TECHNICAL NOTE

Injuries associated with continuous miners, shuttle cars, load–haul–dump and personnel transport in New South Wales underground coal mines

R. Burgess-Limerick*[1] and L. Steiner[2]

In the three years to June 2005, 959 injuries associated with continuous miners (CMs), shuttle cars (SCs), load–haul–dump and personnel transport (PT) were reported by NSW underground coal mines, comprising 23% of all injuries reported. The present paper reports an analysis of the narrative field accompanying these reports to determine opportunities for controlling injury risks. The most common combinations of activity and mechanism were: strain while handling CM cable (96 injuries); caught between or struck by moving parts while bolting on a CM (86 injuries); strains while bolting on CM (54 injuries); and slipping off a CM during access, egress or other activity (60 injuries). For the other equipment considered, the common injury mechanism was the vehicle running over a pothole or other roadway abnormality causing the driver or passengers to be injured (169 injuries). Potential control measures include: monorails for CM services; hydraulic cable reelers; handrails on CM platforms; redesign of CM platforms and bolting rigs to reduce reach distances during drilling and bolting; improvements to guarding of bolting controls; standardisation and shape coding of bolting controls; two handed fast feed; improvements in underground roadway maintenance, vehicle suspension, visibility and seating; and pedestrian proximity warning devices.

Keywords: Underground coal, Injury, Ergonomics, Development equipment

Introduction

Working with or near underground coal mining equipment is inherently hazardous owing to the multiple sources of injurious energies and adverse environmental conditions. Australian compensation statistics suggest that 22% of all lost time claims in the mining industry are associated with mobile plant and transport.[1] A previous analysis of injury data obtained over 10 years from six mines suggested that the equipment most commonly involved in these injuries were continuous miners (CMs), shuttle cars (SCs), load–haul–dump (LHD) vehicles and personnel transport (PT).[2] The present paper reports an analysis of the narrative text fields accompanying all reports of injuries associated with these equipment types in New South Wales (NSW) underground coal mines in the three years to June 2005.

Conventional analyses of injury statistics typically provide tables detailing the breakdown of injuries by body part, nature of injury, mechanism of injury or agency of injury. Such analyses are appropriate and may especially be helpful in tracking broad trends over time, however further information is available in the narrative text field completed for each injury reported to the workers' compensation insurer for coal mines in NSW (Coal Services Pty Limited).

The detail contained in these narratives varies, however they generally provide additional insight into the causes of the injury, such as the activity being performed at the time of the injury. Analysis of injury narratives has previously been undertaken in mining[3,4] and construction.[5] Helander and Krohn[3] conducted an analysis of injury narratives for most hazardous underground machinery in hard rock mining, coding the narratives for worker activity, suggested cause of accident, machine part involved and body part injured. Similarly, Helander *et al.*,[4] examined injury narratives from 600 roof bolter accident reports from mines in the USA and coded each for cause, machine part and body part injured, concluding that roof bolting was the most dangerous job in US underground coal mines and that rock falls accounted for 25% of roof bolting injuries.

The information available in injury narratives has potential to aid in prioritising effective control measures.

[1]School of Human Movement Studies, The University of Queensland, Australia
[2]National Institute for Occupational Safety and Health, Pittsburgh Research Laboratory, USA

*Corresponding author, email robin@hms.uq.edu.au

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The aim of the present investigation is to utilise injury narratives to identify opportunities for reducing common injury risks associated with underground coal mining equipment in NSW.

Method

The narrative text fields for all equipment related injuries reported by NSW underground coal mines during the three financial years to June 2005 were provided by Coal Services Pty Limited. Injuries associated with CM, SC, LHD and PT were identified for further analysis. Contextual data such as the number of active underground mines, number of employees and total injury numbers were also obtained for each year.

Analysis involved 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 (*see* Table 1 for examples). The coding categories were not prestructured, but rather evolved during the data analysis in a method similar to Glaser and Strauss' constant comparative coding.[6] Frequencies of the cross-tabulated combinations of codes were calculated and presented graphically in Figs. 1–4 to aid interpretation.

