The Development of an Accident/Incident Investigation System for the Mining Industry Based on the Human Factors Analysis and Classification System (HFACS) Framework

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Abstract

As a historically high risk industry, mining continues to be associated with high accident/incident rates. Investigation of accidents/incidents is a vital step in the control of mining safety. The first step in uncovering failures within the mining industry is to develop an accident/incident investigation and analysis tool. The human factors analysis and classification system (HFACS) framework was modified to meet the needs of the mining industry (HFACS-MI). In this preliminary study, 68 accident/incident cases from the southern region of Queensland from 2005-2008 were analysed. The results suggest that skill-based errors are the most frequent error form in mining. Higher level leadership and organizational factors were less frequent suggesting that either they do not contribute to accidents/incidents or the impacts of these factors are underreported. The results of this study are still preliminary and more accident/incident cases must be analysed to ensure valid, nonbiased results.

INTRODUCTION

High risk industries such as mining are complex systems in which operators often work in harsh conditions. These systems are often prone to human errors which can result in adverse events. The role of human error in accident investigation has shifted focus in the last two decades. In the old view of human error, the error was the result of an incorrect action on the part of the operator. This system is often referred to as a ‘blame and train’ system or person approach. Accident investigations focus on the unsafe acts of the operator and attribute the cause of an accident/incident to a breakdown in the operator’s mental process. In the new view of human error, the failure is viewed as a symptom of a deficient system (Dekker 2002). In this new view, accidents/incidents are investigated beyond the immediate actions of the operator. The entire system is taken into account and the failings within the system are viewed as important as failings of the operator.

With this new approach to accident investigation, system approaches to identifying human error have emerged. One widely used model 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. 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 result from memory lapses or attention failures. 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 wilful 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 defences (Reason 2000). Reason’s Swiss-cheese model of human error defines the relationship between active failures and latent conditions.

Numerous accident investigation frameworks have been developed based on Reason's human error model. One of these frameworks is the human factors analysis and classification system (HFACS: Wiegmann and Shappell 2003). The HFACS framework was originally developed for use with United States military aviation. HFACS has been shown to be effective in civil aviation (Wiegmann and Shappell 2001a; Wiegmann and Shappell 2001b; Wiegmann, Faaborg et al. 2005; Shappell, Detwiler 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 (ElBardissi, Wiegmann et al. 2007), and remotely piloted aircrafts (Tvaryanas, Thompson et al. 2006). Based on this past work, an HFACS version for the mining industry (HFACS-MI) has been developed to use in mining accident/incident investigation and to analyse historical data.

METHOD

Development of HFACS-MI

The framework used for this study was based off of the version of HFACS described by Wiegmann and Shappell (2003). This framework was modified to better correlate to the mining industry. The modified framework was called human factors analysis and classification system – mining industry (HFACS-MI). There were no changes to the framework at the unsafe acts level. 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 was changed because of the extensive 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 make decisions at the supervisor level who are not direct supervisors for operators, such as the Site Senior Executive. 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. This level includes regulatory, social, political, environmental, and economic influences.

Examples of each causal factor were generated to use as a guide during accident investigation. The first step involved in developing these examples or 'nanocodes' as named by Wiegmann and Shappell was a brainstorming session with a focus group. The focus group consisted of 7 people and included inspection officers, mines inspectors, and regional inspectors of mines. All members of the focus group worked for the Department of Mines and Energy and had at least 5 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 first hand knowledge of active and latent failures. A total of ten interviews were conducted. Mine workers interviewed had between less than 1 year and 20 years experience in the industry. After this list of examples was compiled, it was reviewed and categorized by a group of 4 people with HFACS experience. Where disagreements existed, discussions were held until a consensus agreement was reached. The final framework for HFACS-MI can be seen in Figure 1.

Preliminary Analysis

At this stage of the project, only a preliminary analysis of data could be completed. Data included accident and incident reports from the Southern Region from January 2005 to March 2008. Reports indicating mechanical failures, rock falls, and vehicle fires were excluded from analysis. All demographic information was removed prior to the coding process to ensure that the individual mines or people involved could not be identified. Reports were coded using a narrative description of the event, hazards identified from the event, and factors leading up to the event. A total of 68 accident and incident reports were used. Each report was coded by a human factors specialist using the HFACS-MI taxonomy.

