Accident Analysis and Prevention 42 (2010) 1379–1385

Contents lists available at ScienceDirect

Accident Analysis and Prevention

journal homepage: www.elsevier.com/locate/aap

Operator error and system deficiencies: Analysis of 508 mining incidents and accidents from Queensland, Australia using HFACS

Jessica M. Patterson*, Scott A. Shappell

Industrial Engineering Department, Clemson University, 110 Freeman Hall, Clemson, SC 29634, United States

ARTICLE INFO

Article history:
Received 14 September 2009
Received in revised form 28 January 2010
Accepted 26 February 2010

Keywords:
Accident investigation
Human error
Mining
Human Factors Analysis and Classification System (HFACS)

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 needs to be addressed. A modified version of the Human Factors Analysis and Classification System was used to analyze incident and accident cases from across the state of Queensland to identify human factor trends and system deficiencies within mining. An analysis of the data revealed that skill-based errors were the most common unsafe act and showed no significant differences across mine types. However, decision errors did vary across mine types. Findings for unsafe acts were consistent across the time period examined. By illuminating human causal factors in a systematic fashion, this study has provided mine safety professionals the information necessary to reduce mine incidents/accidents further.

1. Introduction

While the mining industry has witnessed tremendous successes in safety over the last several decades, it remains among the highest risk professions worldwide (Coleman and Kerkering, 2007). In the United States for example, mining was listed as having the second highest fatality rate of any private industry (Poplin et al., 2008). Some have attributed the increased risk to the variety of adverse working conditions miners are exposed to. From flooding to explosive agents and the risk of asphyxia, miners are exposed to some of the most hostile working conditions of any occupation (Mitchell et al., 1998). Nevertheless, the majority of accidents cannot be solely attributed to adverse working conditions. For instance, a study by the US Bureau of Mines found that nearly 85% of all mining accidents identified human error as a causal factor (Rushworth et al., 1999). Clearly, if safety is to be improved, it is vital to study the impact of human error on mining accidents.

Dekker (2002) describes the shifting role of human error in accident investigation over the last two decades. With the old models of accident investigation, a person approach was taken to identify contributing factors. This approach focused on the unsafe acts of the people immediately involved with an adverse event. It was a deficiency or lack of action on the part of the individuals involved that lead directly to an accident occurring. In the new approach to accident investigation advocated by Dekker (2002), a systems or organizational approach should be taken. The goal of this approach is to identify the deficiencies within the system rather than simply "blaming" the individual involved in the incident. It is within this over-arching systems approach to accident investigation that root causes are identified.

The Human Factors Analysis and Classification System (HFACS) is an investigation framework that utilizes a systems approach. The HFACS framework was originally developed for use with the United States Navy and Marine Corps by Wiegmann and Shappell (2003). Drawing upon Reason's (1990) concept of latent and active failures, HFACS describes human error at four levels: (1) the unsafe acts of operators, (2) preconditions for unsafe acts, (3) unsafe supervision (i.e., middle-management), and (4) organizational influences. In other words, the HFACS framework goes beyond the simple identification of *what* an operator did wrong to provide a clear understanding of the reasons *why* the error occurred in the first place. In this way, errors are viewed as consequences of system failures, and/or symptoms of deeper systemic problems; *not* simply the fault of the employee working at the "pointy end of the spear."

The original HFACS framework (Wiegmann and Shappell, 2003) describes 19 causal categories within Reason's four levels of human failure. While useful as originally designed for aviation, the nomenclature and examples within some of the causal category proved incompatible within the mining industry. Therefore, the original HFACS framework was modified and a new HFACS-Mining Industry (HFACS-MI) framework was developed and is presented in Fig. 1.

* Corresponding author.
E-mail address: jessicam.patterson@gmail.com (J.M. Patterson).