Results

Table 2 provides relevant background data. Of the 4169 injuries reported during the three years to June 2005, 447 were associated with CMs, 232 with LHD, 140 with SCs and 122 with PT; a total of 959, or 23% of all injuries reported during the period.

Tables 3–6 provide the cross-tabulated frequencies of codes for injuries associated with each of the four equipment types under consideration. The same data are represented in Figs. 1–4 as a means of highlighting the predominant injury risks.

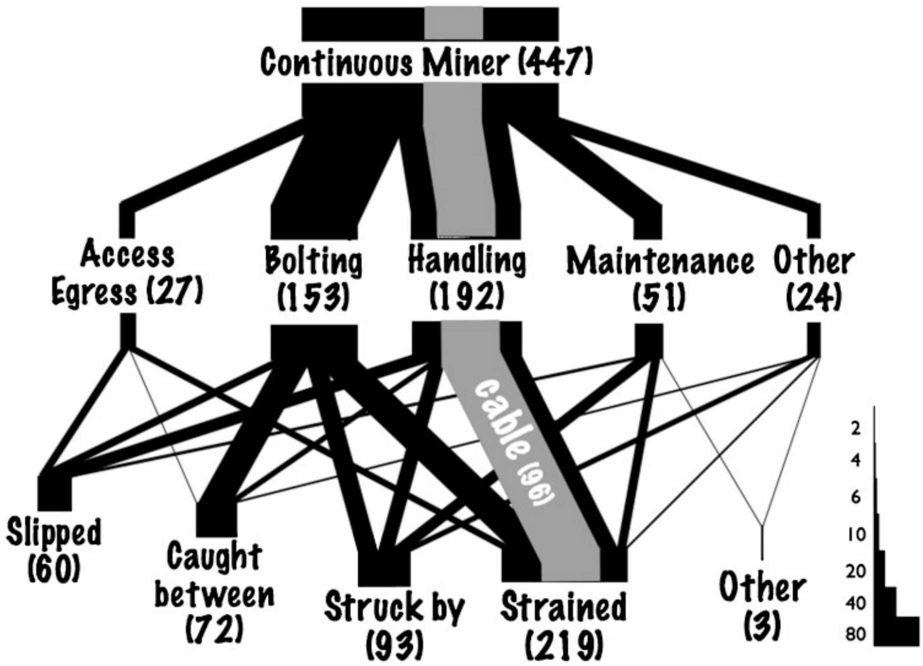
The data provided in Table 3 and illustrated in Fig. 1 highlight a number of opportunities for controlling injury risks associated with CMs. Strains while handling was the most frequent cause of injury associated with CMs. The majority of these injuries involved handling CM cable. Strains (typically of the shoulder) while bolting were also relatively common and are likely a consequence of handling drill steels and bolts at a distance from the body. Slipping off the CM platform, whether during access or egress, or during operation on the platform, accounted for 60 injuries in the three year period.

Injuries caused by a body part (typically hand or fingers) being 'caught between' during bolting were also a frequent combination of activity and mechanism. These injuries are unintended consequences of the operation of controls. The control operation was sometimes unintentional, typically caused by bumping a control with self-rescuer or battery, or the control was struck by a falling object. Injuries caused by intentional control operation may be further divided into cases where:

