manual handling due to the increase mechanization of most tasks on a mine site.

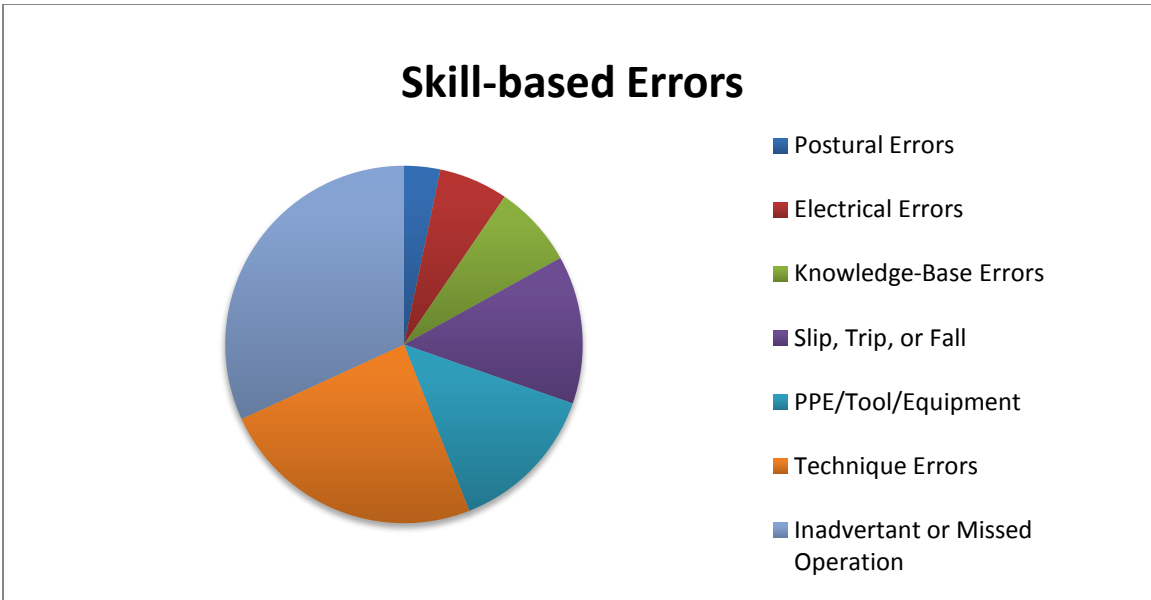


Figure 10: Skill-based errors- breakdown of exemplars

Decision errors are associated with 49.0% of all incident/accident cases analyzed and represent 41% of unsafe act codes identified. As can be seen in Figure 11, “procedural” errors are the major contributor to decision errors at 29%. “Situational assessment” also heavily contributes to decision errors at 22%. “Electrical errors” and “other decision errors” contribute very little to decision error codes at only 2% each.



Figure 11: Decision errors- breakdown of exemplars

The majority of violations (62%) can be attributed to the “procedural” violations exemplar. Twenty-one percent of violations can be attributed to the exemplar “PPE usage.” Even though violations contribute to a small percentage of unsafe acts overall (5.5%) they need to be investigated given their serious nature.



Figure 12: Violations- breakdown of exemplars

While perceptual errors only contributed to 4.2% of all codes at the unsafe act level, the classification of these errors is still relevant. The majority of perceptual errors (52%) can be attributed to the “misjudgement” of height, distance, speed, or weight (see Figure 13). More importantly, 72% of cases where a perceptual error was identified also identified the physical environment as a contributing factor. Given this, to decrease the frequency of perceptual errors, the physical environment—specifically “visibility” and “road/surface conditions”—would need to be improved.

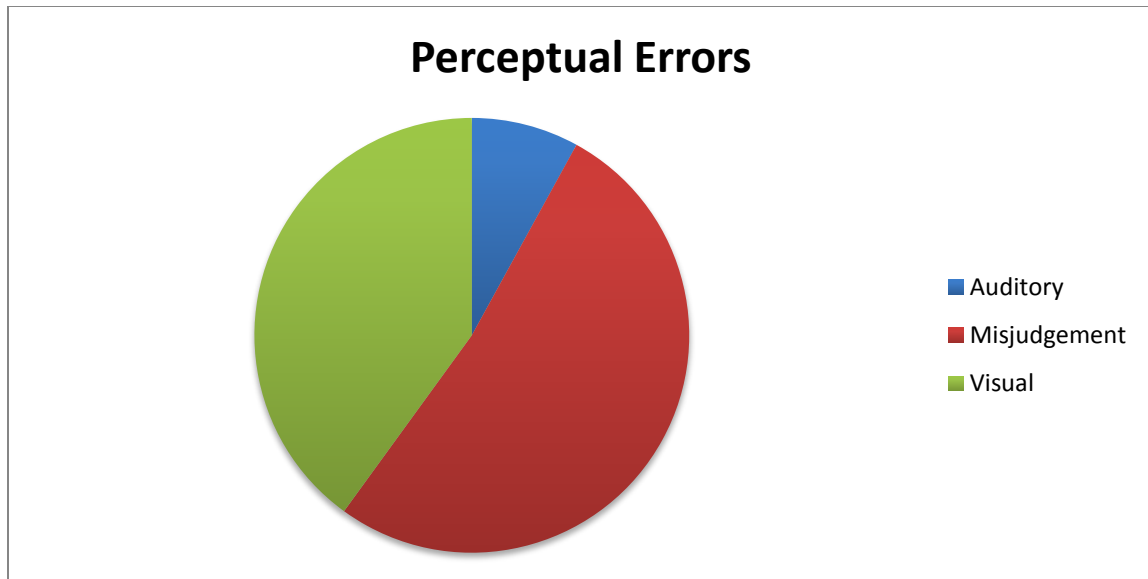


Figure 13: Perceptual errors- breakdown of exemplars

Unsafe acts were examined further by mine type. Five basic mine types were used in this analysis; underground metal/non-metal mines, underground coal mines, open cut metal/non-metal mines, open cut coal mines, and quarries. Since all incident/accident cases were attributed to a particular mine, the entire data set was used in this analysis. Figure 14 presents the breakdown of unsafe acts for all mine types.

Skill-based errors were the most prevalent error form and were generally stable across all mine types with the noted exception of underground metal/non-metal mines; although, the latter was not significant ($\chi^2 = 4.37$, ns). This result suggests that differences in environmental factors and mining techniques do not affect the likelihood that operators will commit skill-based errors.

Unlike skill-based errors, decision errors did significantly differ across mine types ($\chi^2 = 10.39$, $p < 0.05$). For example, underground coal mines had the lowest percentage (23.1%) of incident/accident cases associated with decision errors while quarries yielded

the highest percentage (48.0%). The larger issue is why decision errors are more frequent at quarries than any other mine type. Decisions are based on three key elements: 1) information – is the information accurate and timely; 2) knowledge – does the individual have the required understanding of the situation and training to make the decision, and 3) experience – with experience comes a better understanding of one's decisions. If any of these three components are absent or lacking, the likelihood of successful decision making is markedly reduced. Given that, it could be that the information available to quarry miners may be suspect or absent. Likewise, the knowledge base of the quarry miners may be less than other mine operations for a variety of reasons (i.e., poor training practices, more complex tasking, etc.). Finally, it could be that the experience level of quarry miners may be less than observed in other mine types. Regardless, successful interventions should focus on improving information access and quality while ensuring that all quarry miners are provided sufficient training and knowledge to act safely on the information. Experience, unfortunately, is something that can neither be taught nor substituted for; it merely comes with time. However, depending on the experience level of the quarry workforce, these data suggest that efforts to retain and employ more experienced quarry miners may be beneficial.

In contrast to quarries, underground coal mines exhibit a much lower percentage of cases associated with decision errors. This may be due to the highly structured nature of the tasks coupled with the reality that most operations are associated with written and practiced procedures; as a result, employees are never compelled to create their own course of action. Also of note, coal mines tend to be populated by a more experienced

workforce. One way to measure workforce experience is to look at the retention rate of operators. Coal mines exhibit the highest retention rate of all mining sectors in Australia (MOSHAB, 2002). This decrease in turnover naturally leads to a more experienced workforce.

For all mine types (except for open cut coal), violations were attributed to more cases than perceptual errors. Violations were identified in 5.5% of cases when all the data was aggregated. No significant differences exist between violations across mine types ($\chi^2 = 3.49$, ns). In this analysis, it can be seen that open cut coal and underground metal/non-metal mines have less incident/accident cases associated with violations as a causal factor with 3.8% and 4.6% of cases respectively. Overall, underground coal mines have the greatest number of cases with a violation as a contributing factor (9.6%).

Perceptual errors were most often identified with underground coal mines (9.6%). Given that the number of underground coal mines analyzed was smaller than any other type of mine and the high percentage of perceptual errors present in such mines, it may be that the environment at underground coal mines lends itself to create perceptual errors. No significant differences in the percentage of cases associated with perceptual errors across mine types exist ($\chi^2 = 7.22$, ns). Perceptual errors may decrease if the sensory environment is improved, for example, by improving the lighting to prevent degraded visual cues.

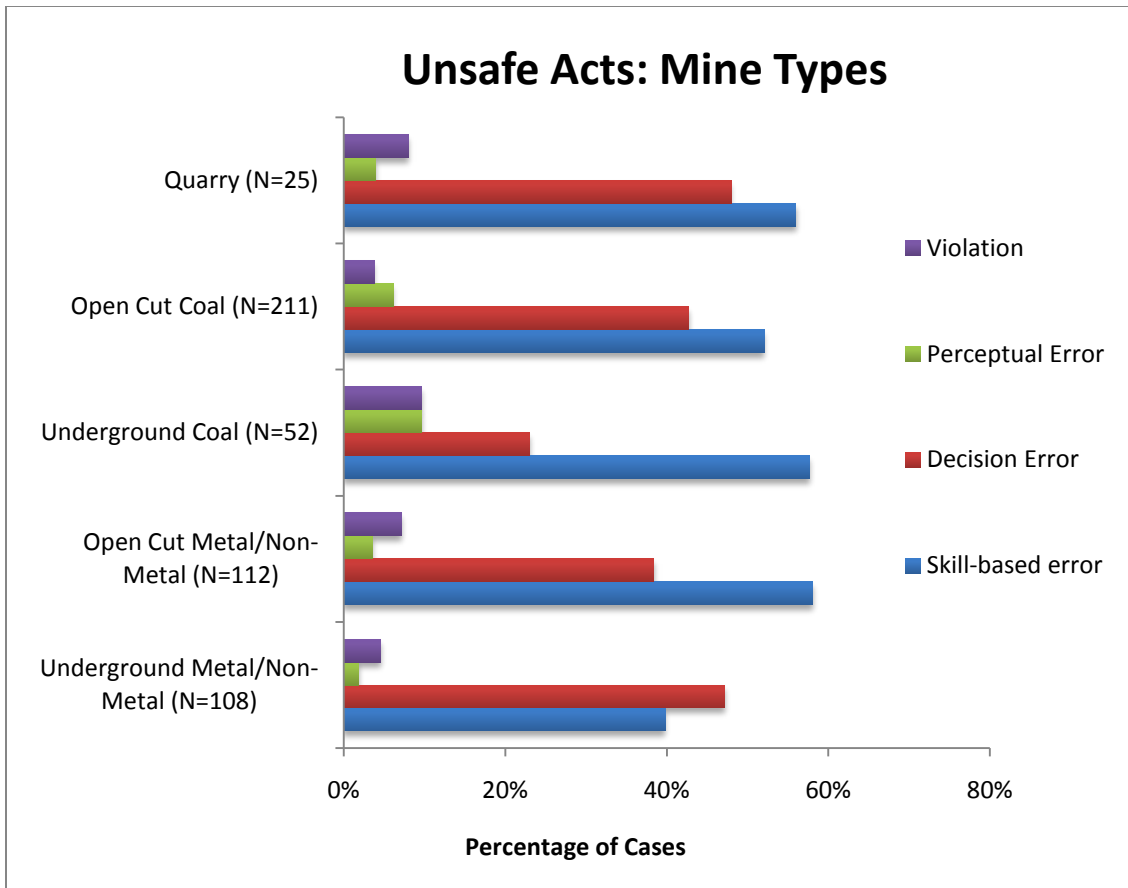


Figure 14: Unsafe acts of the operator by mine type

There are two basic categories for mining material used in this analysis, coal and metal/non-metal. Metal/non-metal includes a variety of materials such as zinc, copper, gold, lead, sand, etc. All 508 cases were used in this analysis.

When the data is clustered based on mining material, differences in unsafe acts are less noticeable (Figure 15). In fact, skill-based errors are nearly identical, as coal mines have 59.7% of cases associated with a skill-based error and metal/non-metal mines have 58.0% of cases associated with a skill-based error. A non-significant difference ($\chi^2 = 0.3, p > 0.05$) is seen with decision errors. Coal mines had 46.4% of cases associated

with a decision error where as metal/non-metal mines had 51.8%. This would suggest that operators in coal mines are better at handling abnormal or novel situations quickly.

Neither perceptual errors nor violations are greatly associated with incident/accident cases—regardless of mining material. Perceptual errors, which occur in degraded sensory environments, appear to be more often attributed with coal mine incidents/accidents than metal/non-metal mine incidents/accidents; however, the sample size was too small to perform a meaningful analysis. From the previous analysis on mine type, the main contributor of coal perceptual errors was underground coal mines. Violations, on the other hand, exhibit the opposite trend and are more often attributed to metal/non-metal mining incidents/accidents.

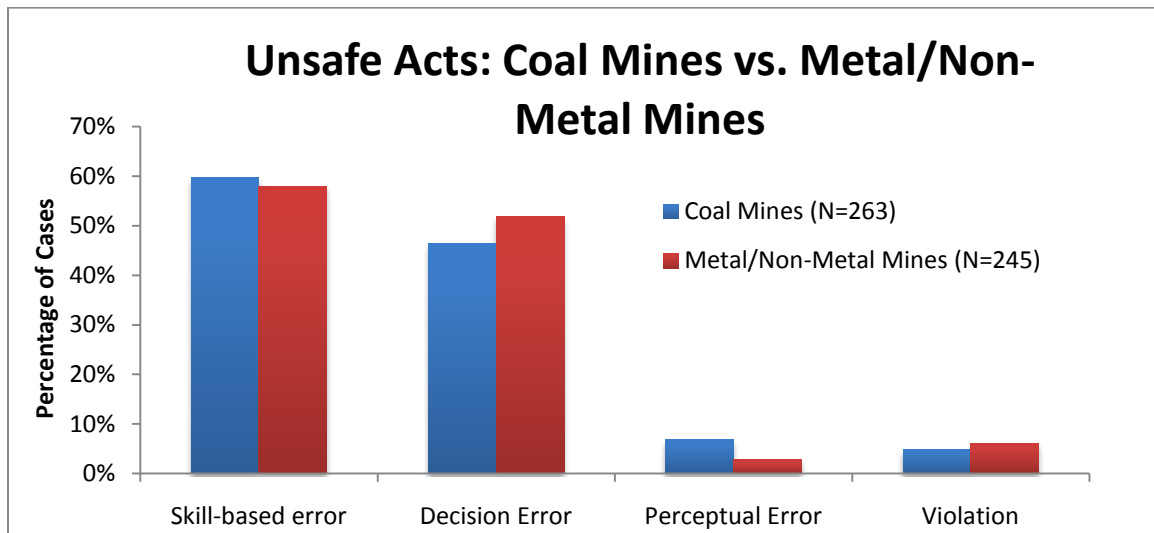


Figure 15: Unsafe acts of the operator by mining material

Data regarding the time of day when an incident/accident occurred was available for all cases. Incident/accident event times were sorted into six four-hour groups, and these groups were organized based on typical shift times. For example, most 12-hour morning shifts start at 0600; so this was used as the start of one time group. Each group

consists of accidents and incidents in a four-hour time span to ensure that enough events occurred for a comparison to be made.

While in other analyses skill-based errors remained fairly consistent across categories, they showed an interaction with the time of day. Skill-based errors are identified in a higher percentage of incident/accident cases between the hours of 2200 and 0159. This time frame generally represents the beginning of a 12-hour night shift and occurs during the middle of the circadian trough potentially causing an increase in fatigue and a decrease in attention. As skill-based errors generally occur during tasks that are repetitive in nature, special consideration should be made to ensure that operators on the night shift remain vigilant and engaged in the task at hand. This can be done in numerous ways including task rotation, increased communication, and job monitoring. Although the percentage of cases associated with skill-based errors appears to vary across time, these differences are not significant ($\chi^2 = 7.55$, ns).

No significant difference exist across time periods for decision errors ($\chi^2 = 10.1$, ns). Decision errors were found to contribute to the lowest percentage (24.0%) of incidents/accidents between the hours of 1800 and 2159. From 0600-0959, decision errors are also lower than the other time periods. Both of these time periods represent the first four hours of a typical twelve hour shift. One possible explanation for the decrease in decision errors during these times is that the beginnings of shifts are generally spent in set up and briefings. Operators may be engaged in fewer activities and those in which they are engaged have recently been explained. If briefings are helping to reduce decision

errors during the beginning of the shift, then repeating briefings throughout the shift may help to reduce decision errors during other time periods.

Perceptual errors also showed a trend when viewed by incident time. The percentage of perceptual errors are significantly different across time ($\chi^2 = 14.71$, $p < 0.05$). Fifty-two percent of all perceptual errors identified occurred from 2200-0559. About 11% of incidents/accidents that occurred between 2200-0159 and 0200-0559 had at least one perceptual error as a contributing factor. During these periods, there is less natural light available which could lead to a degraded sensory environment. During the time period of 1000-1359, the lowest percentage (0.8%) of cases associated with perceptual errors was identified.

Violations showed a steady trend across time with the highest percentage of cases (7.0%) with at least one violation as a contributing factor occurring from 0600-0959. Violations did not appear to be a major contributing factor for any one time period. The available sample size for violations was too small for analysis.

