Preventing equipment related injuries in underground U.S. coal mines

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In 2004, underground coal mines in the United States reported 3,405 injuries to the U.S. Mine Safety and Health Administration (MSHA). Of these, 17 percent were associated with the use of bolting machines, 8 percent with continuous miners, and 4 percent each with scoop/load-haul-dump (LHD), shuttle cars and personnel transport. Analysis of the injury narratives identified five hazards that required attention. They are rock falling from supported roof, inadvertent or incorrect operation of bolting machine controls, handling continuous miner cable, collisions while driving underground vehicles and driving or traveling in underground vehicles on rough roadways.

The rate of lost-time injuries has steadily decreased during the past 10 years (from more than 10 per 100 FTE in 1995, to six in 2004). However, underground coal mining remains a hazardous industry. One of the contributors to this elevated injury risk is working with or near underground coal mining equipment. Roof bolting machines and continuous miners have been consistently identified as high risk equipment. They account for approximately 24 percent of all injuries to underground coal miners (Sanders and Shaw, 1989). LHD's, shuttle cars and personnel transports are also associated with injuries in underground coal mines (Burgess-Limerick, 2005).

Conventional analyses of injury statistics typically provide tables detailing the breakdown of injuries by body part, nature of injury or mechanism of injury. Such analyses are worthwhile and may be helpful in tracking broad trends over time. Further information is available in the narrative text field completed for each injury reported. The detail contained in these narratives varies. However, they generally provide some insight into the causes of the injury, such as the activity being performed at the time of

the injury and the mechanism by which the injury occurred.

Analysis of injury narratives has previously been undertaken in underground mining. Helander and Krohn (1983) conducted an analysis of injury narratives for most hazardous underground machinery in hard-rock mining. They coded the narratives for worker activity, suggested cause of accident machine part involved and body part injured. Similarly, Helander, Krohn and Curtin (1983) coded the injury narratives from 600 roof bolter accident reports for cause, machine part and body part injured. It was concluded that roofbolting was the most dangerous

Photo: Studies have found that roof bolting is the most dangerous job in underground coal mines.

job in underground coal mines and that rock falls accounted for 25 percent of roof bolting injuries.

The additional information available in injury narratives has the potential to aid in prioritizing effective control measures. The purpose of this investigation is to use injury narratives to identify opportunities for reducing common injury risks associated with underground coal mining equipment. It also discusses potential risk control strategies.

Risk is understood to be a combination of the probability of exposure to a hazard and the potential consequences of that exposure. Risk reduction can occur through reducing the probability of the hazard occuring, (although this typically requires the elimination or substitution of the hazard) or by reducing the severity of the potential consequences through design or administrative controls.

Table 1

Examples of injury narratives and coding.

Narrative example	Codes
Drill steel became lodged in top, employee attempted to put wrench on drill steel and slipped hitting up lever catching index and middle fingers on right hand between wrench and drill steel. (Required 11 stitches).	Bolter: drilling: caught between.
EE was installing outside bolts next to ribline. While in drilling procedure, a piece of top (15.24 mm (6 in.) thick, 91 mm (36 in.) long 79 mm (31 in.) wide struck backside, pushing ee into bolter boom, injuries included contusions to back, nose (fractured) and mouth. Bolter: drilling: struck by: falling rock.	Bolter: drilling: struck by: falling rock.
Injured was moving c.m. cable out of roadway. He was standing bent over reaching to his left and pulling to his right when he felt and heard a pop in his back. EE stated he lay there for approx. 5 min before was able to get up. Stated he was still having excruciating pain.	Continuous miner: handling cable: strained
The repairman was positioned about 7 m (20 ft) in front of the machine & instructed the miner operator to stop because the curtain was caught on the ripper ring. Machine operator heard repairman say OK & assumed he was clear of the machine. He started tramming backwards & repairman was caught between rib & left ripper ring.	Continuous miner: standing near: caught between.
Employee was operating a scoop when he ran over obstruction in roadway and struck head on canopy of scoop.	Scoop/LHD: driving: rough road.
EE was crushed between a coal rib and a rock duster being	Scoop/LHD: standing pulled by scoop. near: caught between.
EE was operating a shuttle car and had just received a load of coal from continuous miner. He trammed from face & made the turn to go west to the feeder. Operator of second Shuttle car waited for EE to clear the intersection. 1st car had to back up a short distance to clear the left rib. Operator of 2nd car thought he had cleared the intersection & pulled forward striking 1st car.	Shuttle car: driving: ran into.
Employee was operating shuttle car when rock flew up and hit him in the mouth causing a laceration to his lip and a chipped tooth.	Shuttle car: driving: struck by.
This is a "low coal" operation. As the injured exited the shuttle car in a rolling motion of his body, he heard and felt something snap in his knee.	Shuttle car: egress: strained.
Employee was in a Mantrip when it hit a pothole causing employee to be thrown from his seat onto the floor on the mantrip, injuring his back.	Personnel transport: traveling; rough road.