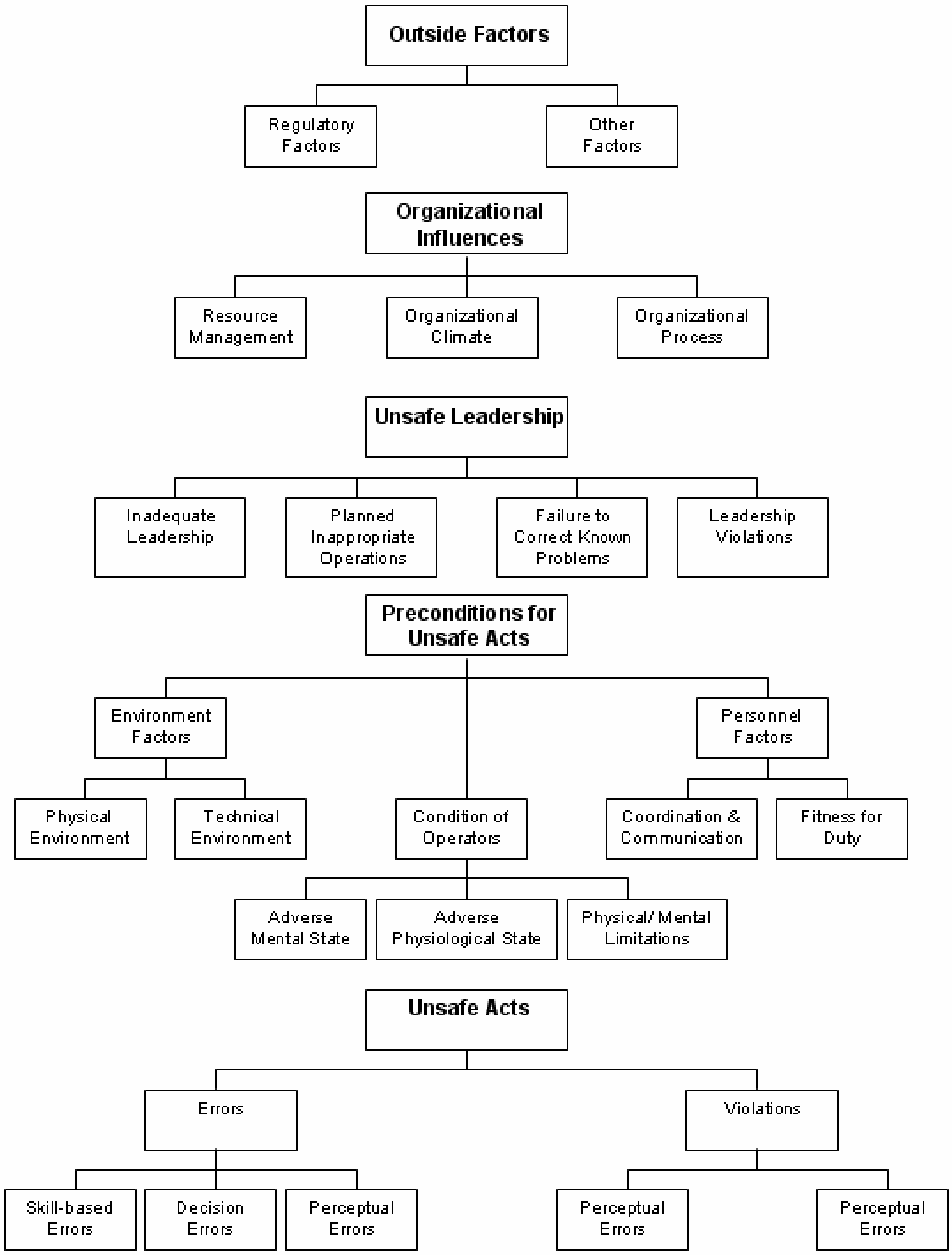

Figure 1: Human Factors Analysis and Classification System – Mining Industry (HFACS-MI) framework

RESULTS

The results given are only a preliminary analysis of the accident data. In order to ensure valid and non-biased results, the final analysis will consisted of a larger sample size and each case will be coded by two independent raters. The results given here may change when the final analysis is completed and should be taken as only a small snapshot of what types of human error may be prevalent in the mining industry.