0001-4575/$ – see front matter © 2010 Elsevier Ltd. All rights reserved.
doi:10.1016/j.aap.2010.02.018

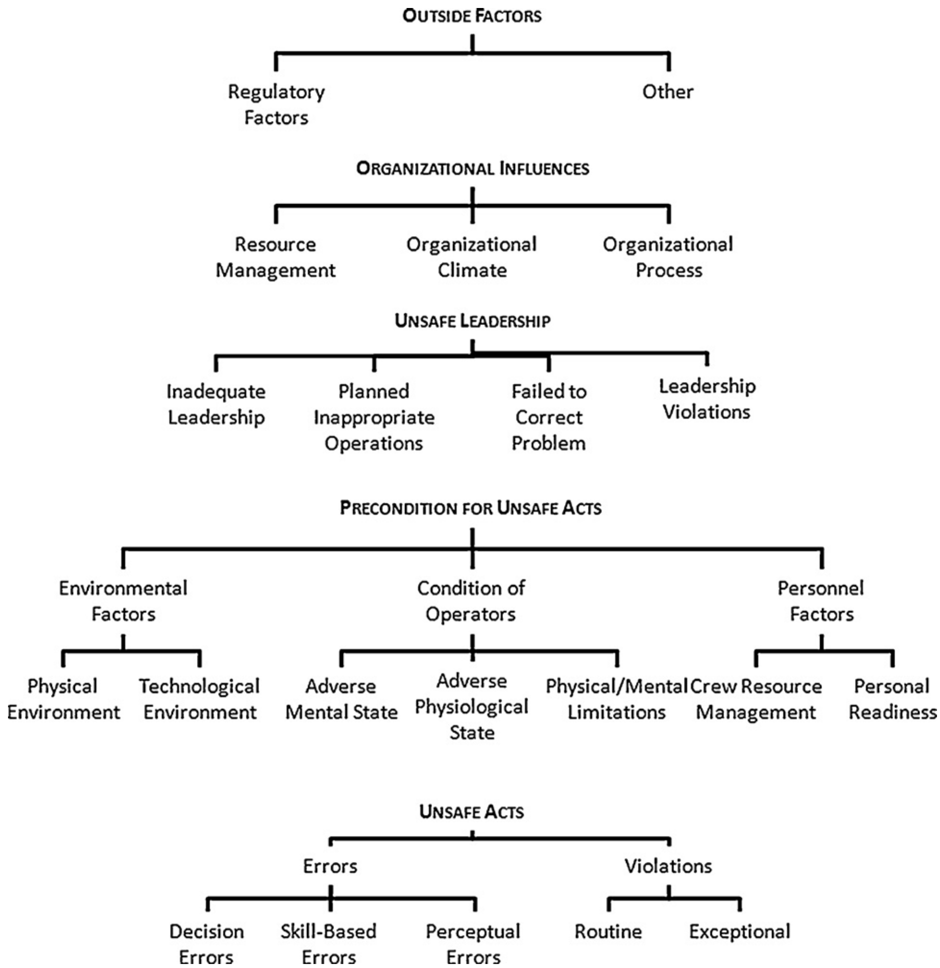

Fig. 1. Human Factors Analysis and Classification System-Mining Industry (HFACS-MI) framework.

Changes to the second tier included the renaming of 'crew resource management' and 'personnel readiness' to 'communication and coordination' and 'fitness for duty', respectively. At the third tier, 'supervision' was changed to 'leadership'. This change was made as there are many levels of management that oversee workers, and the authors did not want users to look only at the operator's immediate supervisor when investigating this level. No changes were made to the fourth tier, 'organizational influences'. A fifth and final tier of the HFACS framework was added based on the work of Reinach and Viale (2006) and was named 'outside factors'. This level is composed of two categories: 'regulatory factors' and 'other' outside factors. In the end, HFACS-MI contained a total of 21 causal categories. A brief description of each causal category within HFACS-MI is provided in Table 1.

2. Method

2.1. Data

The incident and accident reports used in this analysis were obtained from the Department of Mines and Energy (DME) in Queensland, Australia. Information used was gathered from reports and/or forms submitted by responsible personnel from each mine on high potential incidents and lost time accidents. A total of 508 cases occurring between January 2004 and June 2008 were obtained and submitted to further analysis. This was the entire population of cases for which investigation reports/completed forms were available. The completed forms were standard for all mines and across the time period examined. The number of cases obtained represents approximately 10% of the total number of incidents and accidents reported to DME during this time period. The remaining 90% of the reported events did not require a formal report and therefore were not included. The data was obtained from underground and open cut coal mines, underground and open cut metal/non-metal mines, and quarries.