Method

Background data, and the narrative text field for all injuries (N=3405) reported to MSHA (as required under CFR 30, Part 50) as occurring at U.S. underground coal mines in 2004 were obtained from *www.cdc.gov/niosh/* mining/data. Reportable injuries, as defined by MSHA, includes accidents that require medical treatment, loss of consciousness, temporary restrictions in work duties or lost time but excludes "first aid only" injuries. These data include mine employees and independent contractors working on the mine site.

As part of each injury report, mines are required to provide a narrative describing each incident while detailed information is required by the regulation. In reality, though, the narratives reported vary in the detail provided, and rarely approach that stipulated. Analysis of the narratives involved the first investigator reading the full text field for each injury and coding for the activity being undertaken at the time of the injury, and the causal mechanism (Table 1).

The coding categories were not pre-structured but, rather, evolved during the data analysis in a method similar to Glaser and Strauss's (1967) constant comparative coding. In this method of analyzing qualitative data, the analyst initially codes each incident into as many categories as possible. The coding categories used are developed throughout the analysis. The general strategy during coding is to compare each case with previous incidents in the category to determine the category boundaries and relationships between categories, hence "constant comparative." Frequencies of the cross-tabulated combinations of codes were calculated and presented graphically to aid interpretation.

The analysis is not an objective, mechanistic process, but one that draws on the researcher's developing understanding of the phenomenon of interest. The coding process is about conceptualizing, reducing and relating the data obtained in qualitative form. The "grounded theory," which results from such analysis offers insight, enhances understanding and offers meaningful opportunities for action. The advantage of this technique over the use of pre-structured standard coding protocols is that it allows context sensitive categories to be used. This, in turn, assists in the identification of specific opportunities for action. It also allows the possibility of identifying previously unrecognized categories.

Results

In 2004, there were 646 underground coal mines in the U.S. These mines employed 37,445 miners and reported 3,405 injuries to MSHA. Of these injuries, 17 percent were associated with bolting machines (593 injuries), 8 percent with continuous miners (283 injuries) and 4 percent each with scoop/LHD (151 injuries), shuttle cars (134 injuries) and personnel transport (145 injuries). Figures 1 through 3 present the breakdown of these 1,306 injuries by equipment, activity being undertaken at the time of the injury and mechanism of injury. Seventy percent of the reported injuries involved lost time, while the remaining 30 percent involved periods of restricted duties or medical expenses only.

The most common injury mechanism associated with bolting machines is rock falling from supported roof (roof that has been bolted). This caused 208 bolting machine injuries in 2004 (33 percent of injuries associated with bolting machines). This type of event also accounted for 59 injuries associated with the operation of continuous miners in 2004 (21 percent of injuries associated with continuous miner operation). An inspection of all injury narratives suggests that 13 percent of all injuries reported in 2004 were caused by rock or coal falling from supported roof (477 injuries).

Injuries involving a part of the body being struck by, or caught between, during adjusting, drilling or bolting, occurred with relatively high frequency. Relatively minor injuries occurring as a consequence of being struck by falling drill steels, bolts or plates accounted for many of the "struck by" cases. More serious injuries occurred were associated with unintended consequences of the operation of bolting controls causing operators or another person to be struck by a moving part of the bolting machine, caught between the bolting machine and the rib, or caught in pinch points on the machine. The control operation was sometimes unintentional, typically caused by bumping a control with a self-rescuer or battery, or a control being struck by a falling object. Injuries caused by intentional control operation may be further divided into cases where:

- The wrong control was operated.
- The correct control was operated in the wrong direction.
- Operating of the intended control in the intended direction while the injured employee (either the operatoror another person) was in a position of danger (Table 2).

Strains associated with bolting and handling of bolting supplies (drill steels, bolts, plates and resin) also occurred relatively frequently. The most frequent injuries associated

Unintended consequences of the operation of bolting controls is a common cause of injury in underground mines.

with continuous miners are strains while handling cable. Handling cable accounted for 27 percent of the 283 continuous miner related injuries (76 injuries).