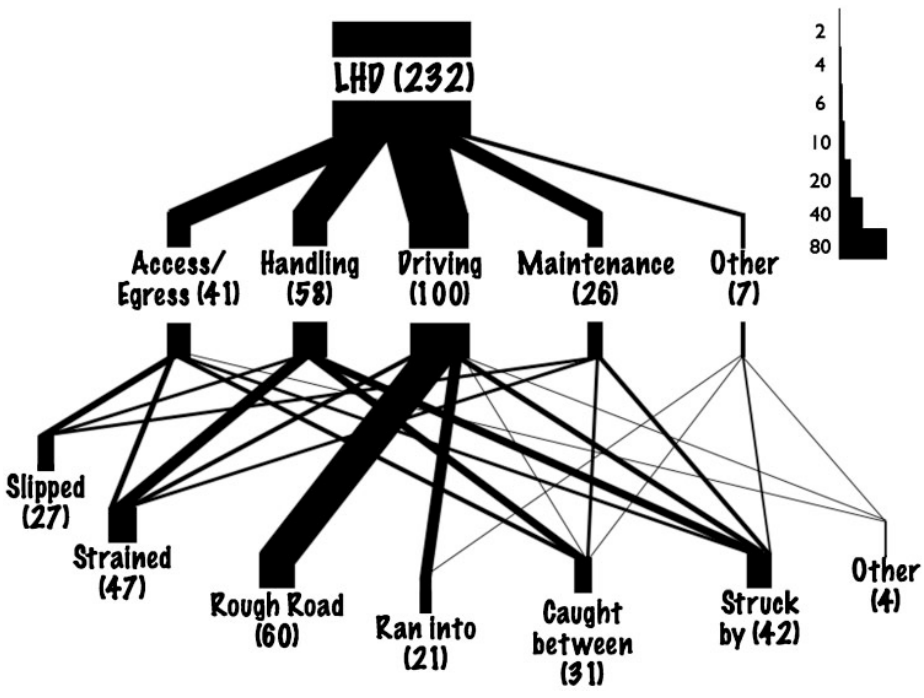
(i) the wrong control was operated
(ii) the correct control was operated in the wrong direction

Table 1 Examples of text fields and coding

Example narrative	Codes
While assisting with face support when he carried steels back to cassette on CM ABM right platform, he slipped falling off the edge of the platform onto coal rubble causing contusion to left thigh and left arm.	CM Handling Slipped
While bolting on the O/D side of CM retrieving the drill steel when he stepped backwards to replace the drill steel onto the rack he slipped off the side of the CM straining his lower back.	CM Bolting Slipped
While roof bolting and putting up mesh when his hand resting on top of steel his hand was caught between bolting rig and drill steel.	CM Bolting Caught between
While roof bolting on ABM 20 lhs outer rig overstretching with chemical in right hand and roof bolt in left hand installing a bolt, he strained his left shoulder.	CM Bolting Strained
While standing on a work platform lifting CM cable to the roof to be placed on hooks, he strained his right shoulder.	CM Handling cable Strained
While returning to EIMCO after having crib he grabbed the greasy handle that provided to help enter the EIMCO, slipped and fell twisting his left knee.	LHD Access Slipped
While servicing Wagner No. 7 he slipped on machine after checking water level in the radiator straining his right knee.	LHD Maintenance Slipped
While he was crossing the road, he was struck by EIMCO bucket when deputy reversed the EIMCO ready to turn a corner lacerating his forehead.	LHD Driving Ran into
While driving a SC running over a packer the car bounced violently throwing him out of the car; he managed to stop the machine and when he got out he felt pain to his left knee.	SC Driving Rough road
While driving away from the CM, the SC bumped the rib and came over the top of the canopy pinning him inside lacerating his face, neck and chest.	SC Driving Ran into
While a passenger in PJB when machine hit a mud hole he was thrown around in passenger compartment striking the roof causing neck and upper back pain.	PT Travelling Rough road