2.2. Coding process

Groups of two human factors specialists coded each incident/accident case. The analysts, five in total, had previous training and experience classifying incident/accident data with HFACS. Given the high inter-rater reliability found in previous HFACS analyses (e.g., Pape et al., 2001; Wiegmann and Shappell, 2003; Gaur, 2005; Reinach and Viale, 2006; Li et al., 2008), consensus classification was deemed appropriate for analysis. That is, the group as a whole discussed each case and classified the identified human factors within the HFACS-MI framework. The presence or absence of each HFACS-MI category was evaluated from the narrative, sequence of events, findings, and conclusion. Each HFACS-MI category was counted a maximum of one time per case.

3. Results and discussion

3.1. Overall results

As can be seen in Table 2, the majority of causal factors involved operators and their environment. Not surprising, an unsafe act was

Table 1
Brief description of HFACS-MI causal categories.

Outside factors
Regulatory factors: Effect that government regulations and policies have on the operation of the mine. Also includes how actions of the regulator, including inspections and enforcement, affect health and safety.
Other: The effect society as a whole has on the health and safety of a mine site including economic pressures, environmental concerns, and legal pressure.

Organizational influences
Organizational climate: Prevailing atmosphere/vision within the organization including such things as policies, command structure, and culture.
Operational process: Formal process by which the vision of an organization is carried out including operations, procedures, and oversight among others.
Resource management: How human, monetary, and equipment resources necessary to carry out the vision are managed.

Unsafe leadership
Inadequate leadership: Oversight and management of personnel and resources including training, professional guidance, and operational leadership among other aspects.
Planned inappropriate operations: Management and assignment of work including aspects of risk management, operator pairing, operational tempo, etc.
Failed to correct problems: Those instances when deficiencies among individuals, equipment, training, or other related safety areas are "known" to members of leadership yet are allowed to continue uncorrected.
Leadership violations: The willful disregard for existing rules, regulations, instructions, or standard operating procedures by management during the course of their duties.

Preconditions for unsafe acts
Environmental factors
Technological environment: This category encompasses a variety of issues including the design of equipment and controls, display/interface characteristics, checklist layouts, task factors and automation.
Physical environment: Included are both the operational setting (e.g., weather, ground support, terrain) and the ambient environment, such as heat, vibration, lighting, toxins, etc.

Condition of the operator
Adverse mental states: Acute psychological and/or mental conditions that negatively affect performance such as mental fatigue, pernicious attitudes, and misplaced motivation.
Adverse physiological states: Acute medical and/or physiological conditions that preclude safe operations such as illness, intoxication, and the myriad of pharmacological and medical abnormalities known to affect performance.
Physical/mental limitations: Permanent physical/mental disabilities that may adversely impact performance such as poor vision, lack of physical strength, mental aptitude, general knowledge, and a variety of other chronic mental illnesses.

Personnel factors
Communication and coordination: Includes a variety of communication, coordination, and teamwork issues that impact performance.
Fitness for duty: Off-duty activities required to perform optimally on the job such as adhering to rest requirements, alcohol restrictions, and other off-duty mandates.

Unsafe acts
Errors
Decision errors: These "thinking" errors represent conscious, goal-intended behavior that proceeds as designed, yet the plan proves inadequate or inappropriate for the situation. These errors typically manifest as poorly executed procedures, improper choices, or simply the misinterpretation and/or misuse of relevant information.
Skill-based errors: Highly practiced behavior that occurs with little or no conscious thought. These "doing" errors frequently appear as breakdown in visual scan patterns, inadvertent activation/deactivation of switches, forgotten intentions, and omitted items in checklists. Even the manner or technique with which one performs a task is included.
Perceptual errors: These errors arise when sensory input is degraded as is often the case when working underground, in poor weather, around noisy equipment, or in otherwise sensory impoverished environments.