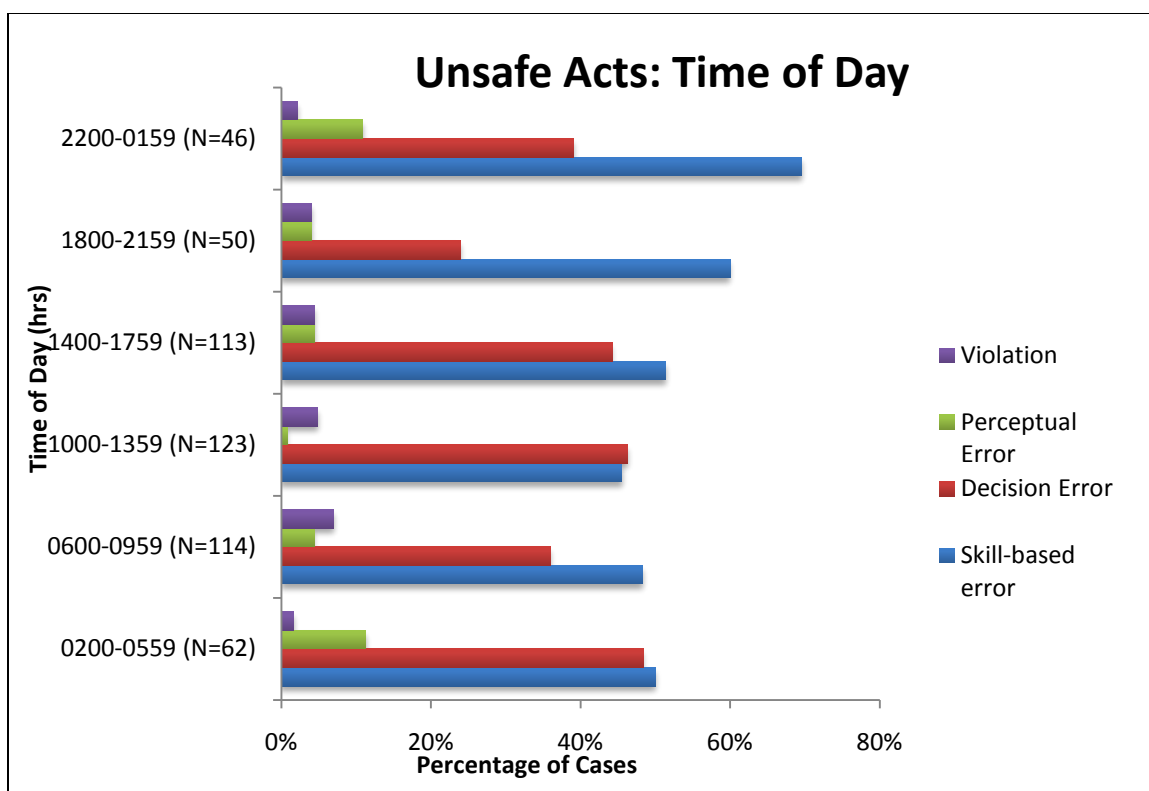


Figure 16: Unsafe acts of the operator by time of day

Incident/accident date information was available for all cases used in this analysis. There are no significant differences in the percentages of skill-based errors, decision errors, perceptual errors, or violations from 2004-2008. Shown in Figure 16, skill-based errors are the main contributor in all years except 2008 where there is little difference between routine disruption and decision errors. Skill-based errors show a slight downward trend from 2004-2006, jump up in 2007, and continue to decline in 2008. Given the greater number of cases analyzed from 2007, the downward trend exhibited by the first three years may simply be caused by fewer incident/accident cases being analyzed, and the count for 2007 may be a more accurate representation. This said there appears to be is no real reduction in skill-based errors during this time period.

There is a decrease in decision errors in 2007, but the percentage of cases in 2005, 2006, and 2008 are similar. Given the relatively stable rate of decision errors before and after 2007, it appears that there is no significant reduction of decision errors exhibited. Perceptual errors and violations remained constant over the five-year period analyzed.

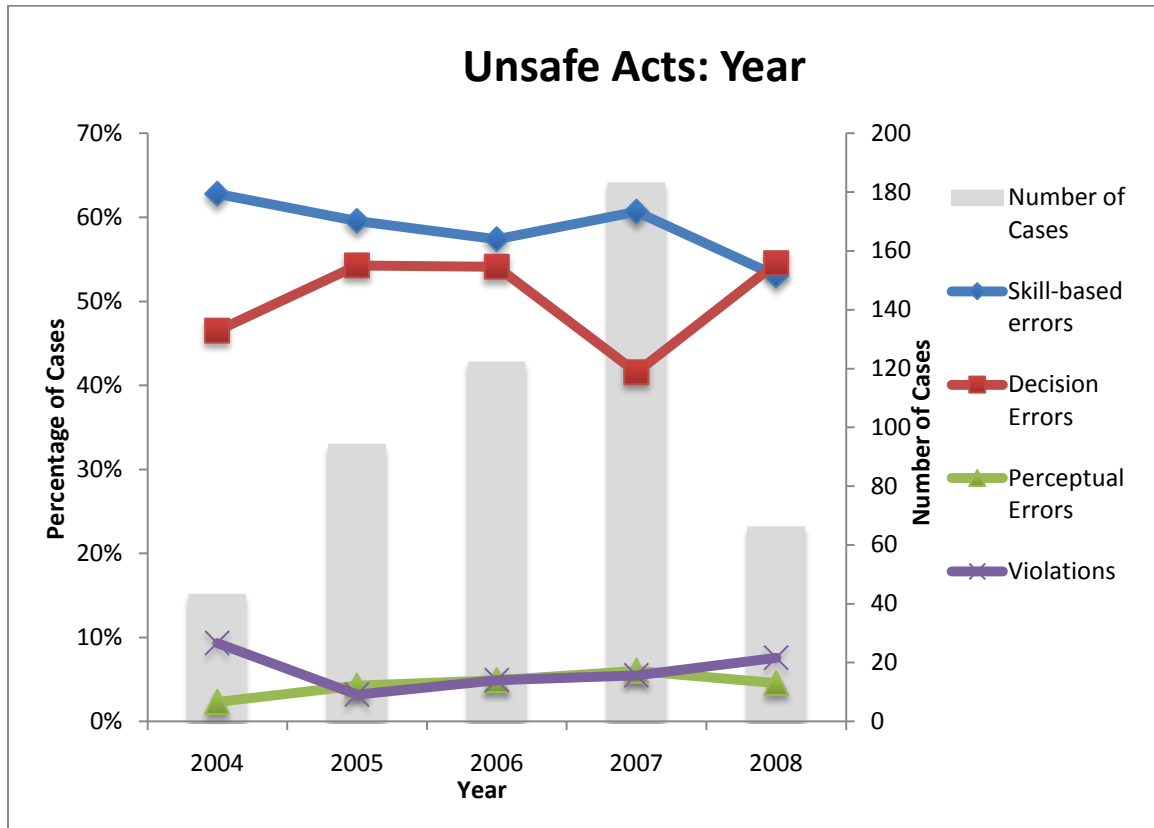


Figure 17: Unsafe acts of the operator by year

Since skill-based errors account for a majority of the unsafe acts, the skill-based errors exemplars were analyzed over the five-year time period (Figure 17). The inadvertent/missed operation exemplar was the highest occurring exemplar for every year except 2005. Inadvertent or missed operations have a noticeable decrease from 2004-2006, but in 2007 and 2008, they return to previous levels. Technique errors dramatically increase in 2005, but in all other years, remain fairly stable. Of note is that all skill-based

error exemplars (except for electrical errors) show a decline from 2007-2008. This mimics the decline in total skill-based errors over the same period. This suggests that there is not a specific type of skill-based error being improved but that there may be an overall improvement in errors.

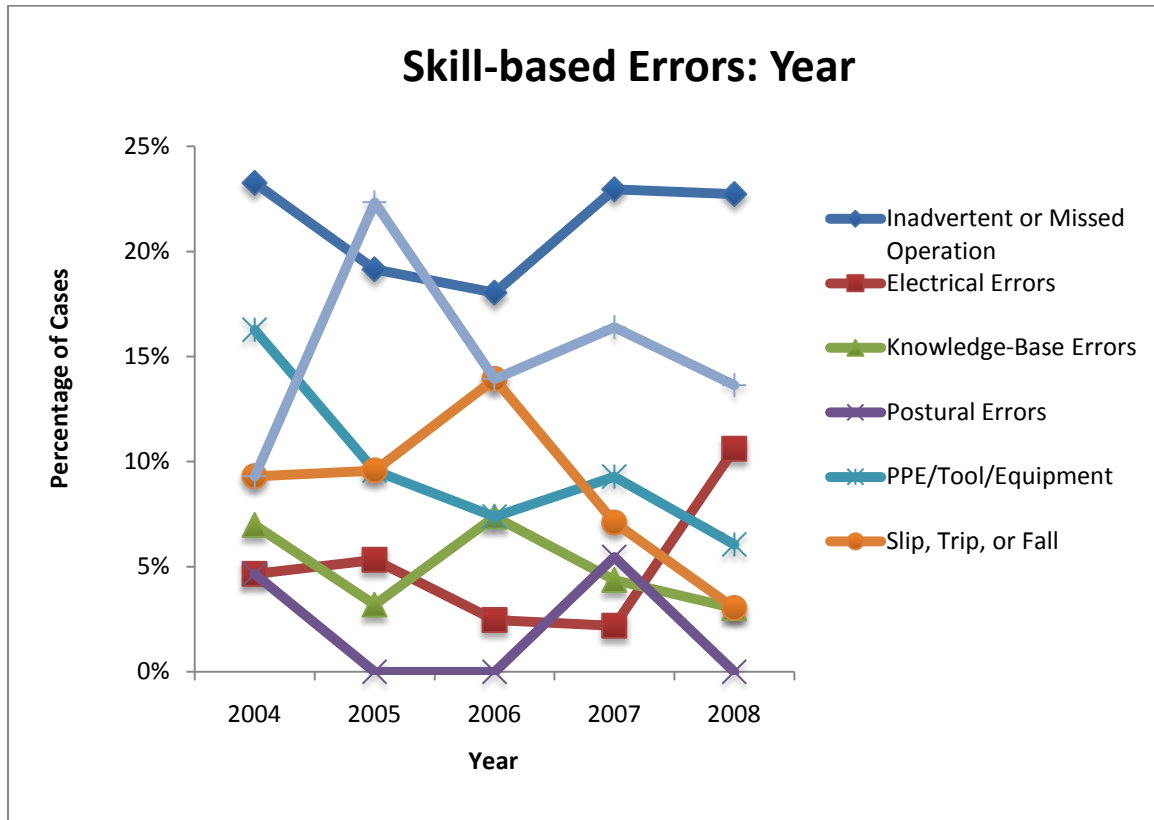


Figure 18: Skill-based error exemplars by year

During the data collection portion of this project, it became evident that age and experience were not readily available for most incidents/accidents. Information on the person(s) involved is only required to be provided to DME when there is a lost time injury. When date of birth is given, it is only for the person who was injured—not necessarily the person attributed with the error. Given this, there was insufficient information to analyze unsafe acts based on age and experience. If this is a factor of

particular interest to DME, notification and investigation requirements to mines needs to be changed to include the collection of age and experience data for all participants in each incidents/accidents.

4.1.2 Preconditions for Unsafe Acts

A precondition for unsafe acts was identified in 81.9% of cases. The most often cited precondition was the physical environment, followed by the technical environment and communication/coordination, respectively (Figure 19). Fitness for duty and adverse physiological states were the least identified factors and do not appear to be significant causal factors.

Given the harsh and continually changing environment that miners work in, it was expected that the physical environment would influence a high percentage of cases. The most often cited physical environment exemplar was “surface/road conditions” which was a causal factor in roughly 19% of the cases. Of note, 25 out of 45 (55.5%) instances of a “slip, trip, or fall” (an exemplar of routine disruptions) also had surface/road conditions as a contributing factor. Water on roadways and surfaces is a result of regular watering done as part of a dust suppression program. As a result, it is almost impossible to remove the slippery surfaces from site. Therefore, this hazard cannot be eliminated while still maintaining a healthy level of dust in the air for operators and people in the surrounding area. Instead, the consequences of this type of error need to be reduced, i.e. decrease severity. Possible ways to decrease the severity include: requiring boots that protect against lateral movement; ensuring all boots are well maintained and free of build-up on the soles; and install handrails in areas that get slippery or muddy.

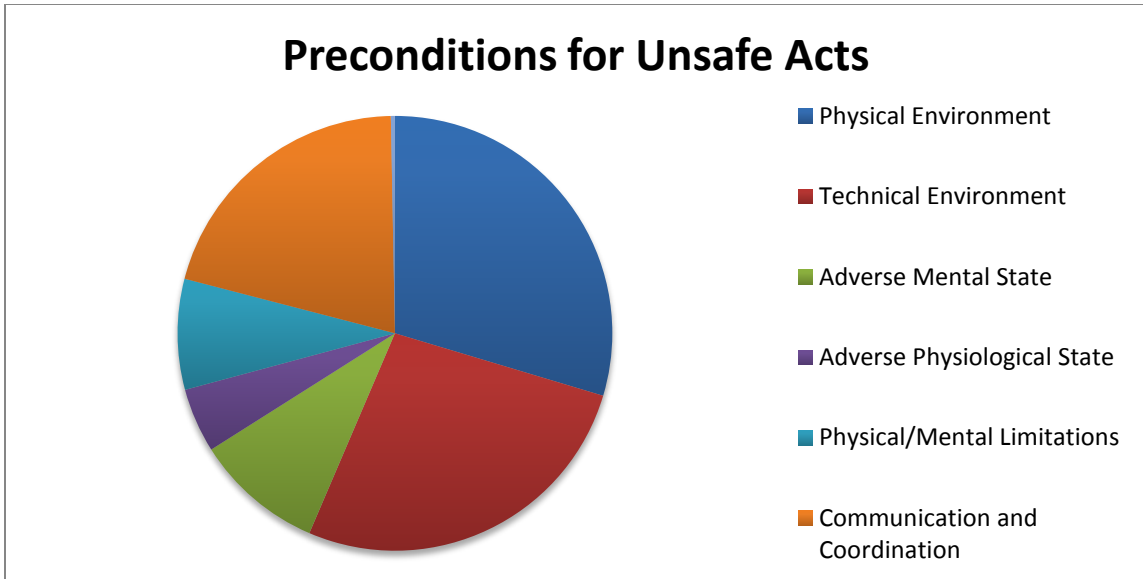


Figure 19: Preconditions for unsafe acts- breakdown of categories

Visibility was also frequently identified as a causal factor, contributing to 11% of cases. Visibility included instances where there was an absence of adequate lighting and when there was glare caused by the sun. A potential way to reduce problems with visibility is to place additional portable lighting in work areas that have low lighting. Problems with sun glare can be reduced by arranging traffic flow in such a way as to reduce driving into the sun or driving where glare is not a problem.

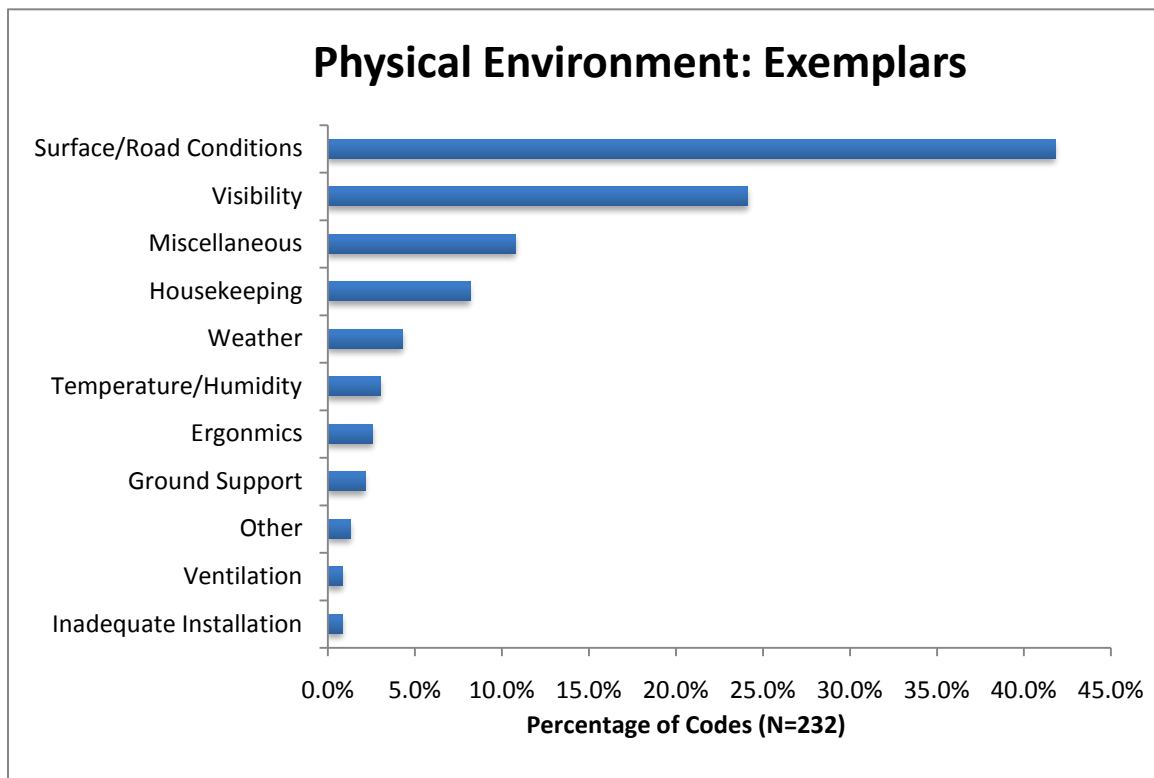


Figure 20: Physical environment exemplars

The technical environment was also highly cited as a contributing factor (Figure 21). The technical environment includes the availability of warnings, PPE, condition of the equipment being used, etc. The most prevalent technical environment exemplar was “equipment design/construction.” This exemplar represented 41.7% of technical environment exemplars. Causal factors identified dealt with both the design of equipment from the original equipment manufacturer and modifications to equipment completed on site. Also included were construction issues on the mine site (excluding the construction and design of roads). Of interest is that 16.2% of codes at this level involved failures with “PPE/guards/safety devices.” Some of these are issues that are government regulated, such as the use of guards, and can be corrected with regular inspections.

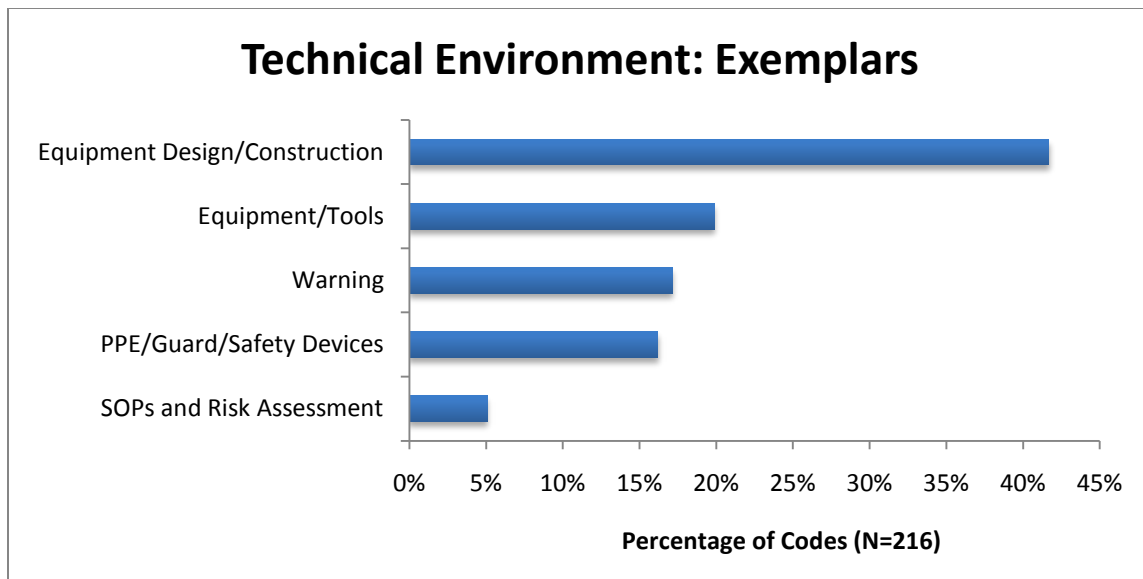


Figure 21: Technical environment exemplars

As can be seen from Figure 19, communication and coordination problems were identified in 21% of cases analyzed. When broken down, 97% of contributing factors for this category involved problems with communication. Communication problems can be described as failure to make positive communication, inadequate communication of work instructions, inadequate communication between workers, etc.