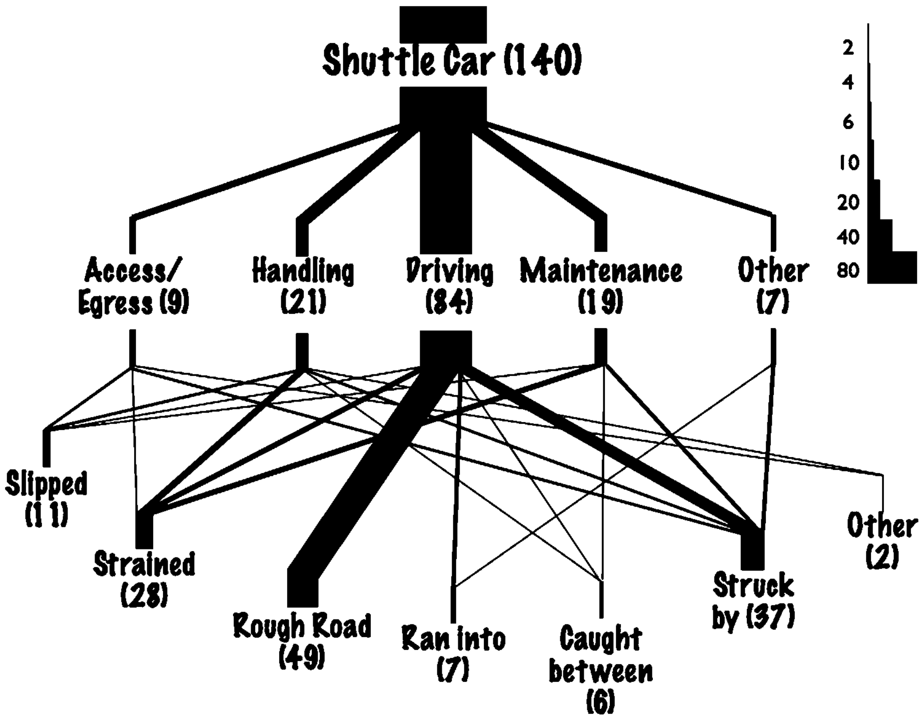
1 Combinations of activity and injury mechanism codes for injuries reported by NSW coal mines involving CMs for three years to June 2005



2 Combinations of activity and injury mechanism codes for injuries reported by NSW coal mines involving LHD vehicles for three years to June 2005

Table 2 Number of active underground coal mines in NSW for each of three years to June 2005, number of employees, total number of injuries reported to Coal Service (MEO and TLC) and injuries coded as involving CMs, LHD, SCs and PT

Year	Mines	Employees	Injuries	CM	LHD	SC	PT
2002–2003	29	5064	1491	114	90	51	40
2003–2004	27	5054	1361	191	73	44	37
2004–2005	28	5620	1317	142	69	45	45
Total			4169	447 (11%)	232 (6%)	140 (3%)	122 (3%)