Violations
Routine violations: Often referred to as "bending the rules" this type of violation tends to be habitual by nature and is often enabled by a system of supervision and management that tolerates such departures from the rules.
Exceptional violations: Isolated departures from authority, neither typical of the individual nor condoned by management.

identified in nearly all cases. Preconditions for unsafe acts were associated with 81.9% of the cases while unsafe leadership was identified in 36.6% of the cases. Organizational influences and outside factors were identified in relatively few cases (i.e., 9.6% and 0.0% of cases, respectively).

Within the category of unsafe acts of operators, the most often cited error form were skill-based errors followed by decision errors, violations and perceptual errors. With regard to the preconditions for unsafe acts, the majority of causal factors involved the physical environment, technical environment and communication and coordination. Fewer causal factors were identified at the unsafe leadership and organizational influence levels. When causal factors were identified at these higher levels, they tended to center around a single category (e.g., inadequate leadership and organizational process).

3.2. Unsafe acts of the operator

In order to standardize the analysis process, examples were created for each HFACS-MI category (e.g., inadvertent or missed operations are an example of skill-based errors). 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. Likewise, "improper isolation of electrical equipment" and the "isolation of the incorrect equipment" were grouped with other electrical errors. The top three examples for skill-based errors and decision errors are presented in Table 3.

As can be seen, the most common type of skill-based errors was inadvertent or missed operations. These errors were typically the result of a breakdown in visual scan or the inadvertent activation of a control. This was not completely unexpected since the large amount of activity occurring at a typical mine site can often lead to a breakdown in visual scan. Logically, any intervention/mitigation strategy should explore ways to reduce operator reliance on visual detection. Alternatively, one might want to focus effort on augmenting vigilance, particularly during times when fatigue and boredom effect performance, like night-time operations or during repetitive and mundane tasks.

Another common skill-based error was technique errors. An operator's technique refers to the way in which they typically com-

Table 2
Frequency and percentage of cases associated with causal code categories.[a].

HFACS category	n (%)
Outside factors	0 (0.0)
Regulatory factors	0 (0.0)
Other	0 (0.0)
Organizational influences	49 (9.6)
Organizational climate	7 (1.4)
Organizational process	42 (8.3)
Resource management	5 (1.0)
Unsafe leadership	186 (36.6)
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	416 (81.9)
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	481 (94.7)
Skill-based errors	299 (58.9)
Decision errors	249 (49.0)
Perceptual errors	25 (4.9)
Violations	28 (5.5)

[a] Note that HFACS levels may add up to more than 100% as more than one category at a given level can be identified for each case.

plete a task. For example, a vehicle operator or pedestrian may get into the practice of failing to wait for permission to enter an area where equipment and other hazards may be present. When entering hazardous areas, operators are trained to request permission, wait for a response, and then enter. Usually the response will be immediate. However, there are instances when an operator may delay their response, which may lead to operators entering hazardous environments out of habit rather than wait for a response. This technique, similar to an automobile driver rolling through a stop sign, may increase the likelihood of an adverse event occurring. Since technique errors result from typical actions, operators may not be aware of the hazard these actions pose and therefore, continue without correction.

Skill-based errors were also observed with the use of PPE, tools, or equipment. One of the more common examples involved 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. Like many of us in real life, it was found that operators often exited the cab without completing one of these duties. One possible intervention to prevent these types of errors may be to install auditory or visual warnings to remind operators of the steps that need to be completed.

Table 3
Top three skill-based and decision errors.[a].

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

[a] Violations and perceptual errors represented a small percentage of unsafe acts and therefore are not shown.

Decision errors were most often identified as procedural errors which typically manifest as the incorrect or misapplication of a procedure for a given task. Like any decision making task, it assumes that the individual has knowledge of the procedure. However, an operator may perform a task incorrectly simply because they do not know the correct procedure either due to lack of training or retention of information. Regardless, these types of errors suggest that additional didactic training or procedural aids like checklists may prove useful.