Adverse physiological state was identified as a causal factor in 6.3% of cases analyzed. Included in this HFACS-MI category were operators that fell asleep while working. Given this, it appears that fatigue still remains an issue on mine sites. Most mine sites have fatigue management plans; however, the effectiveness of these plans needs to be reviewed. Workers need to be encouraged to report symptoms of fatigue to supervisors, and scheduling needs to be flexible enough to allow workers to be taken off the schedule during times of extreme fatigue. When fatigue was reported as a contributing factor, it manifested itself as microsleeps, episodes of sleep less than three

seconds in duration resulting from sleep deprivation and sleep deficit. Being in a microsleep during critical operations can result in missed or tardy responses.

4.1.3 Unsafe Leadership

Unsafe leadership was identified in 36.6% of cases analyzed. The majority of causal factors (62.3%) at the unsafe leadership level fell into the “inadequate leadership” category (Figure 22).

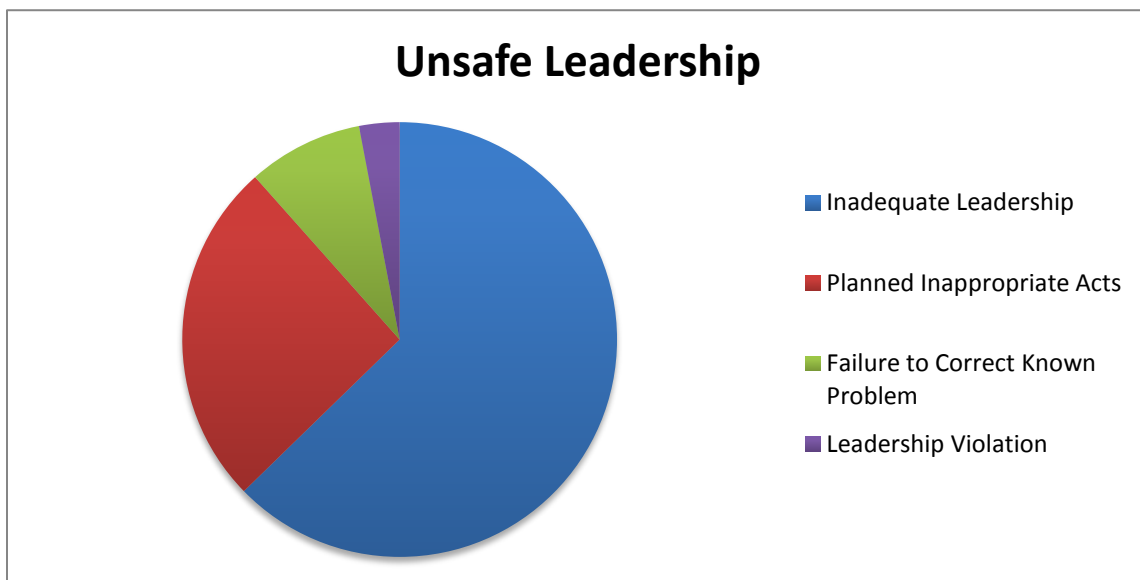


Figure 22: Unsafe leadership- breakdown of categories

The most often cited exemplar at this level was training—accounting for 28.3% of all unsafe leadership codes (Figure 23). Training involves more than just the initial teaching of procedures and policies at a mine site. There is also hands-on training, refresher training, and training when SOPs change, etc. It is not enough to teach an operator once how to perform a task. Retention of material is important, and often a lack of retention will lead to mistakes. An operator must have more than just a casual

understanding of the material. He or she must be competent and able to take what was learned and apply that knowledge in different situations.

As of June 2002, Beach and Cliff (2003) reported that fly-in, fly-out (FIFO) sites in Queensland experienced turnover rates that ranged from 10% to 28%, with an average of 21%. They also found that turnover appeared to be higher amongst professional and managerial staff. This means that more of the experienced workers were job jockeying; one would expect this to affect the training workers' received. Although this study concluded before the analysis of cases in this study began, no major changes in the mining industry in Queensland have occurred that would indicate that this trend has been counteracted.

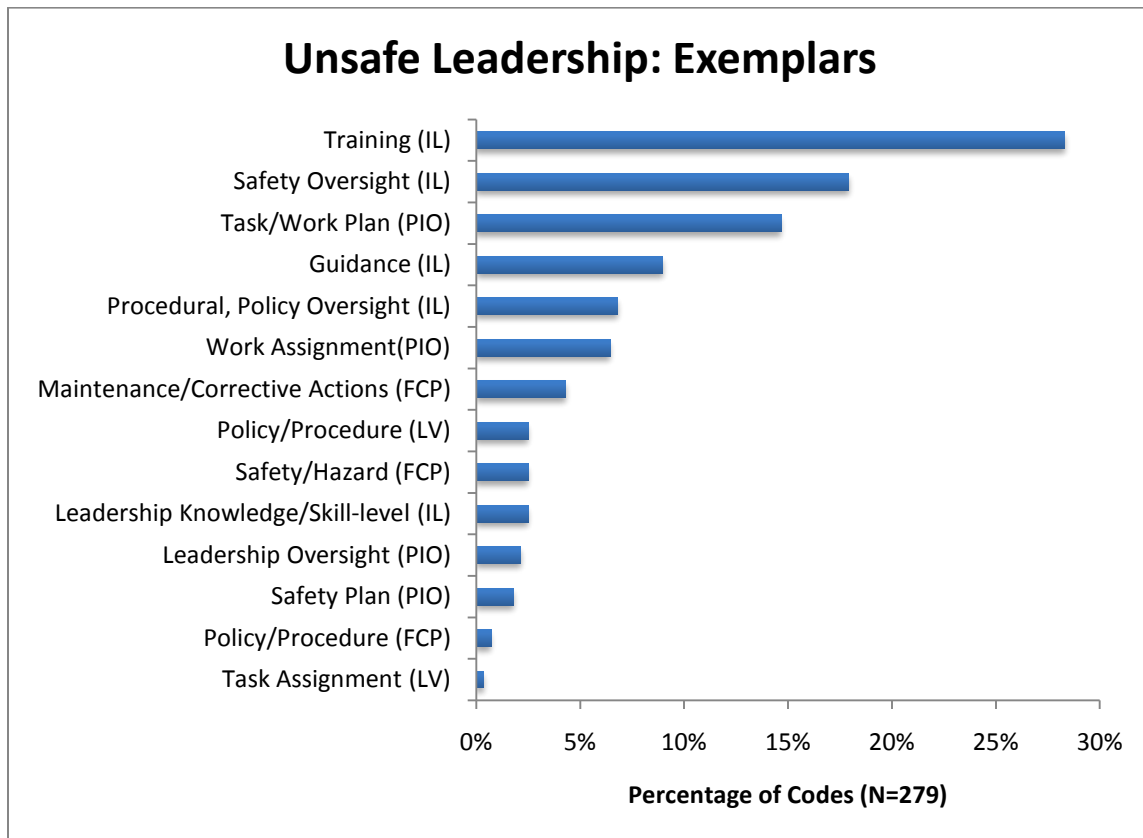


Figure 23: Unsafe leadership exemplars

Safety oversight was another highly cited causal factor. With the large size of some of the mines in this analysis, a lot of operators are working in isolation. With leadership not immediately on hand, workers are unable to quickly ask questions about tasks. Some of these questions could be covered by more comprehensive pre-task briefings between leadership and operators. This would allow a clearer picture on what exactly is to be done. Without consistent monitoring of work, inappropriate behaviors and incorrect procedures cannot be identified and rectified immediately.

4.1.4 Organizational Influences

Causal factors at the organizational tier were associated with fewer incident/accident cases than those at other tiers of HFACS-MI. Only 9.6% of cases identified an organizational influence as a contributing factor. The most common organization factor was organizational process which accounted for 77.8% of organizational codes (Figure 24).

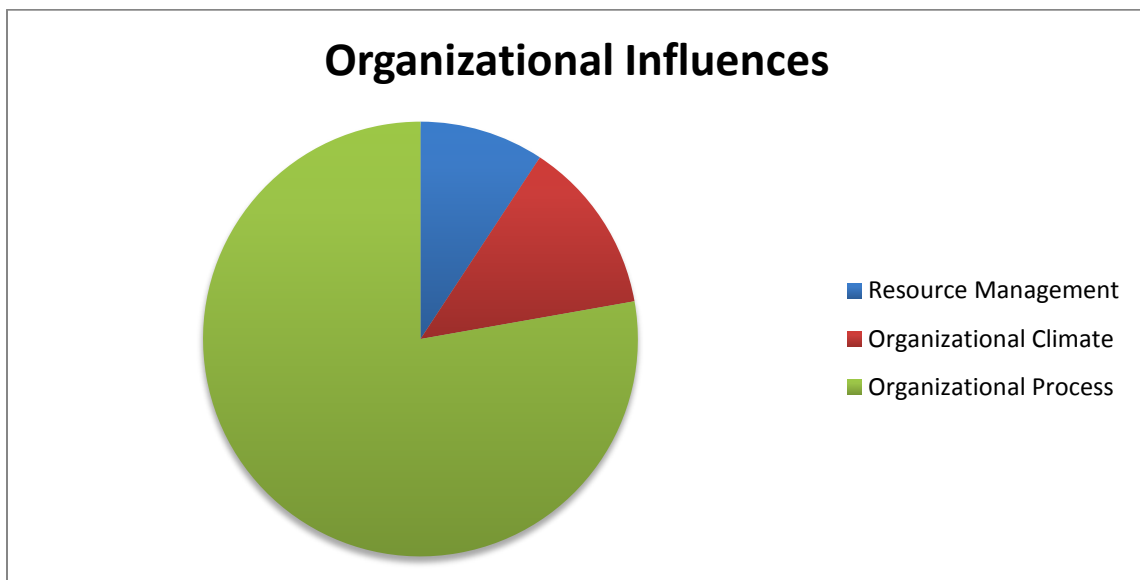


Figure 24: Organizational influences- breakdown of categories

The organizational process category was attributed to 8.3% of cases overall. Within organizational process, problems with “procedures” were most common (77.2% of codes). Problems with procedures mainly dealt with the lack of SOPs or standard work instructions (SWI) for a given task. Without adequate instructions, operators are forced to develop their own method for completing tasks. While these methods may work, they are not always the safest way to perform tasks and could lead to an increase in adverse events.

4.1.5 Outside Factors

As expected, no causal factors were found at this tier. This result reflects the current state of the system in which causal factors attributed to outside of the system are not identified. Gathering information at this level will allow for DME to identify areas of improvement for itself and employees.

4.2 Study Two: Fatal Accidents, USA

Results for fatal accidents in the USA had contributing factors at all five levels of HFACS-MI. Results at the organizational influences and unsafe leadership levels once again centered on a single category. Uppers levels of HFACS-MI are coded as contributing factors in a higher percentage of cases than other analyses have found. Each level can add up to more than 100% as more than one causal factor at a single level can be identified. Table 3 gives the frequency and percentage of cases associated with causal factors at each level. This section will also give a fine grain analysis of each tier of the HFACS-MI framework similar to the analysis for study one.

Table 3: Frequency and percentage of cases- Study Two

HFACS Category	N *(%)
Outside Factors	
Regulatory Factors	2 (0.8)
Other	0 (0.0)
Organizational Influences	
Organizational Climate	2 (0.8)
Organizational Process	72 (28.3)
Resource Management	16 (6.3)
Unsafe Leadership	
Inadequate Leadership	112 (44.1)
Planned Inappropriate Operations	33 (13.0)
Failed to Correct Known Problems	54 (21.3)
Leadership Violations	13 (5.1)
Preconditions for Unsafe Acts	
Environmental Conditions	
Technical Environment	85 (33.5)
Physical Environment	91 (35.8)
Conditions of the Operator	
Adverse Mental State	3 (1.2)
Adverse Physiological State	1 (0.4)
Physical/Mental Limitations	12 (4.7)
Personnel Factors	
Coordination and Communication	22 (8.7)
Fitness for Duty	5 (2.0)
Unsafe Acts of the Operator	
Skill-based errors	111 (43.7)
Decision Errors	107 (42.1)
Perceptual Errors	1 (0.4)
Violations	16 (6.3)

* N = 254

4.2.1 Unsafe Acts of the Operator

For fatal mining accidents in the USA, at least one unsafe act was identified in 79.1% of cases. This percentage is lower than the percentages found in previous HFACS analyses. This reduced percentage of cases associated with unsafe acts may suggest that

fatalities are not always a result of human error by the operator but result from failures within the system.

The most often identified unsafe act was skill-based errors, very closely followed by decision errors. Perceptual errors and violations were associated with very few fatal accidents. The low percentage of violations associated with fatal accidents is contrary to previous findings that violations are three times more likely to lead to fatal accidents than skill-based errors (Boquet et al., 2004). Boquet, et al. (2004) also found that skill-based errors were the least likely error form to be associated with fatal accidents which is contrary to the findings from this study. These conflicting results may stem from the operational differences between aviation and mining. However, with other accident types, aviation and mining exhibited similar trends in unsafe acts.

When identifying the percentage of cases associated with a particular error form, each error form is counted as either absent or present. When all exemplars at the unsafe acts level are analyzed regardless of the presence or absence variable, decision errors become the most often identified unsafe act, followed by skill-based errors. This means that while more accidents are associated with skill-based errors, more decision errors are occurring during fatal accidents. From Figure 25, it can be seen that mining fatalities rarely occur as a result of perceptual errors. Given that the percentage of cases associated with violations and the percentage of codes associated with violations, it seems that single violations—not a series of violations—are causing fatal accidents.

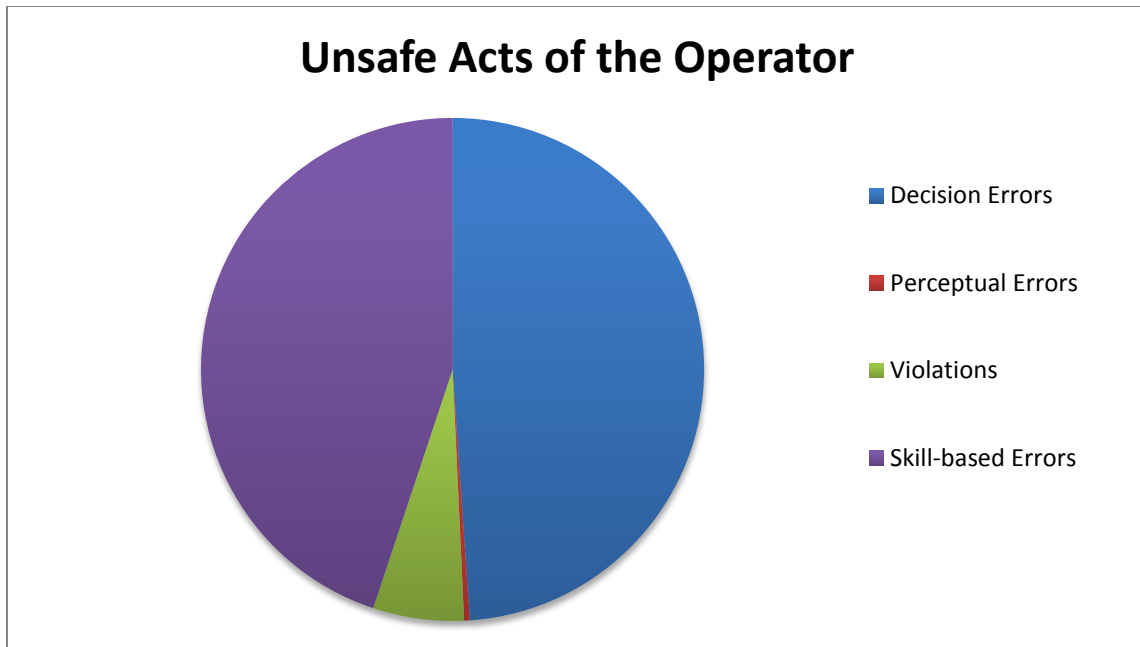


Figure 25: Unsafe acts of the operator: fatal accidents

Once again, similar exemplars were grouped together in order to get a more accurate representation of the data. When exemplars were combined in this fashion, the top exemplars associated with fatal accidents were decision errors. A complete listing of the percentage of exemplars associated with fatal accidents can be found in Figure 26. Procedural errors refer to the operator’s following and usage of SOPs for completing tasks. Operators need to have knowledge of the procedure in order to apply the procedure correctly. PPE/Equipment/Tools generally dealt with the incorrect use or use of defective equipment, tools, or PPE. A technique error refers to the way in which in operator completes a task. The way in which an operator carries out a task can lend itself to an increased risk of errors. Electrical errors generally resulted from operators working on live electrical equipment. Working on live equipment means that the operator failed to lock out and tag out the equipment before commencing work. It is surprising that so

many electrical errors occur as lock out/tag out is a federally mandated safety requirement. Decision errors arise when operators are unaware of how to lock out/tag out equipment, unaware they need to lock out/tag out, or incorrectly locked out/tagged out equipment.