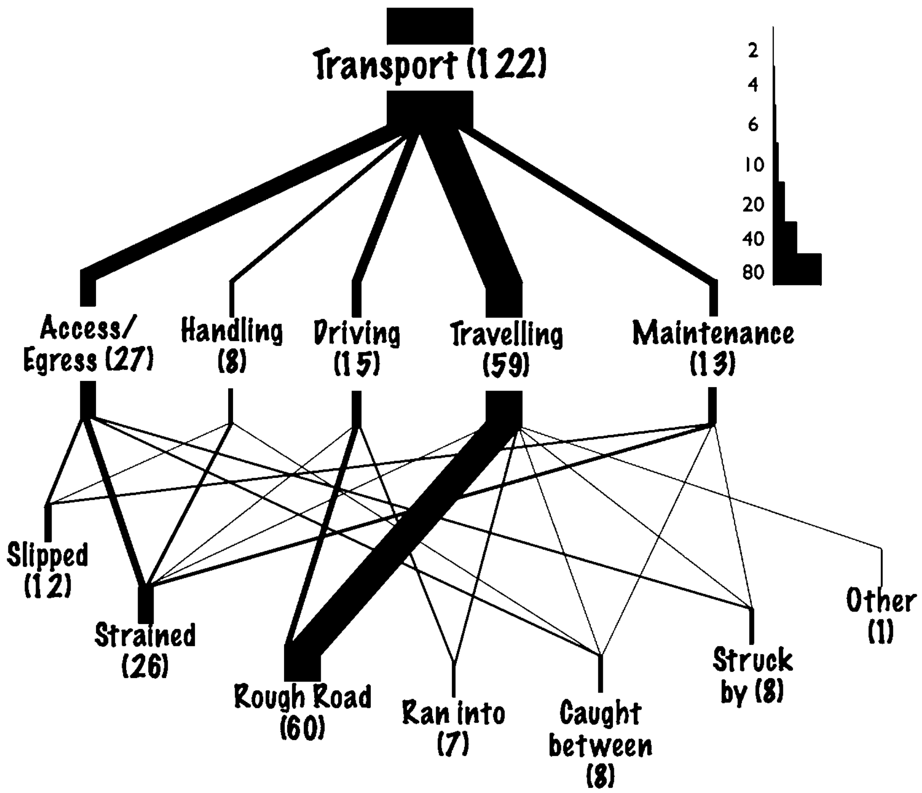


3 Combinations of activity and injury mechanism codes for injuries reported by NSW coal mines involving SCs for three years to June 2005

(iii) operating of the intended control in the intended direction while the injured employee (either the operator or another person) was in a position of danger.

Examples of each type of bolting machine control related injury are provided in Table 7.

The consideration of Figs. 2–4 reveals that the most common cause of injuries associated with LHD, SC and



4 Combinations of activity and injury mechanism codes for injuries reported by NSW coal mines involving PT for three years to June 2005

PT vehicles occurred when the vehicle was driven over a pot hole or other roadway abnormality. This mechanism typically causes the driver and/or passengers to strike their head on an internal structure resulting in neck, back or shoulder injuries. An injury mechanism of particular concern because of the potential severity of consequences is 'ran into' while driving (or travelling) LHD, SC or PT (35 injuries).

Discussion

The use of the frequency of reported injuries for the prioritisation of risk control strategies has limitations because of the tendency to underestimate the importance of relatively uncommon, but potentially high consequence events. Injury reports also underestimate the contribution of risk factors such as whole body vibration which 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:

(i) handling CM cable
(ii) strain while bolting
(iii) slipping off CM platform

Table 3 Cross-tabulation of activity and mechanism injury codes for all injuries associated with CMs reported during three years to June 2005 by NSW underground coal mines

	Mechanism					
Activity	Slipped	Strained	Caught between	Struck by	Other	Total
Access/egress	14	12	1	0	0	27
Bolting	13	54	52	34	0	153
Handling cable	2	96	1	4	0	103
Handling vent tubes	5	27	4	21	0	57
Handling other	16	9	5	2	0	32
Maintenance	6	17	6	20	2	51
Standing near	3	0	1	6	1	11
Other	1	4	2	6	0	13
Total	60	219	72	93	3	447

Table 4 Cross-tabulation of activity and mechanism injury codes for all injuries associated with LHD vehicles reported during three years to June 2005 by NSW underground coal mines

	Mechanism							
Activity	Slipped	Strained	Rough road	Ran into	Caught between	Struck by	Other	Total
Access/egress	13	11	0	0	8	7	1	41
Handling	7	21	0	0	12	10	0	58
Driving	0	8	60	19	2	10	1	100
Maintenance	7	7	0	0	5	7	0	26
Other	0	0	0	2	1	3	1	7
Total	27	47	60	21	31	42		232

Table 5 Cross-tabulation of activity and mechanism injury codes for all injuries associated with SCs reported during three years to June 2005 by NSW underground coal mines

	Mechanism							
Activity	Slipped	Strained	Rough road	Ran into	Caught between	Struck by	Other	Total
Access/egress	4	1	0	0	0	3	1	9
Handling	4	10	0	0	2	4	1	21
Driving	2	8	49	6	1	18	0	84
Maintenance	1	9	0	0	3	6	0	19
Other	0	0	0	1	0	6	0	7
Total	11	28	49	7	6	37	2	140

Table 6 Cross-tabulation of activity and mechanism injury codes for all injuries associated with PT reported during three years to June 2005 by NSW underground coal mines

	Mechanism							
Activity	Slipped	Strained	Rough road	Ran into	Caught between	Struck by	Other	Total
Access/egress	7	12	0	0	4	4	0	28
Handling	1	5	0	0	2	0	0	8
Driving	0	2	9	4	0	0	0	15
Travelling in	0	1	51	3	1	2	1	59
Maintenance	4	6	0	0	1	2	0	13
Total	12	26	60	7	8	8	1	122

(iv) inadvertent or incorrect operation of bolting controls and operation of controls while a person is in a position of danger
(v) hitting pot holes or other roadway abnormality
(vi) collisions while driving underground vehicles.