Taken as a group, the most common injuries associated with LHD/scoop, shuttle car and personnel transport were collisions while driving or traveling (64 injuries), driving or traveling over a pothole or other road abnormality (85 injuries) and being struck by an object while driving or traveling (106 injuries). These latter injuries have diverse origins, including being struck by falling material from a roof, wall or thrown up from the floor, as well as striking objects hanging from the roof.

Table 2

Examples of control operation hazards.

Unintentional control operation (guarding)

- EE had just swung the drill head on the fletcher RRII roof bolter to drill hole for sister hook when his SCSR (Self-contained self-rescuer) hit the swing lever thus pinching his knee to the coal rib from the drill head of the bolter.
- While putting drill steel together in the process of drilling a test hole, a piece of rock fell striking the control lever causing drill pot to rise pushing drill steel into his left hand.
- As EE was installing a cable bolt he accidentally hit the control levers with a bolt causing the drill head to swing out against his left foot, causing a fracture.

Incorrect control (control layout, coding)

- The employee was roof bolting when he went to drop the mast and pulled the wrong lever. He set the jaws on his right hand causing a smashing injury to that hand.
- EE stated he was trying to unplug the head on the roof bolter. He placed his hand on the slide and his coworker was to activate the rotation lever but hit the wrong lever and dropped the head, catching EE's hand.
- While he was being trained on the roof bolter, he caught his right middle finger in the jaws. He then pulled the wrong lever, tightening it against his finger. He fractured the bone at the tip of his finger.

Incorrect direction (direction compatibility)

- Employee was bringing steel out of hole. As he was separating the steel he reached over to lower the head to give more room to get the steel out. When he engaged the head he went the wrong way, catching his finger between the two pieces of steel, causing a laceration as well as a broken bone.
- Injured party had just put up his 1st bolt in the entry. When he started to swing the boom, he pulled the lever the wrong way, striking his right knee.

Operation while person in position of danger (guarding, interlock)

- After finishing bolting a cut, employee was attempting to hand reflectors in the roof bolt plate. Due to high top, he stepped up on the roof drill at the scissor jack of the ATRS so he could reach the top. As he stepped onto the frame, the other bolter operator began dropping the ATRS to prepare to move the machine. Employee's foot was caught in a pinch point resulting in a fracture.
- The EE was watching the bolter operator bolt and upon leaving put his hand on the arms that attached to the head. At the same time the bolter operator raised the head, thus crushing the left pinkie finger of the EE.

Discussion

These results are consistent with previous observations (Sanders and Shaw, 1989; Helander et al., 1983) that roof bolting machines are the equipment most frequently involved in underground mining injuries (17 percent), and being that struck by rock falling from supported roof as the most common mechanism. The proportion of injuries associated with bolting machines in U.S. underground coal mines appears to have remained unchanged since the 1970s (15 percent, Jamison, 1977; 17 percent, Sanders and Shaw, 1989; 16 percent, Klishis et al.,1993).

Similarly, the proportion of injuries associated with continuous miners (8 percent) is consistent with that previously reported for U.S. mines (7 percent, Sanders and Shaw,1989). The total proportion of injuries associated with the equipment considered (37 percent) is considerably higher than that reported recently for underground coal mines in New South Wales, Australia (23 percent, Burgess-Limerick and Steiner, 2006). The differences may be a consequence of different environmental conditions (higher roof heights in Australian mines) and differences in mining methods (in Australia, bolting is predominantly undertaken from integrated bolter-miners). Perhaps in part as a consequence of the higher roof heights, Australian mines have a higher prevalence of the use of screening to prevent minor rock fall injuries.

The use of the frequency of reported injuries for the prioritization of risk control strategies has limitations because of the tendency to underestimate the importance of relatively rare, but high consequence events. Injury reports also underestimate the contribution of risk factors such as whole body vibration that have a long-term cumulative contribution to an elevated risk of injury. However, taking these limitations into consideration, the results of the injury narrative analysis suggests the following hazards as the highest priority for elimination or control:

- Rock falling from supported roof.
- Inadvertent or incorrect operation of bolting controls.
- Handling continuous miner cable.
- Collisions while driving LHD/scoop, shuttle cars and transport.
- Rough road while driving or traveling in LHD/scoop, shuttle cars and transport.