Another common form of decision error observed in the mining data involved situational assessment. That is, did the individual identify the hazard and take 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 (Prince and Salas, 1999). A similar training program could be developed in mining, albeit at a broader scope given the diverse nature of tasks within the industry. Alternatively, potential hazards can be made more apparent with the use of warnings, barriers, and other signalling devices.

Also common, were decision errors associated with risk assessment. Mine 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 may 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 fully understood?

3.2.1. Temporal trends

Although, static numbers do provide some useful information as described above, if one is to identify threats and track the effectiveness of interventions, reliable human factors trends must be established. Traditionally, this is done annually, quarterly, or using some other unit of time. For example, when unsafe acts were examined annually, skill-based errors were identified in the largest percentage of cases for all years except for 2008 (Fig. 2). In 2008, decision errors were identified with the highest percentage of cases, followed closely by skill-based errors, then violations and perceptual errors. That is, roughly 6 out of every 10 cases examined in 2004 involved at least one skill-based error. There may have been more than one in a given case, but the causal code was only counted once in this analysis. Similarly, roughly 5 out of every 10 cases had at least one decision error, roughly 1 out of every 10 had at least one violation, and perceptual errors were rarely identified. Note that the percentages do not add up to 100% since any given case can have multiple human causal factors associated with it. Indeed, a given case could have one of each type of unsafe act (i.e., a skill-based, decision error, violation, and a perceptual error).

The other notable finding is that there were no significant differences at $\alpha = .05$ in the percentage of skill-based errors, decision errors, perceptual errors or violations from 2004 to 2008 (decision errors, $\chi^2 = 3.3$, ns; skill-based errors, $\chi^2 = 2.3$, ns; perceptual errors, $\chi^2 = 1.5$, ns; violations, $\chi^2 = 5.1$, ns). Put simply, all the lines were essentially flat suggesting that any interventions aimed at reducing specific types of human error prior to, or during this time period

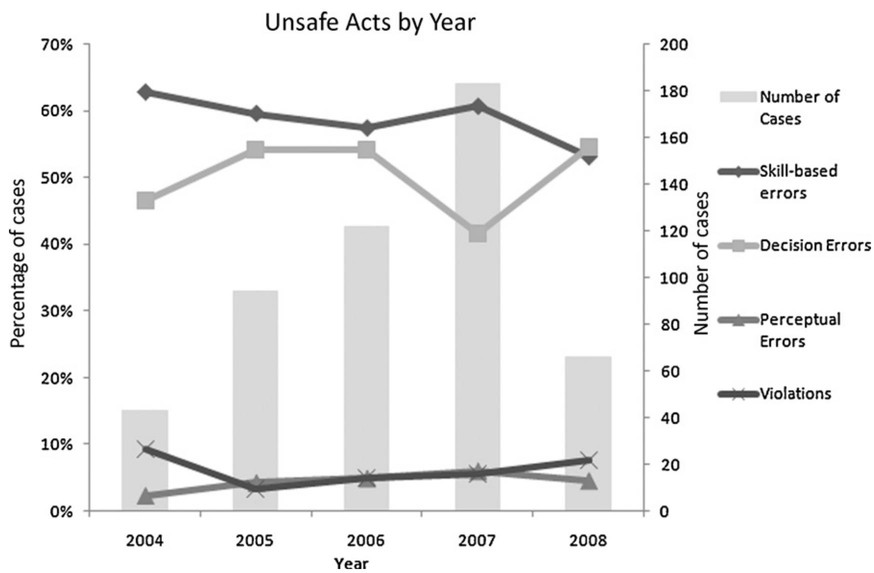

Fig. 2. Unsafe acts of the operator by year.

did not appear to have had any long term impact. There was a slight dip in decision errors identified in 2007; however, the historical trend quickly re-established itself at just over 50% of the cases.

3.2.2. Unsafe acts analysis by mine type

Unsafe acts were examined further by mine type. The percentage of cases at each mine type that were associated with each category of unsafe acts is illustrated in Fig. 3. The percentage of skill-based errors were the most prevalent error form and 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).