A summary of the HFACS-MI analysis of mining accidents and incidents can be found in Table 1. What is can be seen from the data is that the majority of human causal factors involve operators and the environment that they work in. Causal factors in the unsafe leadership, organization factors, and outside influence levels were rare. In fact, no outside influence was found to contribute to any of the accidents or incidents analysed. When organizational influences were involved, organizational process was most often cited. These organizational processes typically included inadequate procedures or lack of procedures. Unsafe leadership was most often cited as inadequate leadership problems such as no formal training provided or inadequate training provided.

Table 1: Frequency and Percentage of Accidents/Incidents Associated with Each HFACS-MI Causal Category

HFACS Category	N (%) Mining Accidents (N = 68)
Outside Influences	
Regulatory Influences	0 (0.0)
Other Influences	0 (0.0)
Organizational Influences	
Organizational Climate	0 (0.0)
Organizational Process	8 (11.8)
Resource Management	1 (1.5)
Unsafe Leadership	
Inadequate Supervision	8 (11.8)
Planned Inappropriate Operations	2 (2.9)
Failed to Correct Known Problems	2 (2.9)
Supervisory Violations	1 (1.5)
Preconditions for Unsafe Acts	
Environmental Conditions	
Technical Environment	6 (8.8)
Physical Environment	23 (33.8)
Conditions of the Operator	
Adverse Mental State	7 (10.3)
Adverse Physiological State	3 (4.4)
Physical/Mental Limitations	4 (5.9)
Personnel Factors	
Coordination and Communication	4 (5.9)
Fitness for Duty	1 (1.5)
Unsafe Acts of the Operator	
Skill-based Errors	44 (64.7)
Decision Errors	23 (33.8)
Perceptual Errors	3 (4.4)
Violations	18 (26.5)

Note: Numbers in this table are frequencies and percentages of accidents that are associated with at least one instance of an HFACS category. Accidents can be associated with more than one causal factor and therefore the percentages do not add up to 100%.

As expected, a high number of environmental conditions were identified. The physical environment was more often identified as causing problems than the technical environment. The most frequently identified physical environment problems dealt with surface and road conditions. Slippery work surfaces and roadways along with debris and clutter on the ground were identified in 30.1% of accidents/incidents in which the physical environment was a contributing factor. Poor road design including factors such as windrow height, berm height, parking area and gradient were identified in 39.1% of accident/incidents in which the physical environment was a contributing factor.

The majority of mining accidents/incidents causal factors were found at the unsafe act level. Over half of the accidents/incidents investigated were associated with at least one skill-based error (64.7%) and one-third with decision errors (33.3%). Violations were associated with over one-fourth (26.5%) of accidents/incidents. In this analysis it was not possible to differentiate between routine and exceptional violations as the investigations did not provide enough detail. Perceptual errors were far less common and were only associated with 4.4% of accidents/incidents.

There appears to be variation in the types of unsafe acts committed annually by mine workers (Figure 2). Some of this variation, in particular that for 2008 may be due to the small sample size used in this preliminary analysis. Across all years investigated, skill-based errors were the most identified error form followed by decision errors, violations, and then perceptual errors for all years except 2008. Out of the total 68 accident/incident reports analysed, six were from 2008, twenty five from 2007 and

2006, and twelve from 2005. The number of skill-based errors (χ^2 = 12.54), decision errors (χ^2 = 5.34), violations (χ^2 = 6.00) and perceptual errors (χ^2 = 3.66) were all found to be significantly different across the years analysed (p = 0.001).