Rock falling from supported roof

Rock fall data are remarkably consistent with previous reports. For example, Klishis, et al. (1993) analyzed 2,685 bolting related injury narratives and found that 911 (34 per-

FIGURE 1

Injuries associated with bolting machines in U.S. underground coal mines in 2004 (593) coded for activity and mechanism of injury event. Line width indicates number of injuries reported.

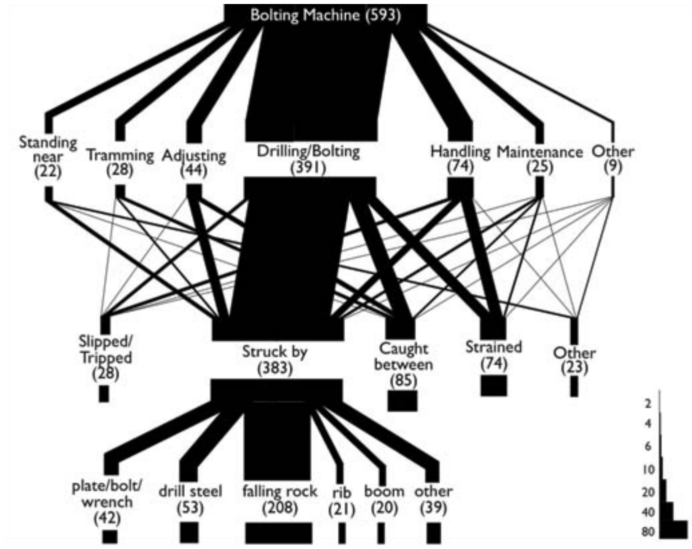
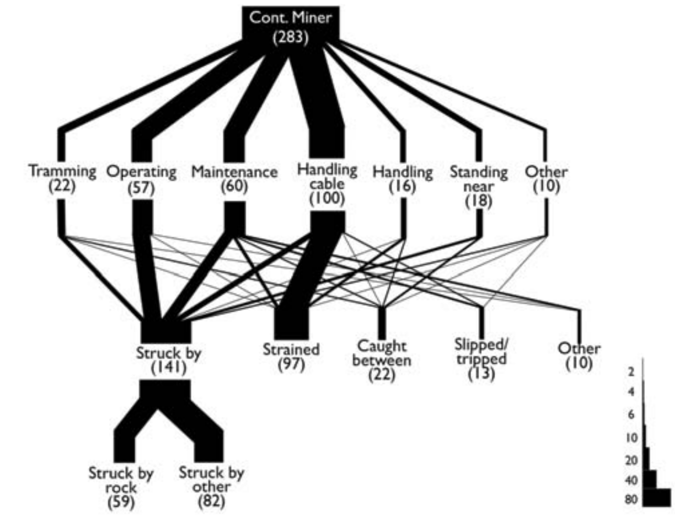


FIGURE 2

Injuries associated with continuous mining machines in U.S. underground coal mines in 2004 (283) coded for activity and mechanism of injury event. Line width indicates number of injuries reported.



cent) involved falls of roof material (cf. 33 percent this report). Similarly, Bise, et al. (1993) determined that in 1987, 57 of 319 continuous miner related injuries (18 percent) were due to falling rock (cf. 21 percent, this report).

The total number of injuries as a consequence of coal or rock falling from supported roof (477) is reduced from the 650 reported by Robertson, et al. (2003) as the annual average from 1995 to 2001. This suggests that there has been a reduction in overall injuries of this type in recent years. While this reduction reflects the overall reduction in injury rate occurring during this period, it is likely that the change is, in part, a consequence of the introduction of roof screening in some U.S. mines. This has been demonstrated to virtually eliminate injuries of this type (Robertson and Hinshaw, 2002). Indeed, injuries due to rock falling from supported roof were almost non-existent in a similar analysis of equipment related injury narratives from Australian underground coal mines where screens are routinely put in place during bolting (Burgess-Limerick and Steiner, 2006).

The importance of preventing rock fall injuries cannot be overstated. Where low seam heights make screening with steel mesh difficult, it may be necessary to develop alternative means of reducing the risk of minor rock falls such as the use of shotcrete or other membrane (Pappas et al., 2002). Preventing minor rock falls, whether through screening or other means, could prevent nearly 500 injuries per year or 13 percent of all injuries in U.S. underground coal mines.