Unlike skill-based errors, decision errors did appear to vary across mine types ($\chi^2 = 10.39$, $p < 0.05$). For example, underground coal mines had the lowest percentage (23.1%) of cases associated with decision errors while quarries yielded the highest percentage (48.0%). The larger question is why decision errors were more frequent at quarries than any other mine types. Decisions are based on three key elements: (1) information – is the information accurate and timely; (2) knowledge – does the individual have the requisite understanding of the situation and training to make the decision,

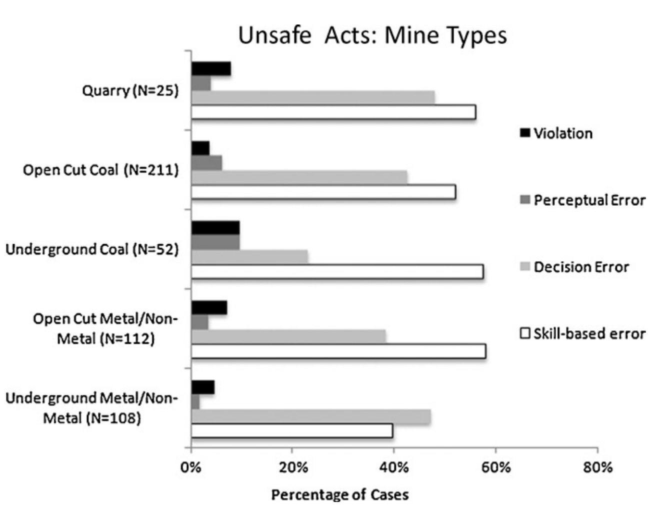

Fig. 3. Unsafe acts of the operator by mine type.

and (3) experience – with experience comes a better understanding of one's decisions. The likelihood that a decision will be successful is markedly reduced if any of these three components are absent or lacking.

Therefore, 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 (e.g., 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 so employees are rarely compelled to create their own course of action. Also of note, coal mines tend to be populated by a more experienced workforce due as evident in the higher retention rate among coal mines in Australia (MOSHAB, 2002). Obviously, the decrease in turnover naturally leads to workers with a more experienced workforce.

Violations and perceptual errors were identified in relatively few cases. Differences in perceptual errors and violations across mine types were not significant, $\chi^2 = 7.2$ and 3.5, respectively. Due to the low percentage of cases associated to violations and perceptual errors, no meaningful insights could be drawn.

3.3. Preconditions for unsafe acts

Although HFACS-MI identifies seven causal categories for the preconditions for unsafe acts, only four (i.e., physical environment, technological environment, adverse mental states, and communication and coordination) were observed in sufficient numbers to be reliably analyzed. Among these, the physical and technological environments were the most often identified precondition for all

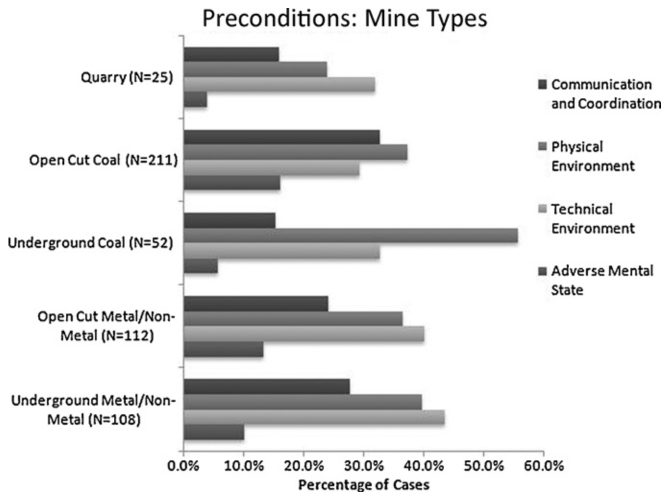

Fig. 4. Preconditions for unsafe acts by mine types.

mine types except open cut coal mines where communication and coordination was more prevalent (see Fig. 4).