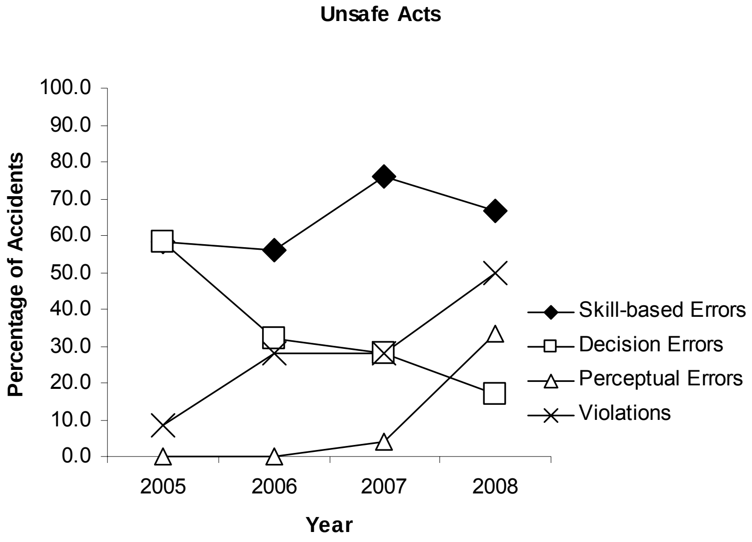

Figure 2: Percentage of unsafe acts committed by miners by year. Note that the percentages will not add up to 100%

The most frequently associated skill-based error was insecure footing (25%). These errors generally resulted in trips and falls. Another frequently identified skill-based error was the failure to use correct communications (16%). This would include using the wrong channel on the two-way radio; call the operator by the wrong name; or forgetting to call on the radio before entering an area. The most frequently associated decision error was working in an unsafe area (19%). Instances of working in an unsafe area include breaching proximity guidelines for mobile equipment and working in environmentally degraded locations. The disregard for procedures, guidelines and/or policies was the most identified violation (50%). Other violations include failure to wear safety restraints, disregard of posted signs, and intentionally not wearing proper PPE. There were only three perceptual errors identified in the 68 cases analysed. All of the perceptual errors were the misjudging of distance. These three cases also identified the precondition of congested/confined work area as a contributing factor.

DISCUSSION

This paper presents the initial work relating to the HFACS analysis of mining accidents/incidents. The result presented represents 68 mining accident/incident cases from the southern region of Queensland, Australia. This analysis is not complete, but does offer some insight into the types of human errors that maybe prevalent in mining accidents/incidents. Further analysis is needed to ensure valid results.

Outside factors, organizational influences, and unsafe leadership were associated with relatively few accidents/incidents analysed. This is not surprising as traditional accident investigation tends to focus on identifying what went wrong with the operator and not the system that the operator works in. Only one-quarter (25%) of accidents identified a deficiency within the system as being a contributing factor to the accident/incident. The vast majority of causal factors identified were associated with operator failure.

Outside influence factors were not identified as contributing factors in any accident/incident reports. Accurately identifying outside factors during an accident/incident investigation is extremely difficult and will require in depth analysis farther up the chain of command than most investigations occur. If an outside factor can be identified the impact of correcting these factors would affect a large proportion of the mining industry in Queensland.

When organizational factors were identified, they were most often associated with the organizational process. More specifically, the factors identified dealt with the inadequacy or lack of procedure. Since mining is generally a highly automated and structured task, it is understandable that accidents/incidents occur when the operators can no longer automatically complete a task. This requires more focused attention and cognition to decide on the steps needed to be carried out to complete the task. To reduce failures within the organizational process, procedures need to be created, reviewed, and updated when needed. It is not only important that there be standard operating procedures, but to ensure that these procedures are communicated to and understood by operators and the leadership that oversees them.

Similar to causal factors associated with the organization, leadership factors centered on a single HFACS-MI category, inadequate leadership, rather than the full range of categories at this level. When supervisors were identified as a contributing factor in an accident/incident, training was the most prevalent issue. Training issues included failure to provide training, less than adequate training on tools and equipments and less than adequate training on site characteristics.

The small number of contributing factors from the outside, organizational, and leadership levels can mean two things. One, the actions of the organization and leadership personnel has little impact on the performance of operators and the subsequent adverse events. Or two, the deficiencies of the organization and leadership are underreported. If the latter is true, accident investigations need to shift focus from viewing accidents/incidents as a failure of the operator to viewing accidents/incidents as a symptom of a deficient system. One possible reason for the underreporting of organizational and leadership factors is the fear of prosecution.