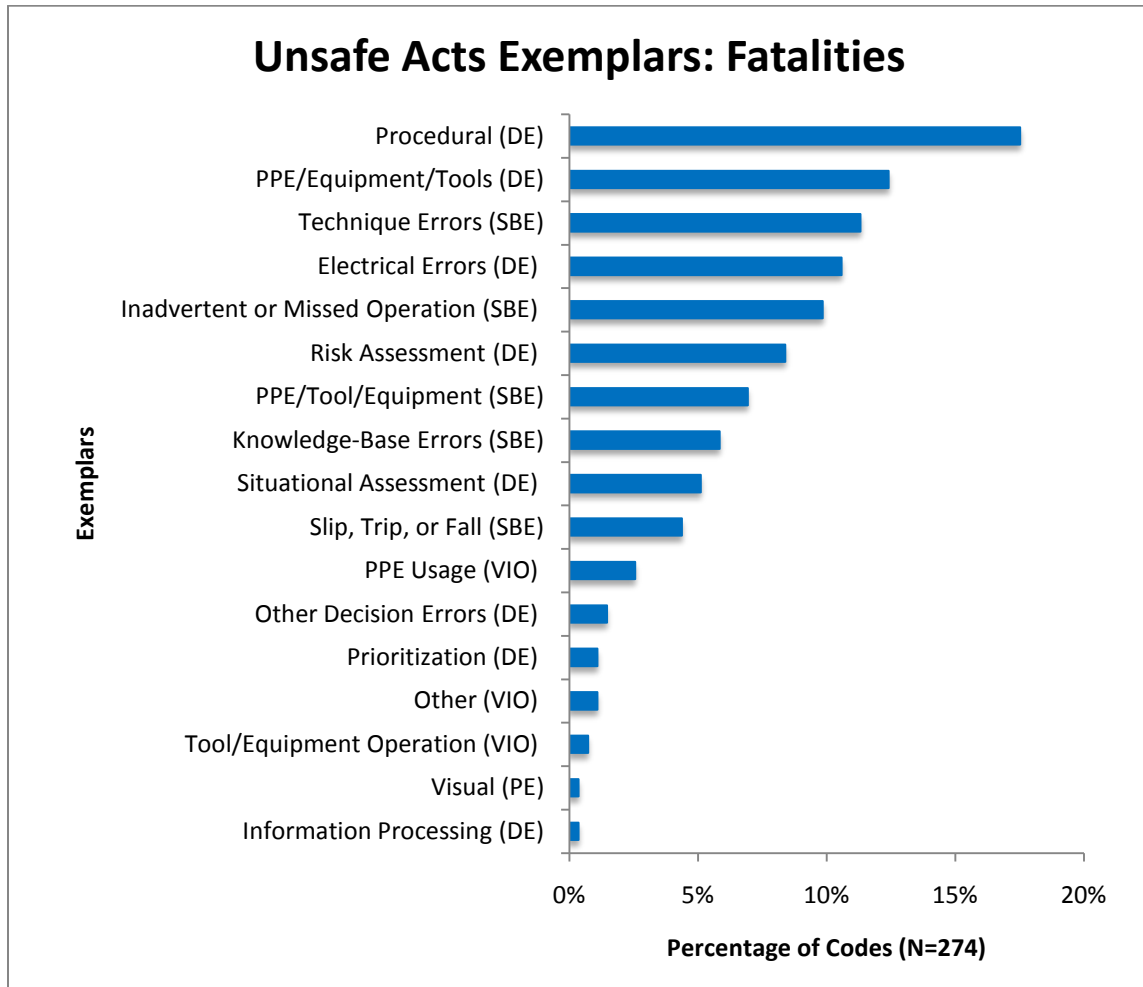


Figure 26: Unsafe act exemplars

When looking at just skill-based errors, technique errors and inadvertent or missed operation account for nearly 50% of all skill-based error exemplars (see Figure 27). Surprisingly, 10% of fatal accident cases and 5% of the total number of unsafe acts exemplars were associated with a slip, trip, or fall. While these fatal accidents included

the more typical types of industrial fatalities, such as falling from ladders, other errors included falling into machinery and tripping on the mine floor causing traumatic injuries. Electrical errors mainly dealt with the isolation of the incorrect equipment or the incorrect isolation of equipment, i.e. forgetting to lock out machinery before working.

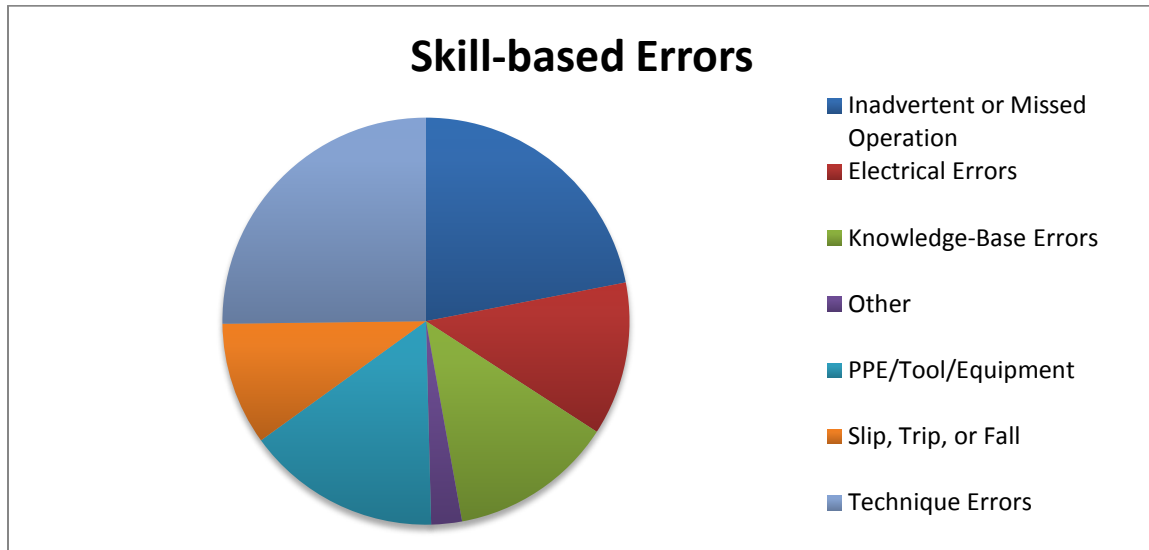


Figure 27: Skill-based errors- breakdown of exemplars

Decision errors are associated with 42% of all fatal accident cases analyzed and represent almost 49% of all unsafe act exemplars. As seen in Figure 28, procedural errors are the most often cited decision error. The incorrect use of PPE, tools, and equipment was also frequently cited. When risk assessment was cited as a causal factor, it usually meant that operators were unable to identify potentially hazardous environments, and in turn, safeguard against hazards. Information processing and prioritization errors were cited rarely.

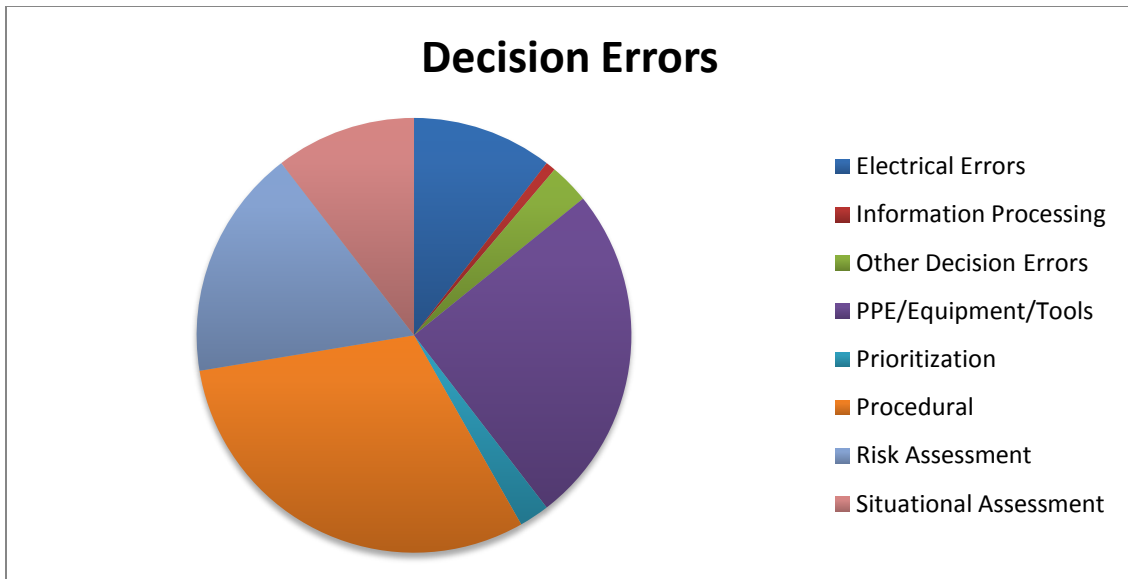


Figure 28: Decision errors- breakdown of exemplars

Violations only contributed to 6.3% of all fatal accident cases. When violations are looked at more closely, procedural violations and PPE usage accounted for almost 44% each of all the violations identified. “Procedural” violations refer to the intentional disregard of established SOPs and regulations. The difference between a procedural decision error and a violation is that with the violation, the operator knowingly went against established procedures; they were aware of how the procedure was to be carried out and consciously decided against it. PPE usage refers to fatal accidents that result from an operator failing to wear the correct PPE, such as helmets, gloves, and harnesses.

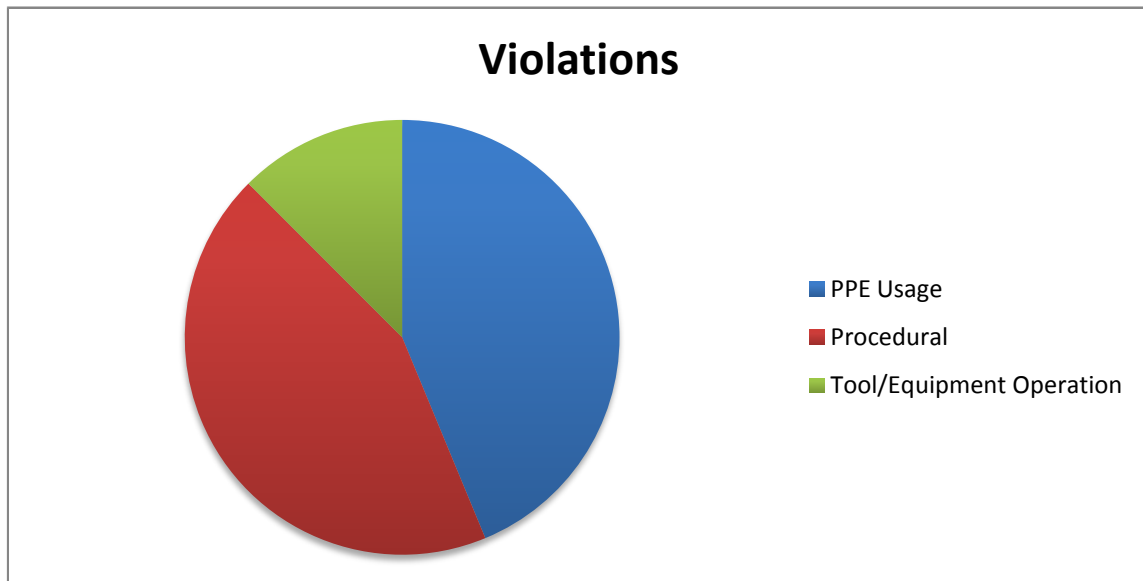


Figure 29: Violations- breakdown of exemplars

Only a single perceptual error was identified in the analysis of fatal accidents. As a result, perceptual errors were removed from further analysis.

There are five different locations analyzed in this study: underground metal/non-metal mines, underground coal mines, open cut metal/non-metal mines, open cut coal mines, and preparation plants. Figure 30 shows a breakdown of unsafe act causal codes by mine types.

Skill-based errors were fairly stable across mine types but were attributed to fewer fatal accidents at preparation plants. This reduction in the percentage of cases attributed to skill-based errors was significantly different than the other locations ($\chi^2 = 10.06$, $p < 0.05$). Tasks performed at preparation plants are different than those performed at mine sites. Preparation plants are highly automated facilities that prepare coal and metals/non-metals for delivery to refineries. Work at preparation plants involves monitoring and maintaining equipment.

Decision errors exhibited similar results across mine types as there were no significant differences between mine types ($\chi^2 = 8.16$, ns). At preparation plants, decision errors are twice as likely to occur as skill-based errors. This large difference between skill-based and decision errors suggests that workers at preparation plants are not often involved in automated tasks, and those workers are not able to handle situations that are out of the ordinary. At open cut metal/non-metal mines, decision and skill-based errors were identified in the same number of fatal accidents.

Violations exhibited a significant difference across mine types ($\chi^2 = 10.99$, $p < 0.05$). At underground metal/non-metal mines, no fatal accidents were attributed to a violation. A possible explanation for no fatal accidents being attributed to violations is that only 24 fatal accidents occurred at underground metal/non-metal mines during this analysis. This low number of cases might explain the differences. The other mine types that had a low number of cases exhibited a higher percentage of cases with a violation as a causal factor. With mine types that have a larger sample size, the percentage of cases associated with violations become more stable at around 6-7%.

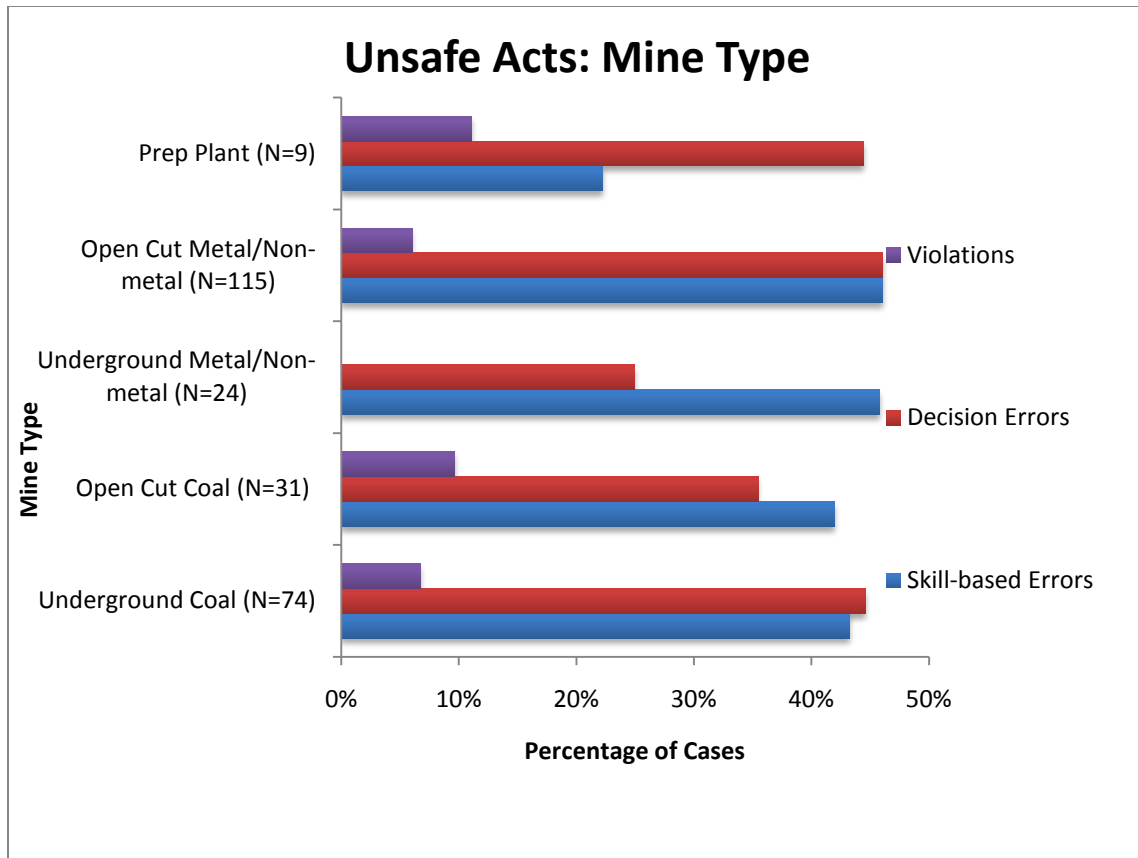


Figure 30: Unsafe acts of the operator by mine type

Mining material was broken down into two basic types, coal and metal/non-metal. Metal/non-metal mining material includes, gravel, sand, gold, zinc, copper, etc. When skill-based errors are examined based on mining material, there is no significant difference between coal mines and metal/non-metal mines ($\chi^2 = .16$, ns). This means that while there is a difference between the environments, hazards, and tasks at coal mines and metal/non-metal mines, these differences do not cause a difference in skill-based errors.

Decision errors were also stable across mine material, and there was no significant difference ($\chi^2 = .16$, ns). This means that operators at coal mines are just as

susceptible to errors based on a lack of knowledge or training as operators at metal/non-metal mines. Given that both mining materials have decision errors associated with over 40% of accidents/incidents, both coal and metal/non-metal mines need to make improvements in knowledge transfer and retention.

Violations were identified as contributing factors in 8% of fatal accidents at coal mines, whereas metal/non-metal mines identified violations in only 5% of fatal accident cases. This difference was not found to be statistically significant ($\chi^2 = .69$, ns). Although the difference is not significant, having 5-8% of cases associated with violations still points to problems with the disregard of rules, procedures, and regulations. In order to correct violations, managers and supervisors need to enforce rules and ensure operators follow SOPs.

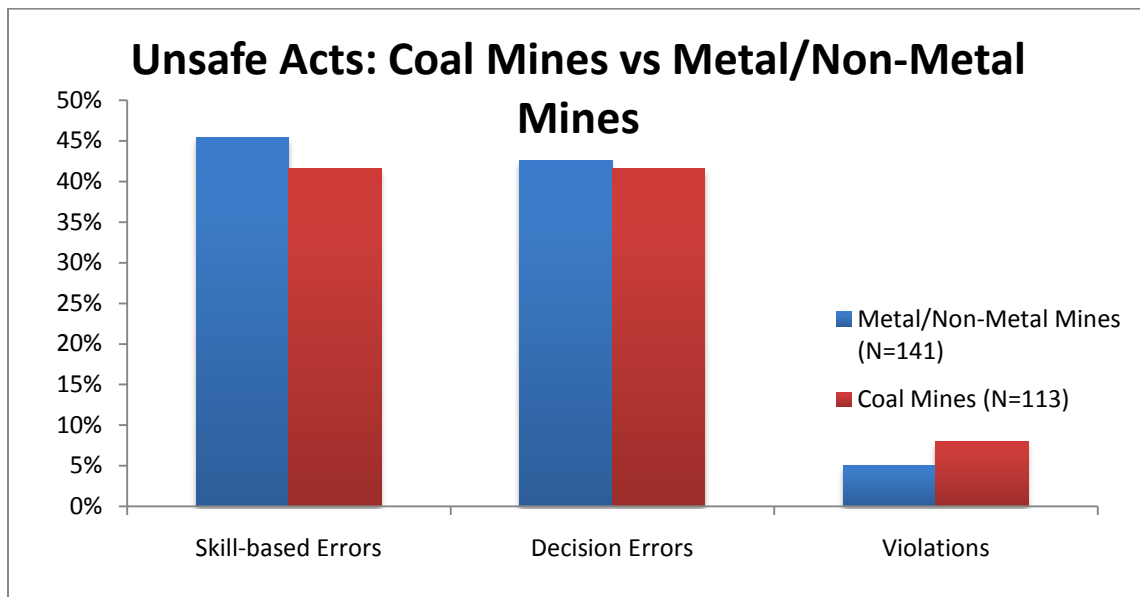


Figure 31: Unsafe acts of the operator by mining material

Time of day was broken down into six four-hour time blocks. These time blocks correspond to the start, middle, and end of a typical 12-hour shift. Skill-based errors, decision errors, and violations were each broken down by time of day.

Skill-based errors showed no significant difference across times ($\chi^2 = 6.51$, ns). Regardless of significance, skill-based errors were found to contribute to the highest percentage of cases from 2200 to 0200. This time period also represents the beginning of the circadian trough. Alertness levels are lowest and fatigue levels are highest during the circadian trough which can lead to a decrease in attention, potentially causing an increase in skill-based errors.

Unlike skill-based errors, decision errors were significantly different across time of day ($\chi^2 = 36.2$, $p < 0.5$). Decision errors were identified in the lowest percentage of cases from 0200 to 0600 with only 11% of cases associated. This time period represents the end of a typical night shift. It appears that during this time period, workers are not encountering tasks for which they do not have SOPs, or they are able to determine the correct course of action. Alternatively, decision errors were associated with the highest percentage of cases from 1800 to 2200.

