Reducing injury risks associated with underground coal mining equipment

2ND EDITION

ACARP
Australian Coal Association Research Program

Reducing injury risks associated with underground coal mining equipment

(2nd Edition)

An outcome of ACARP Project C18012

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ACARP
Australian Coal Association Research Program

PUBLICATION INFORMATION

Burgess-Limerick, R. (2010)
Reducing injury risks associated with underground coal mining equipment (2nd Ed)
ACARP project C18012 – Appendix A

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Foreword

This handbook is an outcome of ACARP project C18012, and a revised version of a handbook published as an outcome of ACARP project C14016 (Burgess-Limerick, 2007). Industry monitors for project C18012 were Dave Mellows (Xstrata Coal NSW), John Hempenstall (Centennial Coal) and Peter Brisbane (Peabody Energy Australia). The project involved an updated analysis of injury narratives describing equipment related incidents occurring at NSW underground coal mines, visits to a range of underground sites and manufacturers, and a review of recent literature.

Dissemination activities associated with the project included the organisation of seminars in Pokolbin and Mackay, presentations at a range of industry conferences and seminars, and this handbook. Results of the project also formed part of the author's contribution to a book titled "Human Factors for the Design, Operation and Maintenance of Mining Equipment" published by CRC press (Horberry, Burgess-Limerick & Steiner, 2010).

Introduction

The objectives of project C18012 were: "To improve understanding of the causes of injuries associated with underground coal mining equipment; to identify existing and proposed improvements to equipment design to reduce injury risks; and to disseminate this information widely to sites and manufacturers".

This handbook includes an updated analysis of injury narratives describing equipment related injuries reported to Coal Services NSW which highlights injury risks associated with underground coal mining equipment. The current state of known or proposed controls is then described, along with guidance for assessing injury risks associated with ergonomics aspects of underground coal mining equipment.

De-identified text describing all incidents reported by underground coal mines in NSW during the 3 years to June 30, 2008 were obtained from Coal Services. Narratives describing injuries occurring underground were manually coded for equipment involvement; activity being undertaken by the injured person immediately before the injury; the injury mechanism; and agent of injury (Burgess-Limerick & Steiner, 2006).

The aim of the analysis was to highlight the most common combinations of activity and mechanism as a means of identifying opportunities for design changes to reduce injury risks associated with underground equipment. While this is valuable, consideration of frequency alone fails to draw attention to low probability, but potentially high consequence, injury risks. Such "sentinel" events were also identified within the injury narratives and highlighted for attention.

The total number of underground injuries reported to Coal Services in the 3 years to June 30, 2008 was 4633 (excludes injuries occurring on the surface at an underground mine, and deafness claims). Equipment was involved in 2149 of these injuries (46%). The most common equipment types involved were: Continuous miner (555, 12%); Bolting machines (257, 6%); LHD (351, 8%); Longwall (332, 7%); Transport (194, 4%); Shuttle Car (152, 3%). Other equipment involved in the remaining 308 injuries included hand-held bolters (115), and a variety of other equipment such as grader, stone duster, dolly car, road header, longwall move equipment, and gas drainage drilling.

The most common injuries associated with underground coal equipment in NSW in the 3 years to June 30, 2008 were:

- strains while handling items associated with continuous miner or bolting machines (176 injuries)
- being struck by while drilling or bolting on continuous miner or bolting machine (175 injuries)
- being caught between while drilling or bolting on continuous miner or bolting machine (69 injuries)
- strain while drilling or bolting on continuous miner or bolting machine (70 injuries)
- driving or traveling over rough roads in a variety of equipment such as LHD, shuttle car and transport (164 injuries)
- being struck by while operating longwall equipment (98 injuries)

A further cause for concern is the number of potentially high consequence events involving contact with hydraulic fluid. The equipment involved included longwall (57 incidents reported); continuous miner & bolting machine (38 incidents, the majority while bolting or drilling); and LHD (5 incidents).

Rare, but high potential consequence events reported during the period included:

- interactions between personnel and mobile equipment such as continuous miners, LHD, and shuttle cars
- interactions between longwall shield movements and personnel
- transport equipment collisions

"Safe Design" (e.g.., Driscoll et al., 2005) is the process of considering hazards and risks associated with equipment and, as far as possible, eliminating these hazards or reducing the risks through improved equipment design. The first part of this handbook examines the hazards and risks associated with the major categories of underground coal mining equipment based on the injury narrative analysis, and identifies current best practice in design to eliminate or reduce these risks. The final part of the handbook provides information to assist the conduct of risk assessments of underground coal mining equipment as part of the Safe Design process.