Cable handling

The injury narratives suggest that in the three years to June 2005, strains occurring while handling CM cable accounted for 96 injuries in NSW coal mines. The severity of injuries associated with handling cable varies from relatively minor shoulder strains to serious back injuries. While the cumulative nature of most musculoskeletal injuries implies that other manual tasks are likely to have also contributed to these injuries, there is no doubt that the handling CM cable represents a high risk of injury, and this is consistent with biomechanical analysis of the task.[7,8] Engineering controls are required to eliminate or reduce manual cable handling. The provision of monorails to carry CM services would likely reduce injuries caused by manual cable handling, however a method of installation and retrieval of the monorail is required which avoids introducing additional musculoskeletal injury risks. The use of LHD mounted hydraulic cable reelers is also likely to be beneficial where they can be used. Integration of cable and other services with continuous haulage has been suggested in the context of remote control.[9]

Strain while bolting

Strains (typically of the shoulder) while bolting were described as the injury mechanism in 54 injuries reports in NSW in the three years to June 2005. These injuries are likely a consequence of the requirement for the shoulder to frequently adopt a posture involving a combination of flexion and lateral flexion to place drill steels and bolts in the chuck, with the resulting requirement of relatively high shoulder torque to perform the task. Alterations to platform and/or bolting rig design to reduce the reach distance associated with placing drill steels and bolts are justified to reduce this injury risk.

Slipping off CM platform

Slipping off the CM platform, whether during access or egress or during operation, was the cause of 60 injuries in the three year period and these injuries justify attention to improving access systems and giving consideration to installation of handrails. While MDG1[10] specifies handrails for platforms higher than 1·2 m, the injury experience in NSW mines suggests this is insufficiently protective, and fall protection may be justified for all CM platforms.

Inadvertent or incorrect operation of bolting controls and operation of controls while person in position of danger

'Caught between' injuries associated with roof or rib bolting were reported by NSW mines on 52 occasions in the three years to June 2005. The resulting injuries varied in severity, but have the potential to cause permanent disability and fatalities. 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 recognised. Improvements to guarding to prevent accidental control operation, standardisation of mining equipment controls especially drilling and bolting controls and the use of shape and length coding have been suggested on numerous occasions over the past 40 years.[11–18]