Violations also exhibited a significant difference across mine types ($\chi^2 = 27.8$, $p < 0.5$). Violations were associated with the highest percentage of cases from 2200 to 0200. One possible reason for this increase (18.8% of cases associated) in violations may be that fewer operators are scheduled to work during this time period. As a result, operators may more often be working in isolation or with fewer supervisors available. Without a

member of leadership present to enforce rules and regulations, it may be tempting for operators to take shortcuts.

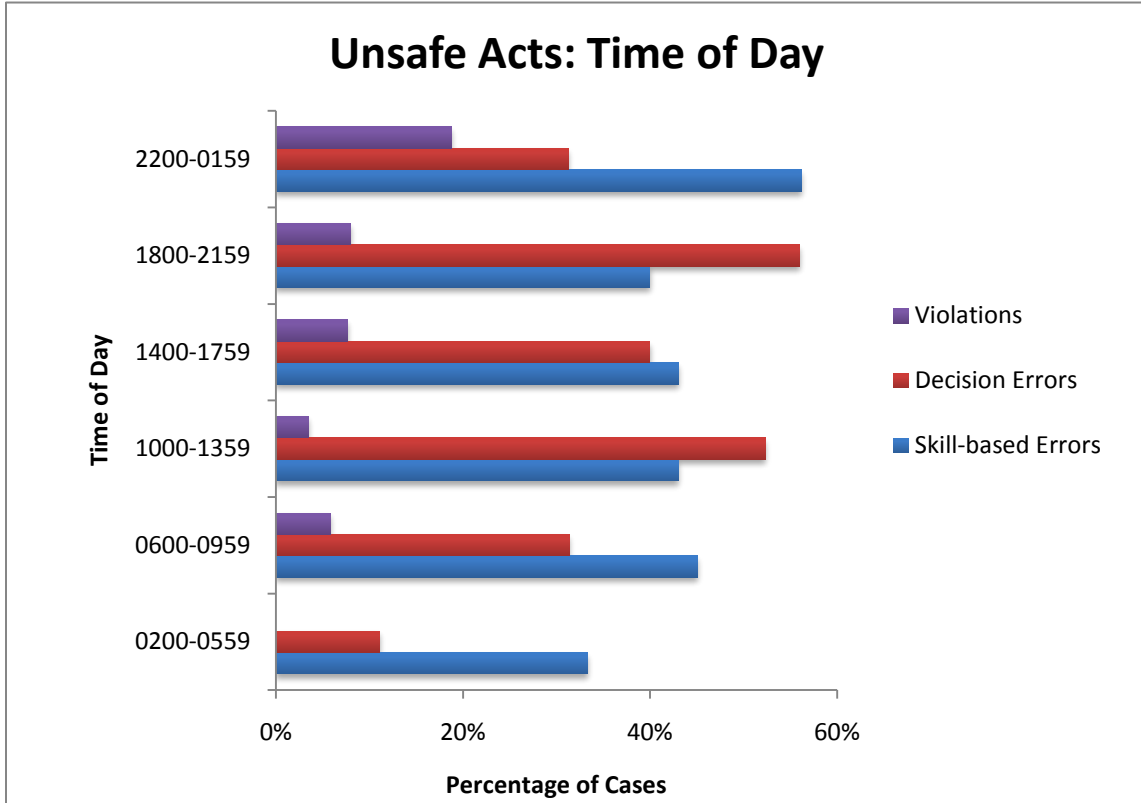


Figure 32: Unsafe acts of the operator by time of day

To determine what affect, if any, that introduced interventions had on human factors issues, unsafe acts were analyzed annually. Like results from previous temporal trends, skill-based errors and decision errors showed no significant differences across years ($\chi^2 = 1.4$, ns and $\chi^2 = 1.8$, ns, respectively). These results suggest that regulatory changes and organizational interventions introduced before or during the time of this study had no affect on routine disruption or decision errors.

Unlike errors, violations showed a significant difference across the time period of this study ($\chi^2 = 24.4$, $p < .05$). During 2004, violations were identified in a markedly

higher percentage of cases than during any other year. In order to determine if there really was a decrease from 2004 to 2005 or if 2004 was just an abnormality, data prior to 2004 needs to be analyzed. If violations associated with fatal accidents have indeed declined, then the interventions introduced that resulted in the identified decline need to be continually enforced and improved to see continuous improvement.

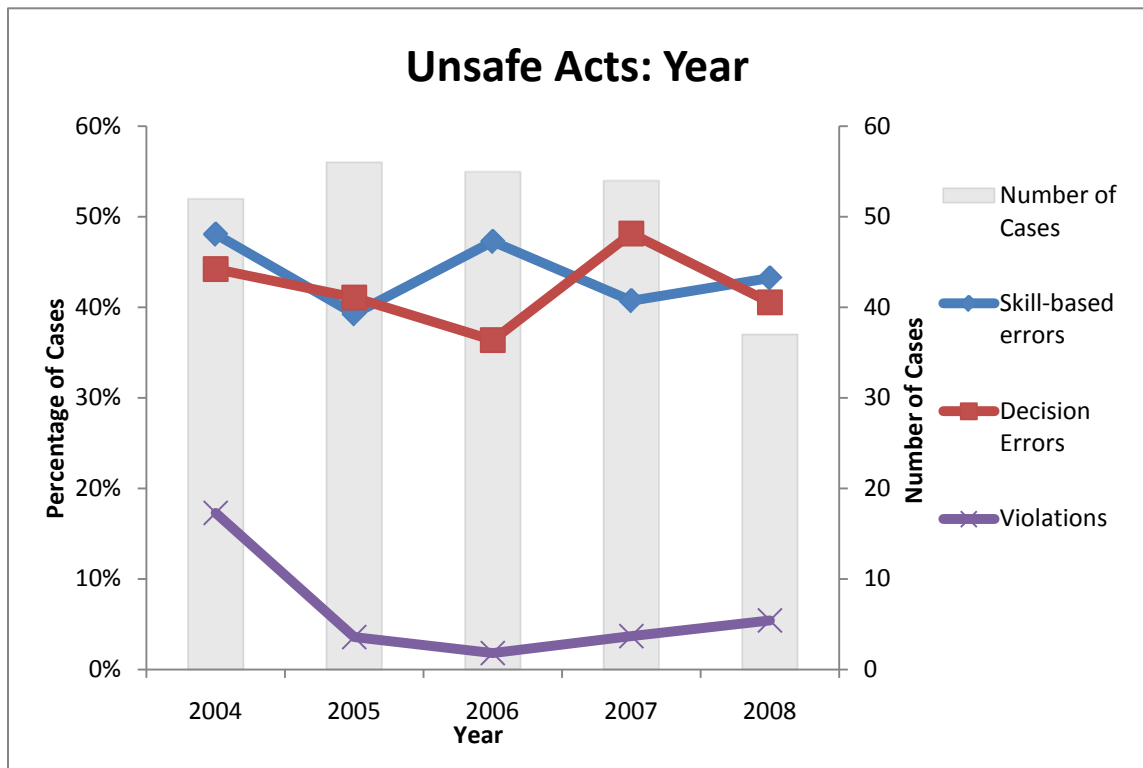


Figure 33: Unsafe acts of the operator by year

4.2.2 Preconditions for Unsafe Acts

Preconditions for unsafe acts were identified in 66.1% of cases analyzed. The most often identified precondition was the technical environment, followed by physical environment, and communication/coordination (Figure 34). Adverse physiological state and adverse mental states were the least identified contributing factors.

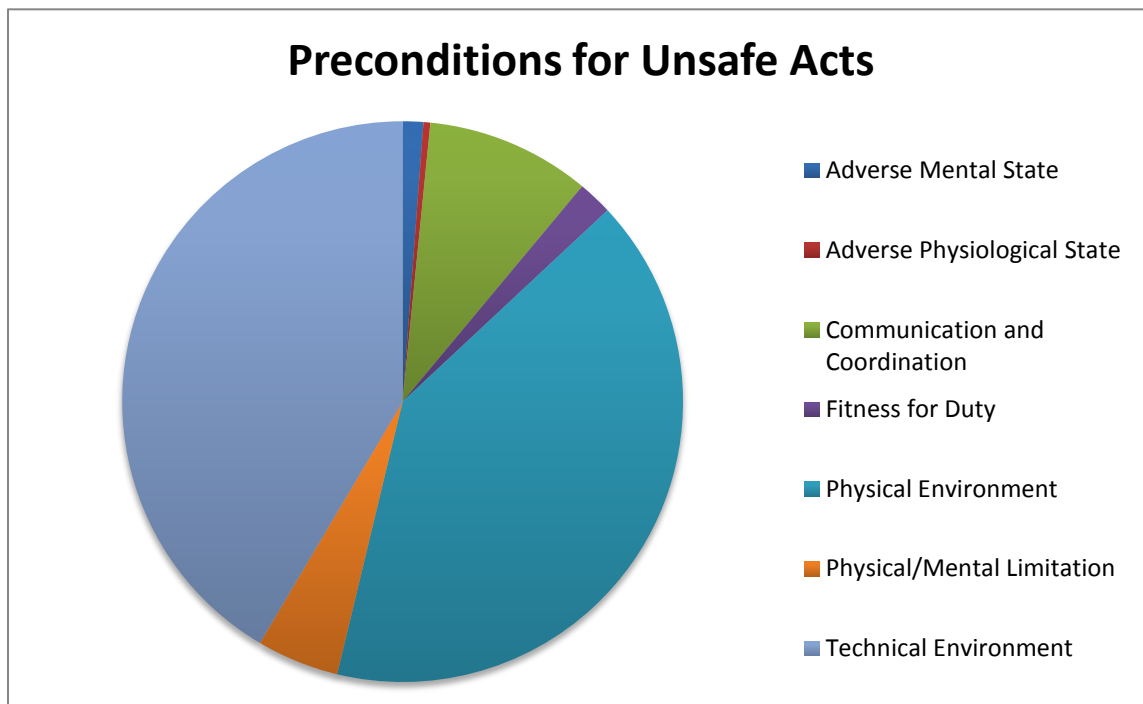


Figure 34: Preconditions for unsafe acts- breakdown of categories

The physical environment was identified as a contributing factor in 40.7% of cases analyzed. This is not surprising given the harsh conditions, particularly underground, in which miners work. Ground support—a very important issue for underground mines—was the most often identified physical environment exemplar. In order to protect workers from cave-ins and shifts of ground, ground support must be installed in all areas where conditions “indicate that it is necessary” (30 CFR 57.3360). The lack of or inadequate installation of ground support leads to workers being put at an increased risk due to additional hazards. Given the critical importance of ground support, it is vital that workers are trained to identify hazardous ground support, and improved monitoring techniques need to be employed.

Problems with surface and road conditions were also a highly identified physical environment exemplars. Slippery road conditions along with inadequately designed roads

were the most often identified surface/road condition problems. Along with ground support, these exemplars accounted for over 50% of all physical environment contributing factors identified.

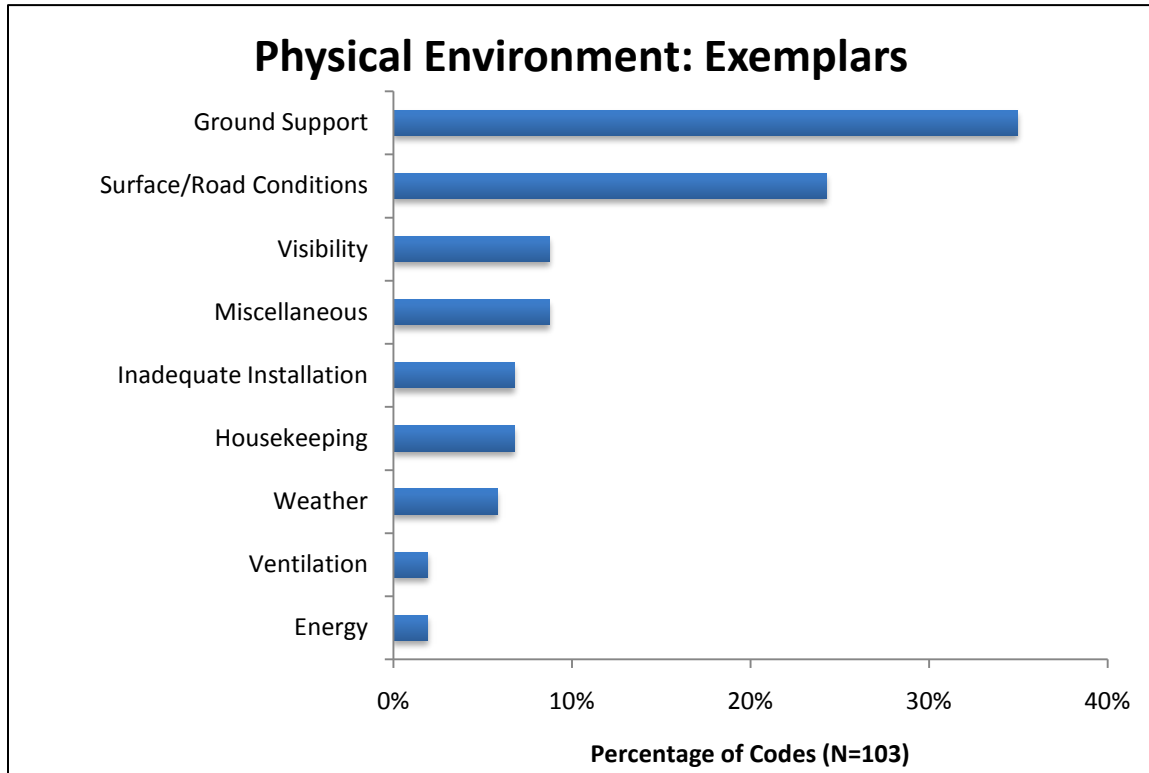


Figure 35: Physical environment exemplars

Half of the technical environment exemplars identified dealt with equipment and tools. Most problems arose as a result of defective or poorly maintained tools and equipment. The responsibility for ensuring that adequate equipment is available and used belongs to both the workers and management. It is the workers' responsibility to inspect equipment before use and tag equipment "out of service" if necessary. It is the responsibility of management to ensure that routine maintenance is scheduled and carried out, proper equipment is ordered and available to workers, and that defective equipment

is removed from service. Failure on anyone's part could result in problems with tools and equipment.

Also highly cited as a contributing factor within the technical environment were PPE/guards/safety devices. The technical environment not only monitors the suitability of PPE, but also the availability and appropriateness. In order to best protect workers, PPE needs to be provided that meets the standards for protecting against all known hazards. For example, requiring workers to wear boots might not be enough when there is the potential hazard of tools and other material falling onto their feet. It is more appropriate in this instance for boots with steel caps to be required.

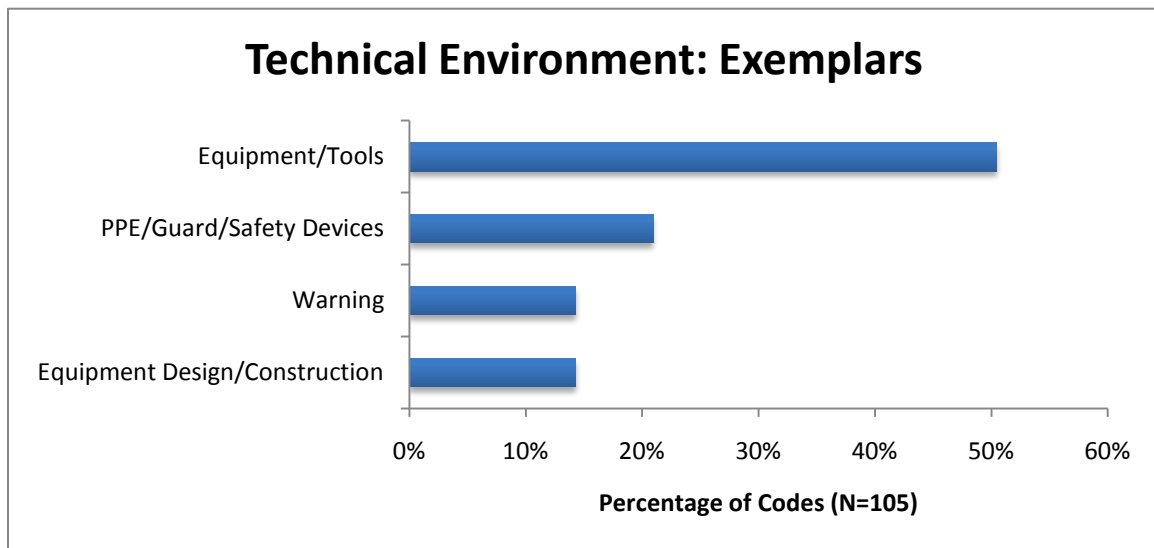


Figure 36: Technical environment exemplars

4.2.3 Unsafe Leadership

Unsafe leadership was identified in 63.8% of fatal accidents analyzed. The majority of causal factors at this level fell into the inadequate leadership category (Figure 37). Failure to correct a known problem was also a highly cited causal factor at this level.

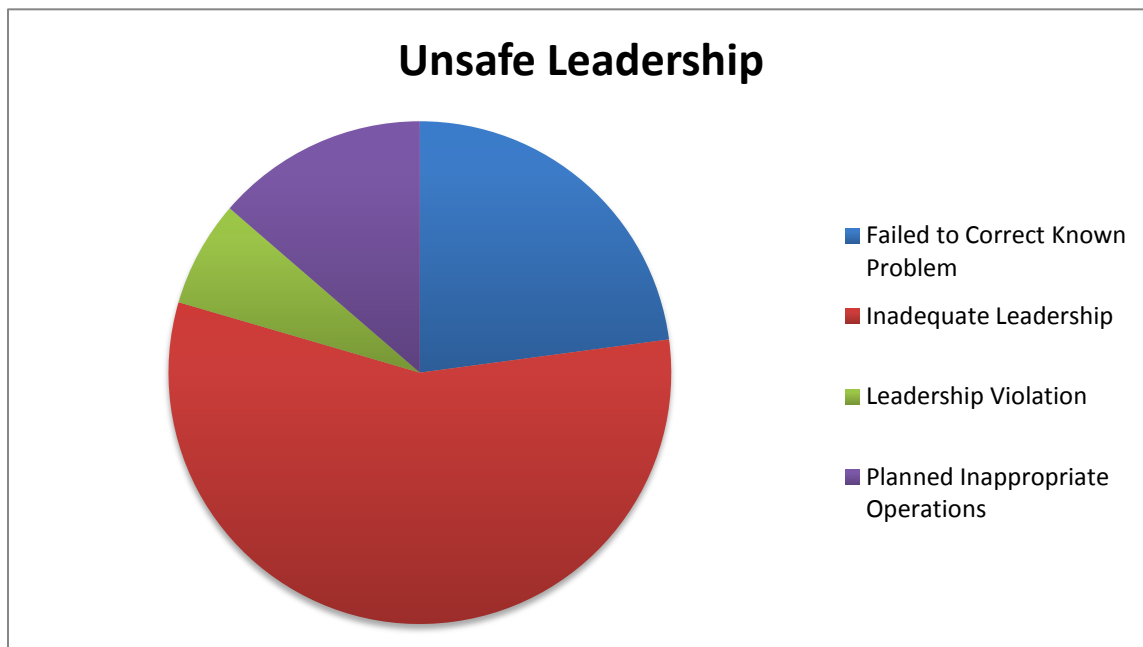


Figure 37: Unsafe Leadership- breakdown of categories

When unsafe leadership was examined more closely, safety oversight (an exemplar of the inadequate leadership category) was found to be the most often identified exemplar at this level, accounting for about one quarter of all unsafe leadership codes identified. Safety oversight encompassed issues relating to safety walk-throughs, leadership’s creation of risk assessments, and leadership’s enforcement of safety. The biggest problems with safety oversight resulted from operators working in isolation, meaning that there was minimal monitoring of operator work practices, ultimately leading to unsafe or inappropriate work practices not being identified or corrected.