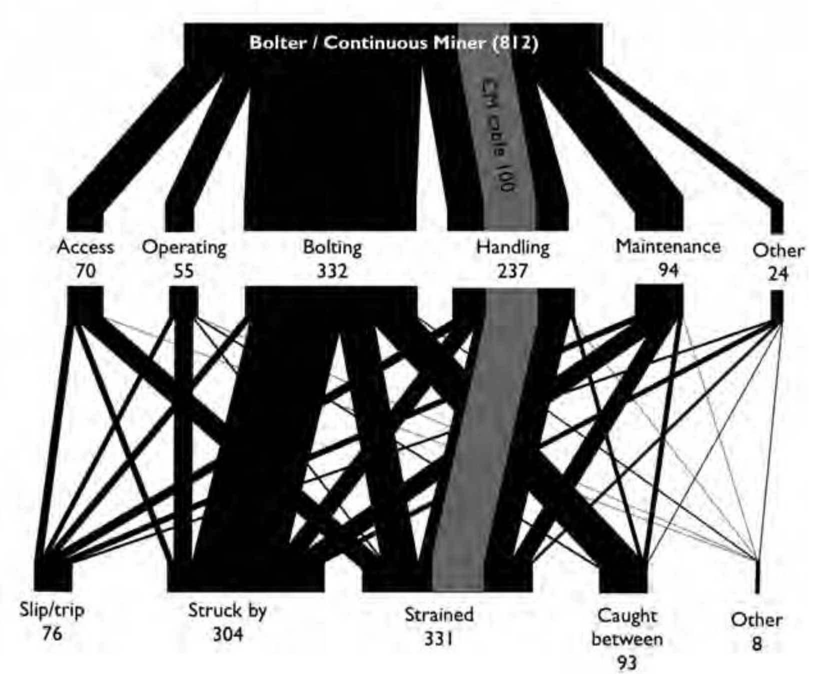
EQUIPMENT RISKS AND CURRENT BEST PRACTICE

Continuous Miner / Bolting machine

A breakdown of the number of continuous mining machine or bolting machine related injuries by activity and mechanism is provided in the table and figure below.

Underground injury frequency by Activity and Mechanism for Continuous Mining and Bolting Machines.

	Caught between	Slip/trip	Strain	Struck by	Other	Total
Access	0	16	41	12	1	**70**
Bolting	69	15	70	175	3	**332**
Handling	8	18	176	34	1	**237**
Maintenance	10	12	34	37	1	**94**
Operating	4	10	4	36	1	**55**
Other	2	5	6	10	1	**24**
Total	**93**	**76**	**331**	**304**	**8**	**812**

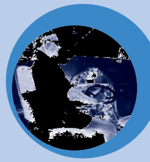


Underground injury frequency by Activity and Mechanism for Continuous Miner and Bolting Machine for NSW mines during the 3 years to June 30, 2008.

Consideration of these data reveals that injuries involving this equipment most frequently occurred whilst miners were drilling and bolting, and handling. Common injury mechanisms associated with drilling and bolting included: striking part of the equipment, or being struck by falling objects such as steels, bolts, plates, or material from the roof or rib, or hydraulic fluid (31 instances); strain; and some part of the person between caught between moving parts of the equipment. Handling a variety of objects including bolting supplies, and especially cable, was associated with strains of various body parts. Maintenance and access, were also relatively common activities. Examples of each of these injury types are provided below.

Example injury narratives for the most frequent combinations of activity and mechanism associated with continuous miners and bolting machines.

Activity and Mechanism	Example Narratives
Bolting: Struck by	While roofbolting he was putting drill steel through mesh when a rock from roof fell striking his r/ring finger causing fracture While roofbolting using c/miner mounted rigs a drill steel got stuck & when he tried to retrieve it a lump of coal fell from the roof striking his r/foot causing fractured 3rd and 4th metatarsals While installing rib bolts on the driver side of c/miner when he lifted the plastic wrap over the hoses he was hit by hydraulic oil from a pin hole in the manifold injuring his r/little finger While roofbolting the drill steel stuck in the roof when he reached up to free drill steel a hydraulic hose fractured spraying HD oil onto his r/forearm – fluid injection
Bolting: Strain	While drilling a 4m hole to install a cable bolt when removing the 8' steel as it was jammed he strained his l/shoulder – rotator cuff tendonitis While installing roof bolt climbing up onto a step on c/miner to insert a chemical into the drilled hole he reached up with his l/hand to hang on straining his l/shoulder
Bolting: Caught between	While attempting to insert drill steel into chuck of machine his r/hand & thumb was squashed when gripper jaws of Fletcher bolter closed on his hand causing crushing injury. While roof bolting a steel bowed jamming his r/middle finger between the steel & drill rig causing compound fracture r/middle finger While rib bolting trying to align dolly to rib bolt & hold mesh at the same time his r/middle knuckle jammed against the rib by the timber jack causing crush injury While roof bolting inserting chemical into drilled hole as he lowered the timber jack it came down too far crushing his r/forearm