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 example 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 example of skill-baseds) 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 the site. Instead, this is an excellent example of where mitigation rather than intervention strategies may prove more useful. For example, by requiring employees to wear boots that protect against lateral movement, ankle sprains can be reduced. Likewise, installing handrails in areas that get slippery or muddy would provide employees an opportunity to recover from slips and falls without injury.

Visibility was also frequently identified as a causal factor, contributing to 11% of the cases examined. Visibility included instances where there was an absence of adequate lighting and when there was glare caused by the sun. Potential ways to reduce problems with visibility include the addition of portable lighting particularly in underground areas where natural lighting is absent. In contrast, glare fro the sun is a problem often seen in surface operations. One way to address glare is the use of tinted eye protection, tinted windows, and even the modification of traffic flow to reduce direct sunlight may prove useful.

As one would expect in a highly mechanized industry, the technical environment was also commonly identified as a contributing factor. The most prevalent technical environment example was "equipment design/construction." Causal factors identified dealt with both the design of equipment from the original equipment manufacturer and modifications done on site. When modifications were made to equipment on site, it is vital that these modifications not affect the original integrity of the equipment. These modifications must also be completed by certified personnel. Also included were construction issues on the mine site not including the construction and design of roads.

Of interest is that 6.9% of cases involved failures with "PPE/guards/safety devices." Many instances were found where protective guards were removed or were never installed. The installation of guards on machinery is of vital importance in keeping operators safe from pinch points and ultimately from being drawn into the machine. Having guards installed on machines is an area where inspectors typically pay particular attention; yet, it continues to be a problem in the industry as seen in this data.

3.4. Unsafe leadership

Unsafe leadership was identified in 36.6% of cases analyzed. The majority of causal factors (62.3%) at this level fell into the 'inadequate leadership' category. The most often cited example involved training, which accounted for 43.9% of inadequate leadership codes and was a contributing factor in 15.6% of all cases. In this data, training involved more than just the initial teaching of procedures and policies at a mine site. There is also hands-on training, refresher training, training when standard operating procedures (SOPs) change, etcetera. However, it is often not enough to teach an operator the correct steps for a task a single time. Repetition and continual reinforcement through additional training and other means is necessary to ensure the task will be performed correctly. In other words, an operator must have more than just a casual understanding of the material. They must be competent and able to take what was learned and apply that knowledge in different situations. On-the-job training programs and didactic courses that do not acknowledge accepted learning principles might fall short and lead to accidents, as was the case in several accidents and incidents in this data.

Moreover, 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% which in some industries would be considered high. They also found that this turnover rate appeared to be higher amongst professional and managerial staff, which also may have affected the training workers' received. One benefit of retaining valued leaders may be the positive impact on training.

3.5. Limitations

The largest limitation of this study was that ad hoc data was used, making it impossible to speak with the people involved in each incident or accident. Only the information presented in the investigation reports or completed forms was used for the identification of causal codes. As a result, causal codes could be missing or that the percentage of cases associated with a causal category could not adequately reflect the true nature of mining incidents. However, given the large number of cases analyzed and the requirements enforced by the Department of Mines and Energy in Queensland, Australia for accident forms and reports, we feel that the frequency and percentages found in this study accurately reflect the role of human error in mining.

Another limitation of this study is that investigation reports and forms used for analysis were completed by mine personnel and therefore, there could be inconsistency in the quality of the reports and the training of those completing the reports. Fortunately, all reports and forms are reviewed by trained and experienced mine inspectors and therefore, inadequacies should have been caught and corrected prior to the analysis of cases.

Finally, the coders used in this study were not experts in mine safety and regulations. Ideally, double subject matter experts, those who are experts in both mine safety and HFACS would have been used. Unfortunately, double subject matter experts were not available for this study. To overcome this problem, all coders were given access to mining terminology dictionaries and had access to experts in mining safety.

4. Conclusions

Operator safety is paramount in the mining industry. While it was known that human error plays a major role in mining incidents and accidents, the specific types of human error had not been identified. This study showed that the HFACS-MI framework could be used to systematically identify underlying human factor causes in mining incidents and accidents. More important, 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 professional to develop targeted interventions.