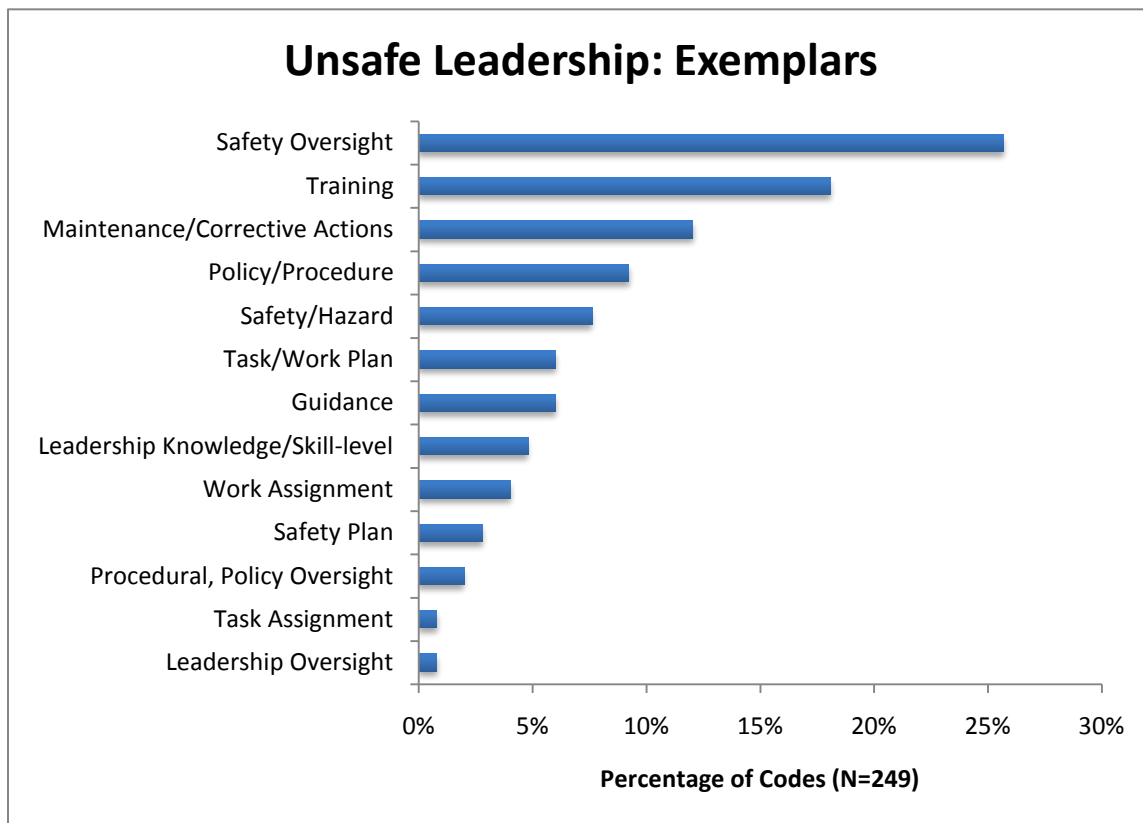


Figure 38: Unsafe leadership exemplars

Training was also a highly cited unsafe leadership exemplar in the inadequate leadership category. Issues with training were primarily focused on the initial training of workers. This inadequate training can lead to a lack of the knowledge base required to successfully and safely work on a mine site. Without sufficient knowledge of SOPs, rules, and regulations, workers can be at an increased risk for committing errors.

4.2.4 Organizational Influences

Causal factors at the organizational level were less often identified than factors at lower levels. Organizational influences were identified as a contributing factor in 33.5% of fatal accident cases analyzed. As can be seen in Figure 39, organizational process accounted for the majority of codes identified at this level. This category was identified

in 28.3% of cases analyzed. Within this category, 86.5% of codes were under the exemplar “procedures.” This exemplar dealt with the establishment, updating, and implementation of SOPs. Without adequate and up-to-date procedures, work processes are left up to the discretion of the operator. This is particularly harmful when inexperienced operators are forced to develop their own plans. These undocumented plans may not be the safest way to perform the task. This in turn can cause an increase in the likelihood of mistakes and result in adverse events.

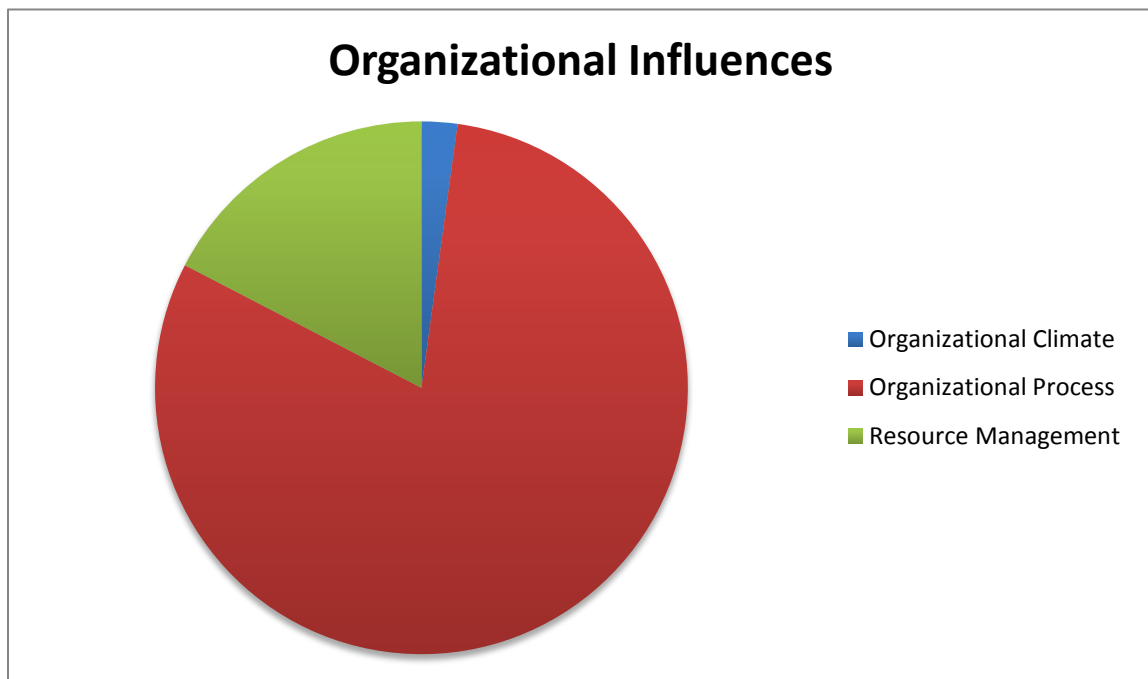


Figure 39: Organizational influences- breakdown of categories

4.2.5 Outside Factors

Once again, outside factors were rarely identified; only two instances of outside factors were identified in the 253 fatal accidents analyzed. Both instances of outside factors were identified as regulatory factors. In one instance, at Sago mine in West Virginia, the MSHA had issued 208 citations in the based year; 96 of these violations

were considered significant and substantial. While MSHA ordered operations ceased in the affected area, a mine with such a large number of violations combined with an accident rate substantially higher than the national average (17.04 and 5.66 respectively) should have signaled to MSHA inspectors that serious problems existed at the mine and required more attention.

CHAPTER 5: COMPARISON OF FATAL VS. NON-FATAL

When discussing the differences identified between fatal accidents in the USA and non-fatal accidents in Queensland, Australia, there are a few caveats that must be presented. The most important point to note is that data was collect from two different sources. While both sets of data were collected from government sources, the writers and investigators for the cases differ. Reports analyzed from the USA were written and investigated by MSHA employees. Reports analyzed from Australia were written and investigated by mine safety personnel. In both cases, biases can occur. When mine personnel investigate an incident, they may be reluctant to place blame on the organization and therefore find fewer contributing factors at higher levels of HFACS-MI. When outside personnel lead the investigation, they tended to be more focused on organizational issues and stayed away from blaming the operator.

Another issue with comparing fatal and non-fatal accidents is the depth of investigation that took place. As a result of the severity and cost associated with fatal accidents, they tend to be more fully investigated. With more thorough investigations, more causal factors tend to be identified and therefore more HFACS-MI categories can be coded.

5.1 Unsafe Acts of the Operator

The unsafe act of the operator is the action that occurs immediately prior to an adverse event. By comparing the results from study one and study two, differences in the actions of the front line operator that cause a fatal accident versus a non-fatal accident can be identified (Figure 40). An unsafe act was identified in far fewer fatal accidents

then non-fatal accidents (79.1% and 94.7% respectively) though this difference was not significant ($\chi^2 = 1.4$, ns). This difference suggests that fatal accidents are not always the result of an incorrect action on the part of the operator. It also implies that nearly one in five fatal accidents are the result of a culmination of events and the fatal operator was merely in the wrong place at the wrong time.

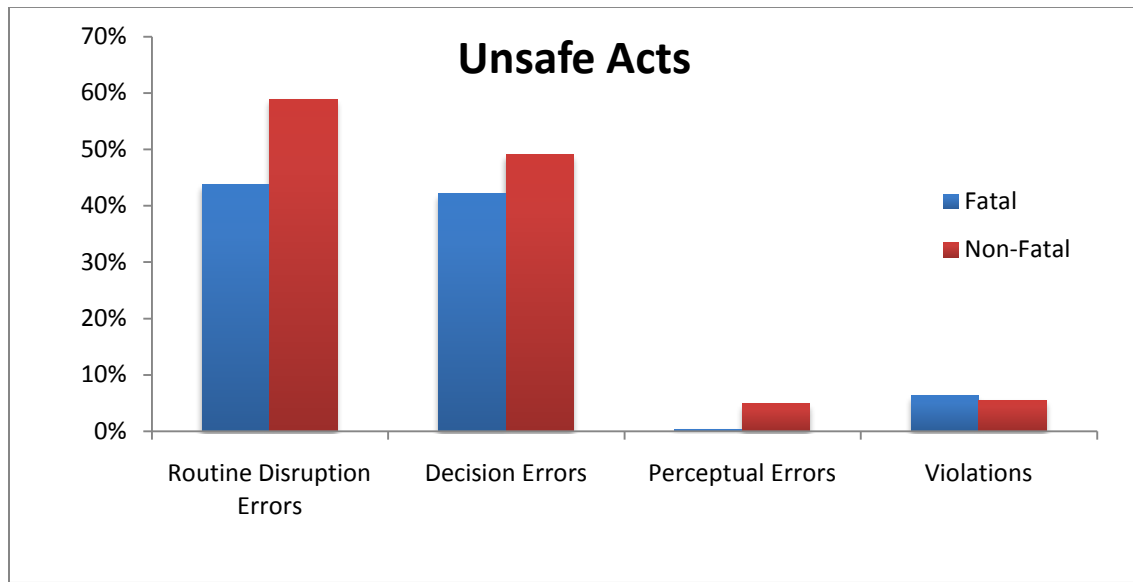


Figure 40: Percentage of cases for fatal and non-fatal accidents

For both fatal and non-fatal accidents, the most often identified causal category at the unsafe acts level was skill-based errors. Although fatal accidents had fewer cases associated with unsafe acts, the percentage of cases associated with skill-based errors is not significantly different than that of non-fatal accidents ($\chi^2 = 2.25$, ns). Within skill-based errors, the top two exemplars—missed/inadvertent operations and technique errors—were the same for both fatal and non-fatal accidents.

Where differences did exist within skill-based errors, they were with less frequently identified exemplars such as electrical errors and knowledge-base errors. Both

of these exemplars accounted for almost twice as many skill-based error codes for fatal over non-fatal accidents. This is not surprising as electrical errors create an increased potential for severe accidents including electrocution.

The percentage of cases associated with decision errors was also not significantly different for fatal and non-fatal accidents ($\chi^2 = 0.52$, ns). The most often identified decision error exemplar for both fatal and non-fatal accidents was procedural errors. For fatal accidents, PPE/equipment/tools was the second most frequently identified exemplar accounting for one-quarter of all decision errors. For non-fatal accidents, this exemplar only accounted for only 17% of codes. This exemplar includes the use of adequate and appropriate PPE. PPE is used as the last means of defense in controlling for hazards. Without the proper use of required PPE, the last defense available to operators is missing. With non-fatal accidents, situational assessment was the second most identified exemplar (22%). This means that operators involved in non-fatal accidents were unable to identify where a hazardous condition existed. With fatal accidents, this exemplar accounts for only 10% of decision error codes. This implies that the inability to identify hazardous conditions is twice as likely to cause an injury as a fatality.

Violations did not show a significant difference in the associated percentage of cases between fatal and non-fatal accidents ($\chi^2 = 0.05$, ns). For both fatal and non-fatal accidents, procedural violations were the most often identified exemplar. This exemplar refers to operators knowingly disregarding the standard operating procedure for a task. It implies that the operators know the correct way to execute the given task but took a shortcut instead. With fatal accidents, PPE usage was identified in the same percentage of

accidents as procedural violations. Similar to the results from decision errors, the lack or inadequate use of PPE increased the likelihood of fatalities. This suggests that the use of PPE as a control against hazards is vital to worker safety.

As fatal accidents have fewer cases associated with an unsafe act but maintain a similar percentage of cases associated with a specific error form, it may suggest that fatal accidents tend to have multiple unsafe acts as causal factors whereas non-fatal accidents more often result from a single unsafe act. This implies that while operators may be able to recover from a single unsafe act with injury or property damage, multiple unsafe acts are more difficult to recover from and lead to severe injuries, sometimes causing death. In order to reduce fatalities, operators need to be able to correctly recover from the first error in order to not create a string of unsafe acts from which they are ultimately not able to recover.

5.2 Preconditions for Unsafe Acts

When preconditions for unsafe acts are present, operators may be more susceptible to unsafe acts. A precondition was associated with 66.1% of fatal accidents compared to 81.9% of non-fatal accidents. These results suggest that preconditions are more often associated with non-fatal accidents than fatal accidents, but this difference is not significant ($\chi^2 = 1.6$, ns).

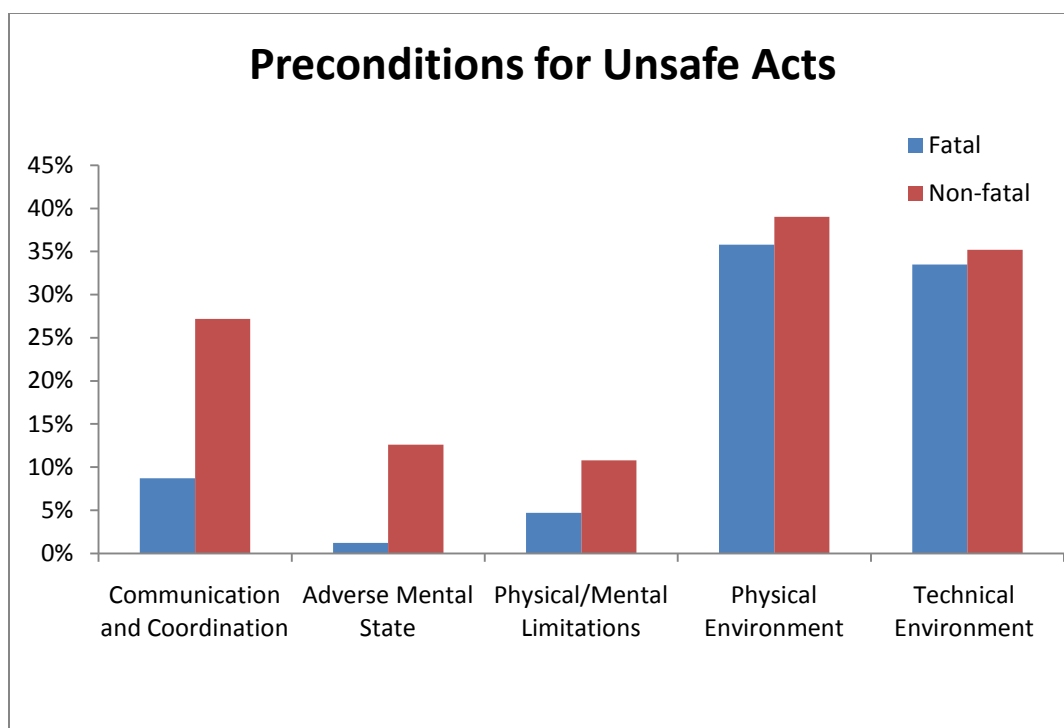


Figure 41: Preconditions for unsafe acts- fatal vs. non-fatal accidents

The most often identified precondition for both fatal and non-fatal accidents was the physical environment as both accident types had over 35% of cases associated with this causal category. For non-fatal accidents, the most often identified exemplar was surface/road conditions which generally lead to slips, trips, or falls. In contrast, ground support issues were most often identified with fatal accidents. Problems with ground support can lead to operators working under unsupported ground, cave-ins, and loose rocks. While the physical environment was identified as a highly contributing factor in both fatal and non-fatal accidents, the types of physical environment exemplars and their associated severity greatly affected the accident consequences.

Similar to the physical environment, the technical environment category was not associated with a significantly different percentage of cases for fatal and non-fatal

accidents. Within the technical environment, the most often identified exemplars were different between fatal and non-fatal accidents. Equipment design and construction was the most often identified exemplar for non-fatal accidents, whereas PPE/equipment/tools was the most often identified exemplar for fatal accidents. These results suggest that there might be exemplars within each category that are more likely to result in injuries/near misses or fatalities.

Instances where significant differences between fatal and non-fatal accidents were found are with communication ($\chi^2 = 9.5$, $p < .05$) and adverse mental state ($\chi^2 = 9.4$, $p < .05$). Both of these categories were associated with fewer fatal accidents than non-fatal accidents. There may be a variety of reasons for these findings. First, it may be easier to identify adverse mental states in non-fatal accidents because operators involved can be directly questioned about any mental states that might have altered his/her performance. Second, the majority of non-fatal accidents involved direct interactions between operators and/or vehicles, whereas with fatal accidents, operators were generally by themselves. This suggests that in instances of non-fatal accidents, workers tended to have more opportunity for communication; therefore, the lack of communication may be more often noticed and identified as a contributing factor.