However, it may take more than technological advances to achieve control of this risk. As Mark (2002) noted in the context of roof bolting, improved technology must be accompanied by changes in the perceptions regarding acceptable risks. A tendency to accept current risk levels and rely on administrative controls was evident from many of the injury narratives. For example, the following is typical:

"Employee was operating a continuous miner in unit 1. He was standing just outby the continuous miner tail and a piece of roof rock fell from between the roof bolts, striking his back. The incident caused a contusion to the back and a fracture to a rib. The employee will be instructed to always check the roof and rib in his work are and to scale down loose material."

The narrative betrays an underlying assumption that the injury was

Increased length of cables might be a contributing factor in some injuries associated with cable handling in underground coal mines.

due to the employee's failure to check the roof and remove loose material, that is, that the employee's behavior is the source of the hazard, rather than the employer's failure to provide a safe system of work. This is a cultural issue that requires change before meaningful reductions in injury risk will be achieved.

Inadvertent or incorrect operation of bolting controls

The hazards associated with inadvertent operation of controls, operation of incorrect controls, operating controls in an incorrect direction, or while a person is located in a pinch point, have long been recognized. Miller and McLellan (1973) commented on the "obvious need" to redesign roof bolting machines. They suggested that, of 759 bolting machine related injuries, 72 involved operating the wrong control Helander et al. (1983) determined that 5 percent of bolting machine accidents were caused by control activation errors. Improvements to guarding to prevent accidental control operation, standardization of mining equipment controls, especially drilling and bolting controls, and the use of shape and length coding has been suggested on numerous occasions during the past 40 years. (Helander et al., 1983; Klishis et al., 1993; Hedling and Folley, 1972; Grayson et al., 1992; Helander et al., 1980; Muldoon et al., 1980).

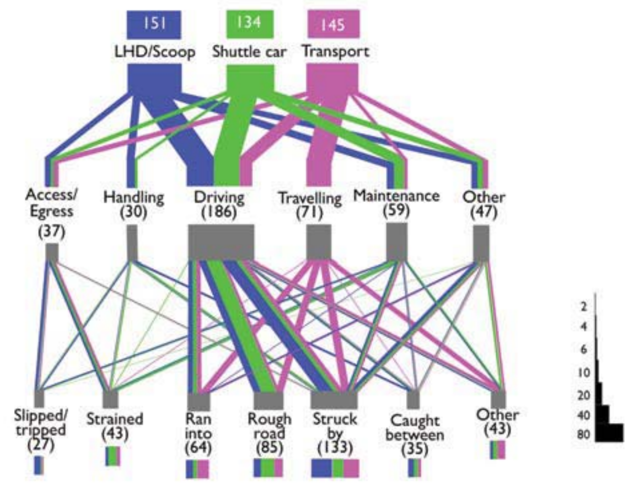
Hedling and Folley noted (in the context of continuous miner controls) that "the widespread use of traditional round control knobs, regardless of function being controlled, is another source of error in operation." They proposed that "each control knob is designed to resemble (at least symbolically) the equipment it represents." Similarly, Helander et al., (1980) suggested that "poor human factors principles in the design and placement of controls and inappropriately designed workstations contribute to a large percentage of the reported injuries." In particular, a lack of standardization of controls was noted, with more than 25 different control sequences being identified, differences existing even on similar machines produced by same manufacturer. Helander et al., also noted the lack of control coding, violation of direction stereotypes, a mixture mirror image and left/right arrangements and the possibility of inadvertent operation.

Helander and Elliott authored a proposal in 1982 for a Society of Automotive Engineers standard titled "Human Factors Guidelines for Roof Drills," which addressed these issues. The proposed standard was later subsumed within a later proposed standard titled Human Factors Design Guidelines for Mobile Underground Mining Equipment that was defeated at a ballot in 1984. Klishis et al., (1993) again noted a lack of standardization of bolting machine controls, even among machines from the same manufacturer and commented on the potential for injuries due to incorrect control operation.

Bolting machine controls require standardization to an appropriate layout (including shape and length coding) to reduce the probability of operation of the wrong control, although open questions remain regarding whether control layouts should be mirrored, and the relative importance of shape, location and length coding for the prevention of "wrong control" type errors. Control standardization must also consider the question of directional control-response compatibility principles to reduce the probability of operation of controls in the wrong direction. Further research is required to determine the most appropriate layout and directional control-response relationships specific to bolting machines. Chan et al., (1985) suggested that "conflicting recommendations and gaps in the literature would need to be resolved before any standardization of control-response relationships for mining machines was possible." This remains true.