Table 7 Examples of control operation hazards

Unintentional control operation (guarding)
While using CM mounted rib bolter the steel jammed in the hole, he tried to free it with a shifter when lamp lead caught control lever which operated timber jack causing bruising to left hand and fracture l/5 finger.
While removing 7' drill steel his battery pouch caught a lever which lowered the timber jack bending the drill steel forcing his right middle and ring fingers in the mast causing laceration.
Incorrect control (control layout, coding)
While extending CM platform he pulled the diversion lever to push platform out, the rib bolter came down jamming his left foot causing fracture to l/5 toe.
While operating RB01 installing roof bolts he placed his left hand on the dolly to remove it, he pulled the wrong lever jamming his left ring finger – crush injury.
While roof bolting putting roof bolt to the roof he pulled the wrong lever which bought the timber jack down trapping his right arm between timber jack and manifold lacerating right forearm and wrist.
While putting rib support in the drill steel stuck and pulled out of chuck as he reached back to fine tune alignment of drill rod he pulled the wrong leaver pushing timber jack out crushing left hand against the rib.
While rib bolting fitting the dolly to a bolt he pulled the lever to send the timber jack out but operated the retraction ram valve squashing his left thumb causing bruise
While operating rib borer guiding 6' steel into rib hit wrong lever crushing his left hand between timber jack and bolting rig.
Incorrect direction (direction compatibility)
While installing roof bolt steel he went to raise timber jack pulling handle the wrong way pinning his right arm between timber jack and top of rig grazing his right forearm.
While attempting to spin off rib bolt he inserted dolly into chuck he pushed the handle in the wrong direction the dolly fell out hitting and bruising his right big toe.
Operation while person in position of danger (guarding, interlock)
While rib meshing using Joy 12cm30 his left lower arm became caught in the rib bolting rig causing fracture.
While operating Joy 12cm30 hydraulic rib bolter holding dolly directing it onto the rib bolt his right wrist was caught between chuck and head of bolter causing crushing injury.
While operating roof bolter on CM 102 he jammed his right wrist between timber jacks and roof bolter head mast causing lacerations.
While bolting using hydraulic rigs on CM he climbed upon head platform to pull mesh back when a coworker lowered a rig drill pot the second stage came down to his right foot causing crush injury.
While bolting on CM his arm was resting on platform of drill rig when he attempted to move drill rig down to clear mesh he moved timber jack down squashing his left forearm causing laceration.

In 1972, Hedling and Folley[11] noted (in the context of CM controls) that 'the widespread use of traditional round control knobs regardless of function being controlled is another source of error in operation' and proposed that 'Each control knob is designed to resemble (at least symbolically) the equipment it represents'. Similarly, Helander *et al.*,[13] suggested in the context of bolting machines 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' (p. 18). In particular, a lack of standardisation of controls was noted, with >25 different control sequences being identified, differences existing even on similar machines produced by the 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. Klishis *et al.*,[14] made similar observations 10 years later, noting a lack of standardisation even among machines from the same manufacturer and commenting on the potential for operating the wrong control.

In a six week period in 1994, three operators of roof bolting machines in the USA were killed. Two were crushed between drill head and machine frame while rib bolting, the third crushed between drill head and canopy. A 'Coal Mine Safety and Health Roof Bolting Machine Committee' was formed by Mine Safety and Health Administration (MSHA) to investigate, and a report was released[15] (which determined the causes to be unintentional operation of controls). The solutions proposed in this report were: two handed fast feed, drill head raise shutoff, auxiliary controls, guarding, pinch point identification, self-centring controls, hands-off drilling, insertion/retrieval devices, standardised control layouts and preoperational inspection. Other suggestions in this report included: 'provide industry wide accepted distinct and consistent knob shapes and relative handle lengths to identify corresponding control function' and 'standardise machine control lever movement and corresponding machine function movement'. Mine Safety and Health Administration subsequently called for industry comment on an advance notice of proposed rulemaking titled 'safety standards for the use of roof bolting machines in underground mines'[16] however no related rule or design criteria were subsequently released.

On 10 June 1999, MSHA released a programme information bulletin[17] which reported an investigation of a fatal accident as having 'revealed that a potential hazard exists on roof bolting machines with machine controls that are not protected against inadvertent operation'. This bulletin recommended mines: relocate controls to protected position; guard controls; redesign controls to prevent operation while operator in pinch point; ensure proper storage of supplies and materials to prevent them falling on controls.

It is clear from the injuries reported by NSW mines in the three years to June 2005 that the design shortcomings previously identified in the context of bolting machines also remain to some extent in the design of controls on the integrated miner bolters which are predominantly employed in Australian mines. Bolting controls require guarding to prevent inadvertent operation (while still allowing access for intentional operation). Bolting machine controls should be standardised across manufacturers to an appropriate layout (and provide shape and length coding) to reduce the probability of operation of the wrong control. This standardisation must carefully consider direction compatibility principles to reduce the probability of operation of controls in the wrong direction. Improvements to bolting machine design are required to guard pinch points and provide interlocks (e.g. two handed fast feed) to reduce the probability and consequences of intentional or unintentional control operation while the operator or other person is in a hazardous location.