5.3 Unsafe Leadership

Unlike the lower two tiers of HFACS-MI, the unsafe leadership category was associated with a significantly different percentage of cases for fatal (63.8%) and non-fatal (36.8%) accidents ($\chi^2 = 7.4$, $p < .05$). Leadership factors were identified with more fatal accident cases than non-fatal cases. This may be due to the differences in the reports

gathered for this analysis. This may also result from more upper tiered causal factors contributing to fatal accidents. If fatal accidents are indeed more likely associated with leadership factors, then efforts to improve leadership roles and responsibilities need to be made.

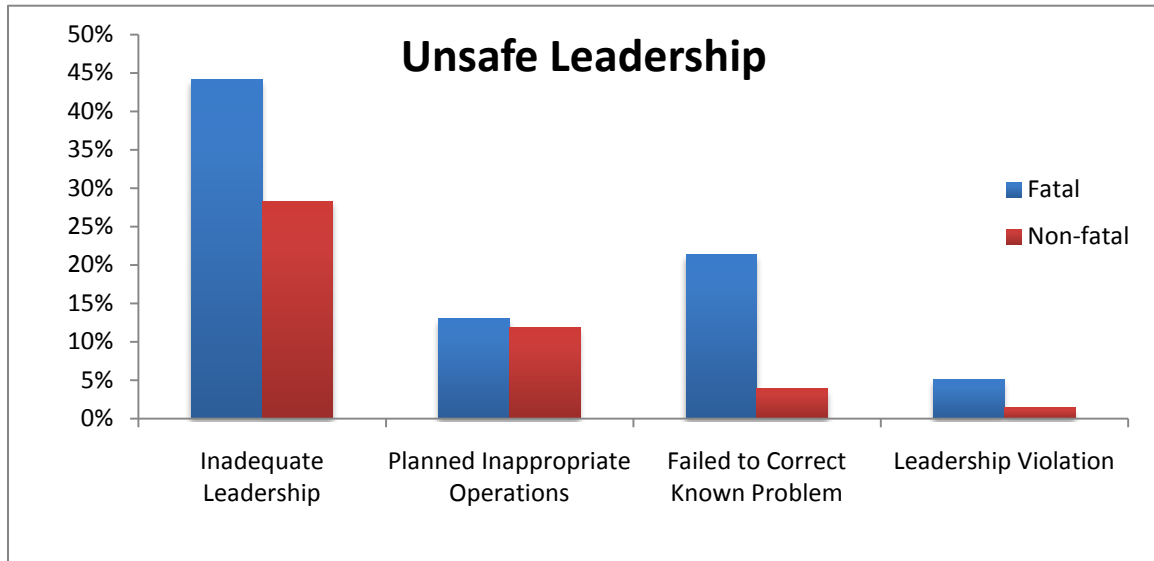


Figure 42: Unsafe leadership- fatal vs. non-fatal accidents

Inadequate leadership was the most identified category for both fatal and non-fatal accidents within this tier. Differences between fatal and non-fatal cases were not significant ($\chi^2 = 3.4$, ns). Within this category, the leading exemplar for fatal accidents was safety oversight, and for non-fatal accidents, it was training. This implies that people are injured or involved in near misses as a result of inadequate knowledge, whereas people are killed by a lack of monitoring by experienced personnel.

Significant differences existed at the unsafe leadership level with the causal factor, “failure to correct known problems” ($\chi^2 = 12.1$, $p < .05$). The percentage of fatal accidents associated with this causal factor was five times more than that of non-fatal

accidents. Members of leadership have an obligation to correct known problems on site before allowing an employee to work in hazardous areas or with defective equipment. It appears that before a fatal accident occurs, operators are already at an increased risk of being involved in an adverse event as a result of the faulty conditions in which they are working.

5.4 Organizational Influences

Similar to unsafe leadership, organizational influences were associated with a significantly higher percentage of fatal (33.3%) accident cases than non-fatal (9.6%) accident cases ($\chi^2 = 13.3, p < .05$). In fact, the percentage of fatal accident cases associated with organizational factors was three time higher than that of non-fatal accidents (Figure 43).

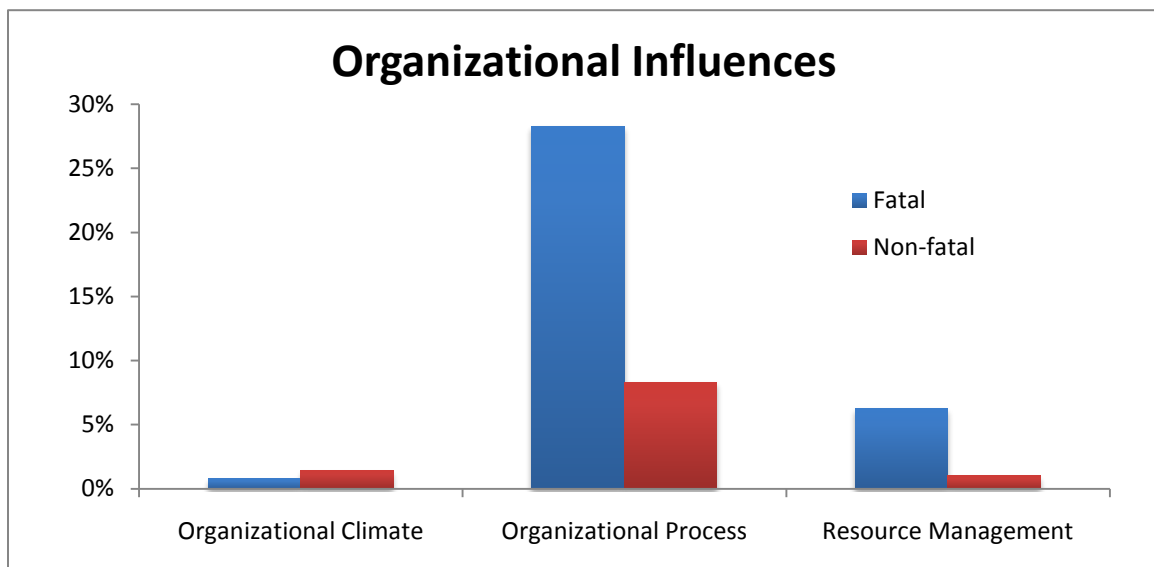


Figure 43: Organizational influence- fatal vs. non-fatal accidents

Within organizational influences, organizational process was the most often identified causal category for both fatal and non-fatal accidents. There were significantly

more fatal accident cases associated with organizational process than non-fatal accident cases ($\chi^2 = 10.9$, $p < .05$). Within this category, problems with organizational procedures were most often identified. Given that inadequate procedures (or lack thereof) are associated with a high percentage of fatal accidents, it appears that improvements in SOPs are needed in order to reduce mine site fatalities. It is vital that not only there be SOPs, but that these procedures also be updated, disseminated to workers, and reflect the safest operating practices.

Overall, it appears that organizational deficiencies are more likely to result in fatal accidents than non-fatal accidents. This said, interventions should be developed and implemented to see a reduction in fatal accidents for identified problems at this tier of HFACS-MI.

CHAPTER 6: CONCLUSIONS

6.1 Findings

While it was known that human error plays a significant role in mining incidents and accidents, the specific types of human error had not yet been identified. These studies showed that the HFACS-MI framework could be used to systematically identify underlying human factors causes in mining incidents and accidents. Results suggest that fatal accidents are more highly associated with higher tiers of the HFACS-MI framework than non-fatal accidents.

At the lowest tier of HFACS-MI, skill-based errors were associated with the highest percentage of cases for both fatal and non-fatal accidents. While the percentage of cases associated with skill-based errors was not significantly difference between fatal and non-fatal accidents, the specific form of skill-based error did differ. The majority of causal factors at the precondition for unsafe acts tier dealt with the physical and technical environment. While there was no significant difference between the overall percentage of fatal and non-fatal cases associated with a precondition, non-fatal accidents were associated with a significantly higher percentage of cases for the adverse mental state, and communication and coordination categories.

At the leadership tier, fatal accidents were associated with a significantly higher percentage of leadership causal factors than non-fatal accidents. Like the leadership tier, organizational influences were also associated with a significantly higher percentage of fatal accidents. Results suggest that fatal accidents are a result of higher level system

deficiencies whereas non-fatal accidents result from lower level operator error and environmental conditions.

While differences in the percentage of cases associated with causal categories at the lowest two tiers of HFACS-MI did not exist between fatal and non-fatal accidents, within these categories, the specific exemplars identified differed between fatal and non-fatal accidents. Differences showed that although the same error forms are identified, the underlying causes of fatal and non-fatal accidents are different.

In addition, these studies identified temporal trends amongst mining incidents and accidents. The trends revealed that human error interventions adapted prior to or during the research period were not targeted at a specific human error form. Instead, it appears that the best interventions targeting human factors were much more general and ubiquitous in their impact.

Another benefit of these analyses is that they can be compared with other mining operations worldwide. In other words, results should transfer to the rest of Australia and other countries that have similar cultures and regulations. For instance, underlying causal factors for fatal accidents in the USA should transfer to those for fatal accidents in Australia.

Finally, some of the results from this analysis were similar to those found from other industries such as aviation and rail (e.g. Shappell and Wiegmann, 2001; Reinach and Viale, 2006; Shappell et al., 2007). In other industries analyzed using HFACS is that violations were not associated with as many incidents and accidents. One of the biggest differences between the findings from this study and previous studies involving HFACS is that violations were not associated with as many incidents and accidents.

When fatal and non-fatal accidents were compared in previous studies, violations were found to be associated with more fatal accidents than non-fatal accidents (Shappell et al., 2006). In fact, there was no significant difference in the percentage of cases associated with a violation between fatal and non-fatal mining accidents.

By using a structured framework to identify human factors trends, results from this study can be compared to those industries as well. This comparison may enable safety interventions that proved successful in other industries to be transferred and increase cross-industry information sharing. After all, a decision error is a decision error regardless of the industry in which it occurs. The underlying causes are still the same, and lessons can be learned across seemingly disparate industries.

6.2 Significance and Contributions

With the completion of this study, the mining industry, particularly that in Queensland, Australia is left with an accident investigation and analysis tool that is based on theoretical human factors research and proven to be usable in industry. With a structured framework, the mining industry will be able to produce better investigation reports including human and system factors, identify causal and contributing factors trends, and identify targeted areas for improvements.

This study revealed the difference in causal factors for fatal and non-fatal accidents. Although it was previously thought that violations are more likely to result in a fatal accident, this data does not support that thought. Rather, it is now known that leadership and organizational factors such as oversight and the development of standard operating procedures are more likely to impact the severity of an accident.

These analyses provide for the development of data-driven interventions. Since different human error forms require different types of interventions, knowing the most common error forms will enable safety professionals to develop targeted interventions. The results of this study reveal that a “one-size-fits-all” approach to intervention development should not be taken. As significant differences were found across mine types, time of day, and accident severity, mines need to identify error forms and system deficiencies specific to themselves and develop interventions to reduce them. The implementation and enforcement of prescriptive standards across all mines might not have the anticipated successful results as all mines are not the same. A better approach would be to work with problem mines to identify underlying error forms and then develop specific interventions to correct them.

Finally, results from this study established baseline data for future comparison. After all, it is difficult to know if a given intervention and/or mitigation strategy had an impact on a specific error form if you don’t know what the current problems are. From this baseline data, it will be possible to measure the effectiveness of future human factors interventions.

6.3 Future Research

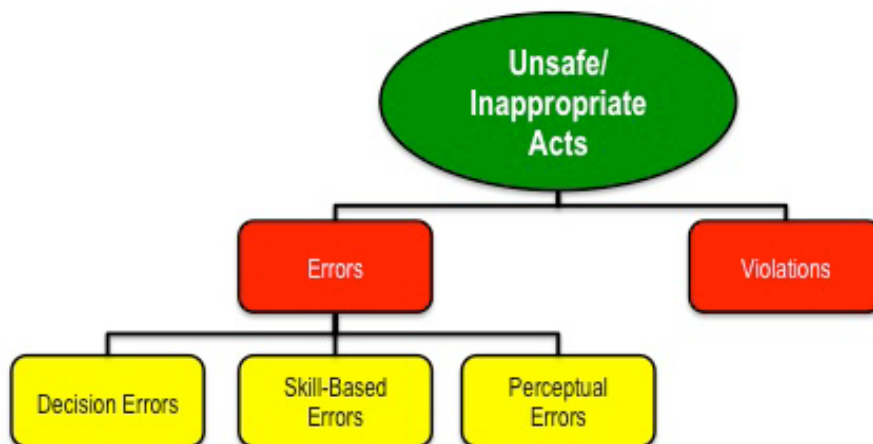
Ideally, mining organizations will start analyzing their own archival data to identify human error forms and associated tasks that are causing adverse events. The next step in continuing this research would then be to work with mining engineers, safety personnel, operators, and members of management to develop interventions focusing on

reducing the identified human error problems. A structured framework such as the Human Factors Intervention Matrix (HFIX) should be utilized to ensure

Future research also includes the analysis of fatal and non-fatal mining accidents from cultures other than those represented here. As previous studies (ex. Li and Harris, 2005; Al-Wardi, 2006) have found that cultural differences exist between western and eastern culture countries, it is necessary to analyze different cultures in order to identify where differences exist not only within non-fatal and fatal accidents, but also between different severity accidents. This will enable a world-wide initiative to reduce human error and system deficiency related mining accidents.

APPENDICES

APPENDIX A: Exemplars



Errors

Skill-based errors: Errors that occur without significant thought based on a response that is highly automated. Vulnerable to failures of attention, memory, and/or technique.

Slip, Trip or Fall

Inadvertent or missed operations

- Inadvertent operation mechanically induced
- Inadvertent operation of incorrect control
- Lapse of memory/recall for procedure
- Navigational error
- Breakdown in visual scan
- Failure to recognize self in line of fire

Postural Errors

- Improper position for task
- Work or motion at improper speed
- Working in awkward posture
- Improper lifting
- Improper loading
- Excessive/over reaching
- Physical force exertion

Timing Errors

- Poor coordination or reaction time
- Timing error
- Task overload
- Task interruption
- Distraction

Knowledge-Base Errors

- Incorrect application of procedure
- Failure to recognize hazard

Technique Errors

- Reversed/omitted steps in a procedure
- Safety checklist errors
- Inadequate practice

- Inadequate performance
- Failure to follow posted signs
- Failure to wait for response communication
- Failure to apply safety device
- Improper position/placement of hands
- Improper passing maneuver

Electrical Errors

- Improper isolation of equipment
- Isolation of incorrect equipment
- Unknowingly working on live equipment

PPE/Equipment/Tools

- Improperly prepared/maintained equipment
- Failure to use horn
- Operating vehicle at incorrect speed
- Improper parking
- Failure to lower attachments

Other

- Negative habit
- Working in incorrect area
- Other

Decision Errors: "Honest mistakes," occur when one does not have appropriate knowledge or made a poor choice, procedural error or problem-solving error.

PPE/Equipment/Tools

- Incorrect use of equipment
- Use of defective/incorrect equipment
- Improper placement of equipment or materials
- Operation of equipment at improper speed
- Use of improvised tools/machinery/equipment
- Exceed equipment capabilities
- Working at heights without fall restraint/arrest

- Improper PPE use

Prioritization

- Improper attempt to save time
- Failure to prioritize tasks
- Necessary action rushed/delayed
- Caution/warning ignored
- Wrong response to abnormal/emergency situation

Procedural

- Improper procedure (i.e. lock out/tag out not done)
- Inappropriate behavior
- Inappropriate maneuver
- Failure to take appropriate action regarding known hazard
- Failure to give way
- Failure to properly use communication devices

Information Processing

- Misinterpretation of information
- Improper decision making

Situational Assessment

- Failure to recognize hazardous conditions
- Failure to report/correct hazardous conditions
- Failure to report equipment faults/failures
- Exceed individual's capability

Risk Assessment

- Inadequate risk assessment
- Risk assessment not completed
- Failure to conduct a risk assessment
- Failure to perform pre-start inspection

Electrical Error

- Working on live electrical equipment
- Improperly working around live electrical wires

Other

- Working in unsafe area
- Failure to gain authorization before beginning task
- Working under unsupported ground
- Standing in/too close to an open brow
- Using unrated anchor points
- Inadequate/failure to scale walls
- Other

Perceptual Errors: Occur when sensory input is degraded and a decision is made based on faulty information.

Misjudgement

- Misjudged distance
- Misinterpreted/misread equipment
- Misjudged speed of object
- Misjudged depth/height
- Misjudged surface conditions
- Under/over estimation of object's weight
- Misinterpreted warnings

Auditory

- Noisy environment leads to misunderstanding communication

Visual

- Decrease in visual recognition due to inadequate lighting
- Failure to identify risk/hazards due to weather conditions

Violations: Violations involve the break of established rules. Violations can be classified as either routine or exceptional. Routine violations are habitual deviation from the rules and tolerated by management. One must look up the leadership chain to identify those in authority who are not enforcing rules. Exceptional violations are isolated deviations from the rules that are not tolerated by management. These violations are difficult to predict as they are not indicative of one's behavior.

PPE Usage

- PPE not used
- Improper use of PPE
- Failure to wear seatbelt

Tool/Equipment Operation

- Failure to secure equipments properly
- Improper use of equipment
- Improper proximity to equipment or vehicle
- Operating vehicle/equipment at speeds greater than the posted limit

Procedural

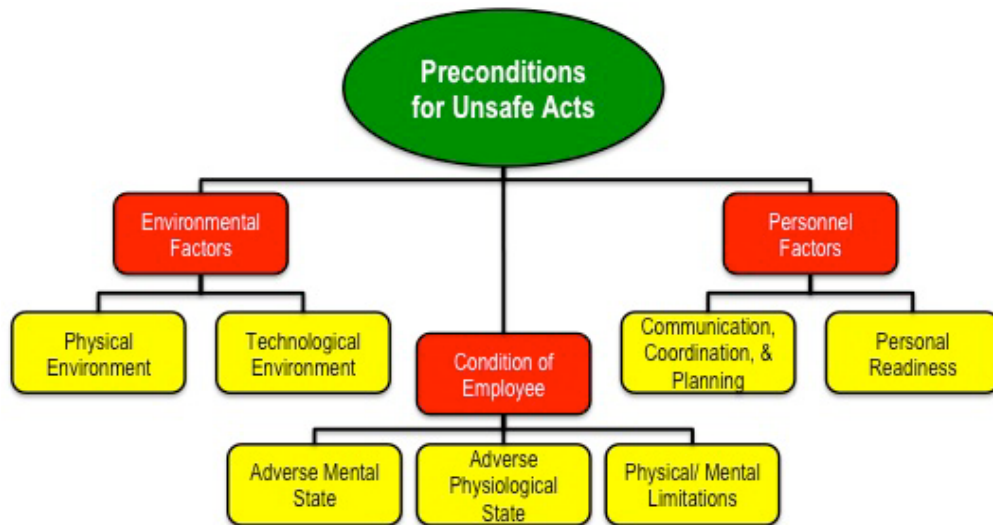
- Excessive risk taking
- Taking shortcuts
- Disregard for SOP
- Entry into unauthorized areas

Knowledge-Based Violations

- Violation of training rules
- Operating equipment without training
- Accepted unnecessary hazard
- Disregard of instructions given by SSE

Other

- Disabling of guards/warning signs
- Contraband unintentionally brought onto site



Environmental Factors

Physical Environment: Operational environment and ambient environment.