In addition, this study 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 at best interventions targeting human factors were much more general and ubiquitous in their impact.

Results from this study also 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 do not know what the current problems are. From this baseline data, it will be possible to measure the effectiveness of future human factors interventions.

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, efforts are underway to examine United States mining accidents with HFACS-MI using data from the Mine Safety and Health Administration.

Finally, 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). 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, if an intervention has been proven successful in one industry, lessons can be learned by safety professionals in other industries.

Acknowledgments

We wish to acknowledge the funding of this research by the Queensland Government, Department of Mines and Energy (DME). We are grateful for the opportunity to carry out this research. We would like to thank the mine sites that allowed the author access in order to learn more about the mining industry. The recommendations presented in the paper are those of the authors and do not represent recommendations from DME or the Queensland Government.

References

Beach, R., Cliff, D., 2003. Workplace Turnover in FIFO Mining Operations in Australia: An Exploratory Study. AusIMM Bulletin Sept/Oct. Centre for Social Responsibility in Mining, Sustainable Minerals Institute, University of Queensland, Brisbane, QLD.

Coleman, P.J., Kerkering, J.C., 2007. Measuring mining safety with injury statistics: lost workdays as indicator of risks. J. Saf. Res. 38, 523–533.

Dekker, S.W.A., 2002. Reconstructing human contributions to accidents: the new view on error and performance. J. Saf. Res. 33, 371–385.

Gaur, D., 2005. Human Factors Analysis and Classification System applied to civil aircraft accidents in India. Aviat. Space Environ. Med. 76 (5), 501–505.

Li, W.-C., Harris, D., et al., 2008. Routes to failure: analysis of 41 civil aviation accidents from the Republic of China using the human factors analysis and classification system. Accid. Anal. Prev. 40 (2), 426–434.

Mitchell, R.J., Driscoll, T.R., et al., 1998. Traumatic work-related fatalities involving mining in Australia. Saf. Sci. 29 (2), 107–123.

MOSHAB, 2002. Safety Behaviours Survey of the Western Australian Mining Industry 2002. Safety Behaviour Working Party, Mines Occupational Safety and Health Advisory Board, Perth, Western Australia.

Pape, A.M., Wiegmann, D.A., et al., 2001. Air Traffic Control (ATC) related accidents and incidents: a human factors analysis. In: 11th International Symposium on Aviation Psychology, The Ohio State University, Columbus, OH.

Poplin, G.S., Miller, H.B., et al., 2008. International evaluation of injury rates in coal mining: a comparison of risk and compliance-based regulatory approaches. Saf. Sci. 46, 1196–1204.

Prince, C., Salas, E., 1999. Team processes and their training in aviation. In: Garland, D.J., Wise, J.A., Hopkins, V.D. (Eds.), Handbook of Aviation Human Factors. Lawrence Erlbaum Associates, Inc., Mahwah, NJ.

Reason, J., 1990. Human Error. Cambridge University Press, New York.

Reinach, S., Viale, A., 2006. Application of a human error framework to conduct train accident/incident investigations. Accid. Anal. Prev. 38, 396–406.

Rushworth, A.M., Talbot, C.F., et al., 1999. Investigating the causes of transport and tramming accidents on coal mines. Safety in Mine Research Advisory Committee. Bluhm Burton Engineering (Pty) Ltd., South Africa.

Shappell, S.A., Detwiler, C., et al., 2007. Human error and commercial aviation accidents: an analysis using the human factors analysis and classification system. Hum. Factors 49 (2), 227–242.

Shappell, S.A., Wiegmann, D.A., 2001. Applying reason: the human factors analysis and classification system (HFACS). Hum. Factors Aerosp. Saf. 1 (1), 59–86.

Wiegmann, D.A., Shappell, S.A., 2003. A Human Error Approach to Aviation Accident Analysis: The Human Factors Analysis and Classification System. Ashgate Publishing Company, Burlington, VT.