These conclusions are consistent with a recent safety alert issued by the NSW Department of Primary Industries[19] which noted serious injuries occurring as a consequence of unintentional and intentional bolting control activation and recommended that roof and rib bolting systems should comply 'as far as practical' with AS4024·1 'Safeguarding of machinery – general principles'. The safety alert included the following as potential control measures: two handed control for fast speed operation; minimisation of pinch points; guarding to reduce inadvertent operation; shape coding; and standardised control layouts. These measures were also included in a draft revision of the Department's Machine Design Guide 35 'Guideline for bolting and drilling equipment in mines' released for industry comment.[20] The draft included suggested knob shapes for the primary bolting controls (rotation, feed and timber jack).

While standardisation of bolting controls is desirable, differences between manufacturers in current designs make this a sensitive issue. There are also at least two open questions regarding principles for optimal control layout. One is whether control layouts on different sides of a machine should be mirrored and the other concerns the appropriate relationships between control and response direction.

Hitting pot holes or other roadway abnormality

Drivers and passengers in vehicles in NSW underground coal mines suffered 169 injuries in the three years to June 2005 as a consequence of the vehicle encountering potholes or other roadway abnormalities. These injuries highlight the importance of maintaining roadway standards, because control at this level is most likely to be effective. Provision of vehicle suspension for SCs and improved seating in all vehicles[20–24] has potential to reduce the likelihood of these acute injuries. These improvements will also reduce exposure to whole body vibration which is strongly associated with the development of back pain.[25]

Collisions while driving underground vehicles

As noted earlier, the analysis of injury frequency tends to underemphasise low frequency, high consequence and events, and has the potential to oversimplify complex causal factors. For example, one of the narratives describes an incident in which a LHD vehicle overturned, with the consequence of an amputated arm. This was coded as LHD – driving – rough road, and disappeared as just one of 60 other similarly coded incidents. However this incident had a range of additional causal factors, and its seriousness has resulted in the company concerned sponsoring a dramatic redesign of the vehicle cab in conjunction with the manufacturer to ensure that this risk is controlled in the future.

Similarly, although not a very frequent occurrence, the 21 injuries which occurred due an LHD collision raise concerns because of the potential consequences were a pedestrian to be involved, such as occurred recently at one NSW mine.[26]

The probability of such events is to a considerable extent caused by the restricted visibility inherent in LHD and SCs. This is not a new observation. Pethick and Mason[27] described the visibility difficulties associated with the design of free steered vehicles and Simpson *et al.*[28] suggested that many underground vehicle collisions are at least in part a consequence of restricted driver visibility. Visibility restrictions while driving LHD vehicles is one of the few aspects of mining equipment design which 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.[29,30] Recommendations for LHD redesign arising from the research include raising the sitting position where possible and redesign of the vehicle to remove obstructions to visibility. A prototype LHD cab which provides height adjustability has been constructed in Australia[31] and would be beneficial for mines where seam height allows this advantage to be utilised. 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 National Institute for Occupational Safety and Health (NIOSH).[32]

Extreme visibility issues also exist with SCs. These are also bidirectional vehicles in that they 'shuttle' coal between the CM and the face and the boot end of the conveyer belt without turning. An incompatibility between the steering wheel action and vehicle response exists in the SCs employed in NSW when driving the SC towards the face. This is an extreme violation of a fundamental human factors principle[33] which has potential to contribute to high consequence events,[34] especially when combined with restricted visibility. A different steering system should be explored.

Conclusion

Analysis of injury narratives has suggested six high priority hazards associated with underground coal mining equipment. Potential control measures include: monorails for CM services; hydraulic cable reelers; handrails on CM platforms; redesign of CM platforms and bolting rigs to reduce reach distances during drilling and bolting; improvements to guarding of bolting controls; standardisation and shape coding of bolting controls; two handed fast feed; improvements in underground roadway maintenance, vehicle suspension, visibility and seating; and pedestrian proximity warning devices.

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