For the most part, categories within the preconditions for unsafe acts level were lightly populated. One exception was the physical environment, which contributed to about a third (33.4%) of all accidents/incidents. Slippery road and work surfaces were associated with 7.3%of the entire accident/incidents analysed and 21.7% of accident/incident where the physical environment was identified as a contributing factor. In order to control dust, roads are watered down throughout the day. Using roads immediately after the watering process and overwatering can contribute to reduced traction on the roadways which in turn can lead to more vehicles sliding. Work surfaces can also become slippery. Though not watered down as part of the dust suppression process, the general work surface can be slippery from water, oil, and other lubricants used during the maintenance of mining equipment and tools.

Road design and maintenance were also associated with a large percentage of accidents/incidents (26.1%) in which the physical environment was a contributing factor. Causal aspects of road design included less than adequate gradients and unexpected road angles. When road gradients are designed and constructed, care needs to be taken to ensure that the vehicles travelling on these roads are capable of operating safely on them. Roads need to be designed to accommodate vehicle movements during less than optimal conditions and situations.

By far, unsafe acts of the operator were the most populated HFACS-MI category. All accidents/incidents were associated with at least one causal category. Skill-based errors were the most often associated (64.7%) causal factor. Skill-based errors occur during highly automated tasks and are done without conscious thought. When performed in this automatic manner, tasks are often susceptible to failures of the memory, attention, and technique. As a highly procedural and structure industry, skill-based errors are expected in mining. Operators engage daily in the same or similar tasks and operations. As a repetitive operation, operators complete task without a lot of conscious thought. Not surprising, slips, trips, and falls are associated with a large number of accidents/incidents. These errors are frequently associated with everyday tasks and therefore are only enhanced when combined with highly structured tasks and adverse working conditions.

Another skill-based error associated with mining accidents/incidents is the failure to use correct communication. When operating large mobile equipment mixed with light vehicles and pedestrians, the use of communication is highly important. Operators rely on radio communication to navigate haulage roads, announce entrance into highly congested areas, warn of developing hazards, etc. With the number of times a day operators must use radio communication and the physical and cognitive demands on operators, it is not surprising that they forget to communicate, use the wrong channels, or simply communicate the incorrect message. Without radio communication, the risks of vehicle interactions increase.

Decision errors were associated with 33% of accident/incident cases analysed. These types of errors occur when operators cannot rely on standard procedures to complete a task. Operators must resort to using procedures for what they believe are similar tasks or create novel responses. The error occurs when an action is carried out as intended but the plan itself proves to be inadequate or when the incorrect action is initiated. With the accident/incident cases analysed, decision errors were associated with the incorrect use of tools or the use of incorrect tools. When the correct tools are not readily available or extra effort is required to acquire the correct tool, it is often tempting and faster to use tools that are readily available. Common practices also promote the use of incorrect tools. When operators routinely use incorrect tools or when they have been taught by other operators that it is acceptable to interchange tools, there will be fewer negative thoughts associated with using the incorrect tools. Sometimes the use of incorrect tools is justified by successful completion of tasks using the incorrect tools. The incorrect use of tools is most often associated with a lack of training on the correct use of the tool.

Violations are associated with over one quarter of accidents and incidents. The most often identified violation is the disregard of standard operating procedures (SOPs) or standard work instructions (SWIs). SOPs and SWIs are constructed so that tasks are carried out in a safe and efficient manner. When they are disregarded, the risk of injury increases. Often the disregarding of SOPs and SWIs are justified by the operators. When leadership condones the disregard of written procedures, the risks of accidents and incidents increase. Constant disregard allows incorrect procedures to become common practice. In order to curb these violations, it is important to identify leadership who are not enforcing the following of formal procedures. It is also important to allow operators to voice concern and comment on the effectiveness of procedures. Operators may be continually disregarding procedures because they are poorly written, do not apply, or there truly is another way to complete the task safely and efficiently. If this is the case, then review of procedures is necessary.

CONCLUSIONS

While this is a good start to identifying types of human errors in mining accidents/incidents, further research is needed to ensure valid, nonbiased, and stable results. From here, more accident/incident cases will be gathered and analysed using the HFACS-MI framework. This research is projected to be completed early in 2009. With a larger sample size, a better understanding of human error trends can be identified and recommendations developed to assist in the minimisation of mine related accidents.

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