FIGURE 3

Injuries associate with load-haul-dump/scoop (151), shuttle car (134), and personnel transport (145) in U.S. underground coal mines in 2004 coded for activity and mechanism of injury event. Line width indicates number of injuries reported.



Cable handling

Analysis of the injury narratives suggest that, in 2004, handling cable accounted for 76 of the 283 continuous miner related injuries (27 percent). That was more than the 11 percent noted previously (Bise et al., 1993), but consistent with recent Australian data in which 23 percent of continuous miner related injuries were associated with handling cable (Burgess-Limerick and Steiner, 2006). Technological changes during the last 10 years have resulted in longer cuts. It may be speculated that increases in the length of cable being handled, combined with reduction in the number of miners and increases in the average age of miners, may, in part, account for the increased proportion of cable handling injuries.

The severity of injuries associated with handling cable varies from relatively minor shoulder strains to serious back injuries. The cumulative nature of most musculoskeletal injuries implies that other manual tasks are likely to have also contributed to these injuries. However, there is no doubt that handling continuous miner cable represents a high risk of injury and this is consistent with biomechanical analysis of the task (Gallagher et al., 2002). Engineering controls are required to eliminate or reduce manual cable handling. Integration of cable and other services with continuous haulage has been suggested in the context of remote control (Schnakenberg, 1997).

Although vehicle collisions are infrequent, the consequences are often severe. Rough roads can also contribute to injuries.

Vehicle collisions

While vehicle collisions represent a relatively small proportion (15 percent) of the injuries associated with scoop/LHD, shuttle car and transport, the consequences of collisions are frequently severe and include fatalities. This figure is also double the proportion of "collision" related injuries for these vehicles found in recent Australian data. The probability of vehicle collisions is increased considerably by the restricted visibility inherent in LHD and shuttle cars. This is likely exacerbated by the low seam heights.

This is not a new observation. Reports by Kingsley et al., (1980) and Pethick and Mason (1985) described the visibility difficulties associated with the design of free-steered vehicles. Similarly, Simpson et al., (1996) suggested that many underground vehicle collisions are at least, in part, a consequence of restricted driver visibility.

The visibility restrictions that driving LHD vehicles is one of the few aspects of mining equipment design that has been the subject of formal research. The research has largely been restricted to documenting the extent of the problem and providing methods for assessing the lack of visibility associated with current designs (Eger et al., 2004). Recommendations for LHD redesign arising from the research include raising the sitting position where possible and cab redesign to remove visual obstructions. Physical separation of pedestrians and vehicles as far as practicable and vehicle mounted proximity sensors and cap lamp battery mounted emitters may also be beneficial in preventing potentially serious injuries. Examples of proximity detection systems include that developed by the National Institute for Occupational Safety and Health (NIOSH) (Schiffbauer, 2001).

Rough road

Injuries associated with driving or traveling in a vehicle that encounters a pothole or other roadway abnormality accounted for 20 percent of injuries associated with scoop/LHD, shuttle car or transport. This is lower than the 34 percent of injuries associated with this mechanism in recent Australian data (Burgess-Limerick and Steiner, 2006). And this may reflect the greater use of rail transport in U.S. mines.

Even so, improvements in roadway standards to avoid potholes and other abnormalities would be an effective means of preventing injuries of this type. Provision of vehicle suspension and improved seating have the potential to reduce these injuries (Mayton et al., 1997, 1999). These improvements will also reduce exposure to high amplitude, whole body vibration, which is associated with the development of back pain through cumulative mechanisms (McPhee, 2001).

Conclusion

The five top priority hazards associated with underground coal mining equipment have been identified and information about potential contributing factors and controls collated. Consideration of these hazards as part of design risk assessments conducted by manufacturers, and operational risk assessments conducted by mines sites, has the potential to prompt implementation of effective control measures.

Further information and tools to assist this process are available elsewhere (Burgess-Limerick, 2007). However, as Mark (2002) observed, effective control measures will only be implemented when current levels of risk are perceived to be unacceptable. The injury narratives revealed a tendency to accept current risk levels and focus on individual behavior and administrative controls rather than directing attention to elimination and design. This must change before significant reductions in injury risk are likely to occur. (References are available from the authors.)

Acknowledgements

This research was supported in part by the Australian Coal Association Research Program and was undertaken while the first author was a National Academy of Sciences, Senior Research Associate at NIOSH Pittsburgh Research Laboratory.