Ventilation

- Inadequate ventilation
- Malfunctioning ventilation
- Exposure to oxygen deficiency

Energy

- Fire or explosion
- Energized electrical equipment

Inadequate Installation

- Controls
- Displays
- Labels/warning signs
- Ladders/stairs
- Walking/working surfaces
- Guards

Ground Support

- Loose/falling rocks
- Inadequate ground control
- Corrosion of installed ground control
- Incorrectly installed ground control
- Incorrectly designed ground control

Weather

- Inclement weather condition
- Weather or acts of nature

Surface/Road Conditions

- Slippery floors or walkways
- Slippery roadways
- LTA road design
- LTA road gradient
- LTA road maintenance

Visibility

- Restricted visibility
- Reduced visibility

- Inadequate lighting

Housekeeping

- Clutter or debris
- Trip hazard
- Hazardous material not contained

Ergonomic issues

- Vibrations
- Repetitive motion
- Noise interference
- Congested or restricted motion

Miscellaneous

- Confined space
- Incorrect or uneven tyre pressure
- Improper blast hole layout/loading
- Build up of gases
- Fall/climb hazard

Technological Environment: (Issues related to design of equipment and controls, display/ interface, checklist layouts, task factors, and automation)

PPE/Guards/Safety Device

- LTA or defective PPE
- LTA or defective guards or protective devices
- No guards or protective devices in place
- LTA safety device
- Safety device missing/not installed

Warning

- LTA or defective warning signs
- Missing warning signs
- Defective warning signs

Equipment/Tools

- Defective equipment or tools
- Dysfunctional equipment or tools
- LTA equipment/tool maintenance

Design

- LTA design of control systems/ displays

- LTA design of electrical system
- LTA ergonomic design
- LTA technical design
- Poor man/system interface

Conditions of Operators

Adverse Mental State: Mental conditions that affect performance.

Attitude

- Overconfidence
- Lack of confidence
- Get-home-itis
- "It won't happen to me" attitude
- Complacency
- Overaggressive
- Extreme boredom
- Carelessness

Fatigue

- Mental fatigue
- Fatigue due to workload (mental)
- Fatigue due to lack of rest
- Circadian rhythm
- Drowsiness

Psychology

- Fears or phobias
- Pre-existing personality disorder
- Personality style
- Pressing
- Expectancy
- Frustration
- Emotional overload
- Misplaced motivation
- Motivational exhaustion
- Stress

Awareness

- Channelized attention
- Perceived haste to complete task
- Inappropriate peer pressure
- Inattention
- Degree of attention applied
- Task fixation
- Task saturation
- Confusion
- Extreme concentration/ perception demands
- Preoccupation with problems
- Distraction
- Mindset/preconceived idea
- Focus/attitude towards task
- Tunnel vision
- Normalization of risks

Adverse Physiological State: Medical/physiological conditions that preclude safe operation

Physiological Condition

- Spatial disorientation

- Visual illusions
- Impairment due to drugs or alcohol
- Overexertion of physical activities
- Sudden incapacitation

Medical Condition

- Medical illness
- Dehydration
- Inability to sustain body position
- Oxygen deficiency
- Previous injury or illness
- Influenced by medication

Fatigue

- Sleep deprivation
- Circadian rhythm/desynchronized
- Fatigue due to lack of rest
- Fatigue due to workload (physical)

Physical/Mental Limitations: Situations exceeds the capabilities of the operator

Mental Limitations

- Emotional disturbance
- Pre-existing psychological disorder
- Incompatible intelligence/aptitude
- Not familiar with job performance standards
- Learning ability limitations
- Memory ability/lapses
- Inexperience with job task
- Limited experience/proficiency
- Inability to comprehend instructions, policies, etc.

Sensory Deficiencies

- Visual limitations
- Vision deficiencies
- Hearing deficiencies

Physical Limitations

- Lack of competency
- Incompatible physical capabilities
- LTA practice of skills
- Lack of proficiency
- Respiratory incapability
- Musculoskeletal disorder
- Inability to sustain body movement
- Restricted range of body movement
- Inappropriate height, weight, size, strength, etc.
- Motor skill, coordination or timing deficiencies
- Uncontrolled body motion
- Substance sensitivities or allergies
- Temporary disabilities

Personnel Factors

Coordination and Communication: Poor coordination/communication among personnel.

Coordination

- Failed to use all available resources
- Lack of teamwork
- Misunderstanding training instructions

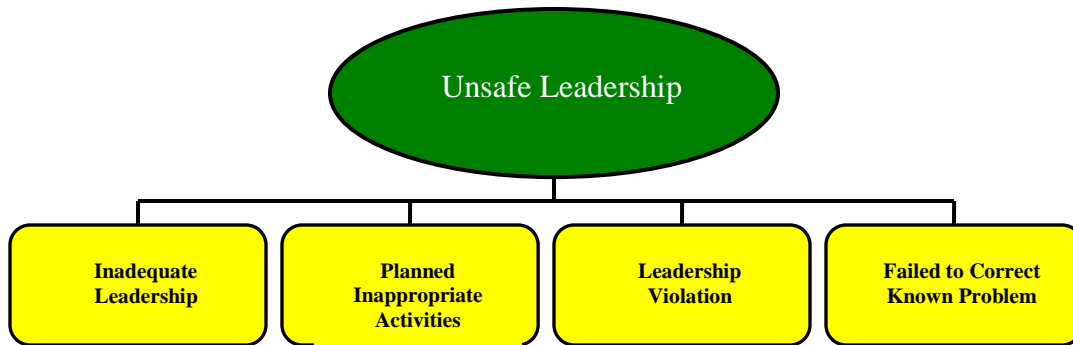
Communication

- LTA communication with contractors
- LTA briefing
- LTA communication of hazards
- LTA communication b/w workers and leadership
- LTA communication between work groups
- Ineffective communication methods
- No communication methods available
- Misunderstanding of instructions
- Standard terminology not used
- Incorrect instructions provided
- LTA knowledge transfer
- Speech interferences

Fitness for Duty: Failure to prepare mentally or physically for duty.

Fitness for Duty

- LTA rest requirements
- Self medicating
- Use of illicit drugs and alcohol
- Hung-over at work
- LTA nutrition
- Lack of physical fitness
- Excessive physical training
- Overexertion off duty
- Lack of sleep



Inadequate Leadership: A leader may demonstrate inappropriate or improper characteristics or actions.

Guidance

- Inadequate performance measures and evaluations
- Inadequate or incorrect performance feedback
- Inadequate leadership situational awareness
- Inadequate monitoring of work
- Leadership inability to manage conflict
- Inadequate matching of individual qualifications to requirements
- Unclear or conflicting assignment of responsibility
- Failed to provide professional guidance/oversight
- Lack of accountability
- Failed to provide adequate rest period
- Crew shortage

Training

- Inadequate assessment of required skills
- Failure to track job qualifications/skills
- Lack of coaching/training on the job
- Training not reinforced on the job
- Change introduced without training
- Inadequate refresher training provided
- Inadequate design of training programs
- Inadequate training objectives/goals
- Inadequate new hire training
- Inadequate on-the-job or departmental training
- No measurement of training effectiveness
- Failure to provide adequate training
- Inadequate training on equipment operation
- Inadequate training on site characteristics
- Inadequate training on SOPs, policies, regulations
- No training provided
- Need for training not identified
- Training records incorrect
- Leadership decision not to provide training

- Failure to provide adequate risk assessment training

Safety Oversight

- Inadequate reinforcement of safe behaviors
- Failure to conduct safety walk-through
- Failure to conduct worksite inspections
- Inadequate incident reporting/investigation
- Inadequate promotion/enforcement of safety
- Inadequate or lack of safety meetings
- PPE not available
- Failure to ensure individual's competence
- Failure to perform adequate risk assessment
- Inadequate implementation of risk assessment
- Risk assessment completed to meet production needs
- Risk assessment not based on safety
- Lack of quality risk assessments
- No internal review of risk assessments
- Risk assessments done w/o use of all available resources

Incentives

- Lack of appropriate incentives
- Failure to reward safe behavior

Leadership Knowledge/Skill-Level

- Inadequate leadership job knowledge
- Leadership unaware of risks associated with task
- Leadership unaware of procedures associated with task
- Inadequate knowledge base for job
- Leadership unwilling to adapt to change
- Unqualified/under qualified leadership
- SSE inexperience
- Failure of SSE to be knowledgeable of ongoing operations
- Improper leadership example
- Inadequate skills/training to perform risk assessment

Procedural, Policy, Oversight

- Inadequate communication of policy/procedures
- Improper/insufficient delegation of responsibilities/duties
- Giving objectives, goals or standards that conflict
- Failed to provide adequate/proper tools for the job

Other

- Personality conflict
- Leadership unwilling/afraid to confront workers
- Failed to provide adequate technical design

Planned Inappropriate Operations: A leader may fail to correctly assess the hazards associated with an operation and allows for unnecessary risk.

Task/Work Plan

- Inadequate assessment of needs
- Inadequate standards/specification
- Inadequate implementation of company policy and procedures
- Inadequate communication of company policy and procedures
- Inadequate equipment
- Inadequate maintenance planning/scheduling
- Inadequate working plan
- Meaningless or degrading activity
- Inadequate assessment of required skills
- Infrequent opportunities to practice skills
- New process introduced without training
- Inadequate controls used

Worker Assignment

- Ordered/led job beyond the capability of the crew
- Excessive workload
- Poor shift turnover
- Inadequate work turnover process
- Poor matching/pairing of crew members
- Poor matching of operators to equipment
- Failure to provide adequate opportunity for break(s)
- Failure to provide adequate work/break schedule
- Failure to provide adequate brief time
- Assigning workers to unfamiliar situations/tasks/equipment
- Allocating the wrong skills for the job/task

Safety Plan

- Failed to conduct accident investigation timely
- Inadequate hazard assessment
- Inadequate safety/hazard inspection system
- Inadequate industrial hygiene risk assessment
- Inadequate initiation of safety review
- Inadequate safety records

- Inadequate environmental permit representation
- Risk outweighs benefits
- Inadequate reinforcement of safe behaviors
- Failure to identify hazards
- Risk assessments done in isolation
- Failure to sign off on risk assessments

Leadership Oversight

- Failure to provide adequate leadership
- Improper/insufficient delegation of authority
- Leadership implied haste
- Unrealistic expectations
- Improper performance is rewarded
- Proper performance is punished
- Failure to provide appropriate incentives
- Lack of contractor communication

Other

- Inadequate instructor qualifications
- Inadequate ergonomic design
- Inadequate preventive maintenance

Failure to Correct Known Problem: A leader may fail to correct a known problem, and the shortcomings of supervision may lead to an unsafe act or situation.

Safety/Hazard

- Inadequate identification of work place hazards
- Improper performance is rewarded or tolerated
- Improper recognition for at-risk behavior
- Failure to correct inappropriate behavior
- Failure to report unsafe tendencies
- Inadequate health hazard evaluation

Policy/Procedure

- Failure to update/revise SOPs, policies, and procedures
- Inadequate enforcement of SOPs, policies and procedures
- Failure to implement accountability system

Maintenance/Corrective Actions

- Failure to initiate corrective actions
- Failure to correct known reported problem
- Inadequate correction for prior safety hazards/incidents
- Failure to place appropriate priority on needed repairs

Other

- Authorized unnecessary hazard

Leadership Violation: A leader may knowingly disregard instructions, guidance, rules, or SOPs and create an unsafe act or situation.

Safety/Hazard

- Enabling excessive risk taking
- Inadequate inspection
- Authorized unnecessary hazard

- Set priority of production/cost over company requirements

Policy/Procedure

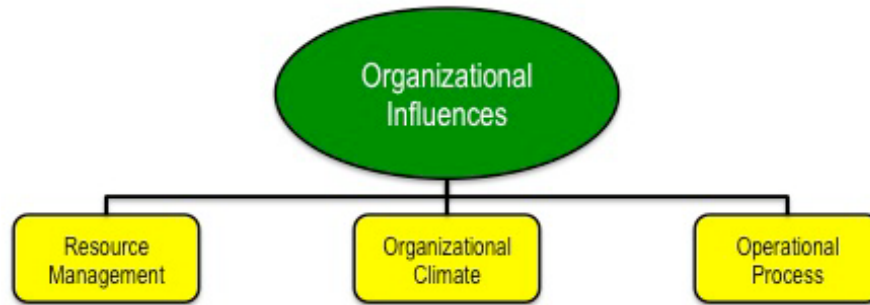
- Violation of SOPs, policy, and procedures by leaders
- Leader encourages bending of rules/taking shortcuts
- Failure to enforce rules and regulations
- Fraudulent documentation
- Inadequate documentation

Task Assignment

- Authorized unqualified worker to perform tasks
- Assigning incompetent operators to equipment

Other

- Wilful disregard of authority by leader(s)



Resource Management: Corporate-level decision-making regarding the allocation and maintenance of organizational assets such as human resources, monetary assets, and equipment/facilities.

Human Resources

- Selection
- Staffing/manning
- Training (i.e. not developed)
- Procedures not integrated into training process
- Background checks
- Personnel resources
- Inadequate matching of qualifications for job
- Inadequate company approval process
- Inadequate contractor pre-qualification
- Use of non-approved contractor
- Inadequate specifications to contractor
- Inadequate research (i.e. materials, equipment)
- Inadequate review of potential failures
- Failure to check qualification for positions
- High turnover rates
- Short staffed
- Pay scales unreflective of position hierarchy
- Hiring/promotion schemes based on availability of workers not skills
- Promotions outside of subject area

Monetary/Budget Resources

- Excessive cost cutting
- Lack of funding
- Lack of logistical support
- Failure to correct known design flaws

Equipment/Facility Resources

- Inadequate design
- Workspace working conditions
- Purchasing unsuitable equipment/parts
- Inadequate vehicle for the purposed used
- Inadequate equipment working conditions
- Inadequate specifications on invoice
- Inadequate mode or route of shipment
- Inadequate receiving inspection and acceptance
- Improper handling of materials
- Improper storage of materials

- Improper substitution
- Inadequate material packaging/container
- Exceeded shelf life
- PPE not available
- Improper salvage and/or waste disposal
- Failure to update/supply MSDS
- Inadequate monitoring of construction
- Other

Organizational Climate: The working atmosphere within the organization can be reflected in an organization's structure, policies, and culture.

Structure

- Inadequate organizational chain of command
- Inadequate organizational communication
- Inadequate accessibility/visibility of leadership
- Improper/insufficient delegation of authority
- Inadequate formal accountability for actions
- Inadequate accountability system in place
- No accountability of SOPs
- Unclear/conflicting reporting relationships
- Unclear/conflicting assignment of responsibility
- Organizational structure

Policy

- Human resource policy/practice/procedure not practiced, enforced or consistent
- Inadequate evaluation/promotion/upgrade
- Promotions within crews
- Inadequate hiring, firing, and retention
- Drugs and alcohol policy not enforced
- Inadequate incident reporting, investigation, and corrective action policy and practice
- Shift rostering

Culture

- Norms and rules
- Organizational customs/values not clearly defined
- Organizational customs/values not clearly understood
- Safe organizational customs not established
- Organizational justice
- Citizen behavior

- Inadequate organizational influence of behavior
- Inadequate response to worker feedback
- Workplace culture hinders communication
- Assuming competence in safety critical tasks
- Avoid conflict
- Lack of knowledge sharing
- Workplace bullying, harassment, discrimination
- Top management not involved in day to day operations
- Safety not a priority
- Production first, safety second
- Other
- Inadequate risk management
- Inadequate incident reporting/investigation
- Inadequate performance measures
- Failure to document change
- Inadequate or incorrect performance feedback
- Inadequate program oversight: management failed to monitor resources, climate, and process to ensure a safe work environment.
- Other

Organizational Process: The formal process by which things get done within the organization.

Operations

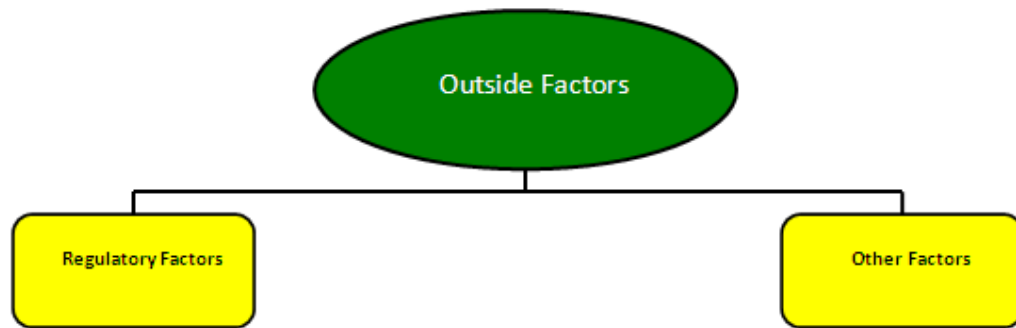
- Inadequate operations: operational tempo creates risks
- Worker/production schedules create risks
- Proper incentives lacking
- Measurement/appraisal
- Quotas
- Time pressure
- Deficient planning

Procedures

- Policy/standard guidelines not written
- Lack of SOPs
- SOPs inconsistent with work practices
- Inadequate performance standards
- Lack of working involvement with SOP creation
- Unclear definition of objectives
- Unclear definition of corrective action
- Outdated SOPs/no revision schedule
- Inadequate procedural guidance/publications
- Inadequate procedures/instructions about procedures
- Inadequate organizational training issues/programs
- Inadequate organizational training: objectives and goals not well defined
- Inadequate organizational training: curriculum and delivery process not well defined
- Inadequate procedural documentation
- Lack of job safety analyses conducted
- Inadequate job safety analysis performed

Oversights

- Lack of established safety program/risk management program
- Risk management program not adequately implemented/maintained
- Safety management process not adequately implemented/maintained
- Inadequate safety and health management system



Regulatory Factors: The affect government regulations and policies have on health and safety

Regulatory Factors

- Inadequate guidance by Regulator
- Incorrect guidance by Regulator
- Failure of Regulator to oversee company/site
- Infrequent inspections by Regulator
- Failure of Regulator to identify safety risks
- Inexperience of Regulator inspector
- Inadequate training of Regulator inspector
- Inadequate enforcement of regulations by Regulator
- Inadequate regulations
- Unclear or ambiguous regulations
- Other

Other Factors: The affect outside pressures including economic and social have on health and safety

Other Factors

- Social obligations
- Impact on safety of individuals after leaving site
- Fly-in fly-out communities
- Encouraged to disregard regulations by economic stimulus
- Economic pressure to forgo safety
- Economic pressure to continue mining in unsafe areas
- Environmental influences
- Political pressure
- Legal pressure
- Fear of prosecution
- Decrease of workers entering industry
- Overall aging workforce
- Other

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