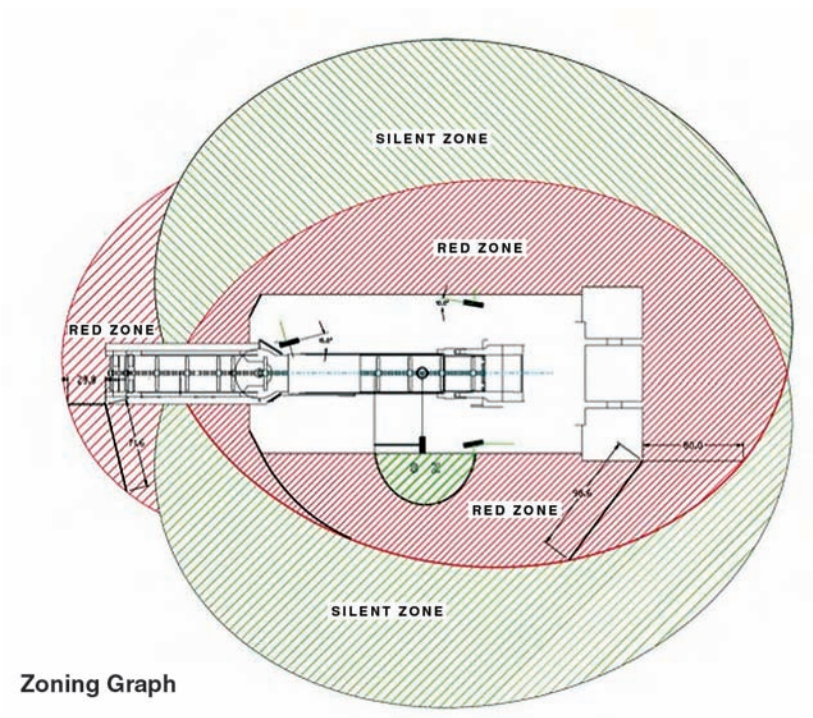
Activity and Mechanism	Example Narratives
Bolting: Caught between (*continued*)	While on c/miner rig 6' hole drill steel became bogged he lowered the chuck operated feed handle in the wrong direction bending the drill squashing his r/thumb – fracture While bolting bottom rib bolt on c/m he reached over to advance drill motor holding drill steel at the same time grabbed wrong lever and closed clamps lacerating little finger While installing 1.8m rib bolts the second stage of hydraulic bolter activated jamming his l/middle finger between the top of second stage and top of the rig causing traumatic amputation While bolting on c/miner trying to put chemical in roof when timber jack was lowered his r/middle and ring fingers were caught between timber jack & ram block causing crush injuries While roofbolting his l/arm was entangled between steel – rib mesh & a drill steel causing amputation to his l/forearm
Handing: Strain	While flitting c/miner he bent down to lift c/miner cable over his head onto a cable roller straining his lower back. While pulling the c/miner cable & putting the cable over the roller suspended from the roof he strained his r/shoulder While lifting roof mesh onto top of ABM25 he strained his neck and l/shoulder
Maintenance: Strain	While lifting hydraulic jack under head of c/miner he strained his groin While assisting with boom repair on c/miner when holding a weight of a 15kg large steel pin he injured his lower back While attempting to lift a TRS cylinder with another person back on c/miner he felt lower back pain
Maintenance: Struck by	While removing track pin off c/m he was struck by another on l/thumb by a hammer swung by another fitter While changing a pressure gauge on c/miner pump started up & oil came from the hose hitting his face
Access: Strain	When stepping down from ARO roofbolter he landed on uneven ground straining his l/ knee After servicing the c/miner he jumped 1.2m to the roadway jarring his r/lower leg While stepping up onto c/miner platform he strained his r/knee

Infrequent, but potentially high consequence events associated with miners and bolters included:

While operating c/miner filling a s/car rib fell pushing him into the s/car bruising his lower back
While he was walking past left side of c/miner it turned forcing him into rib jamming him between the c/miner & rib bruising l/thigh.

The proximity between pedestrians and the continuous mining machines constitutes a fatality risk, which is highlighted by the observation that 32 fatal crushing accidents involving remote controlled continuous miners have occurred in the USA since 1984 (Dransite & Huntley, 2009). The prevention of injuries and fatalities caused by interactions between pedestrians and the continuous mining machine currently relies on soft controls. The use of proximity devices may be possible soon and, when approved systems are available, is likely to be mandated by regulatory bodies.

Early work on proximity detection by NIOSH (Schiffbauer, 2001) has been licensed by multiple manufacturers (Chirdon, 2009). One system which has received approval in the USA (HazardAvert) establishes a magnetic field around machinery via one or more generators which are detected by a personal alarm device worn by miners. Multiple zones can be created to allow miners to work close to machinery in specified zones (Kent & Schiffbauer, 2010).



Zones created by HazardAvert

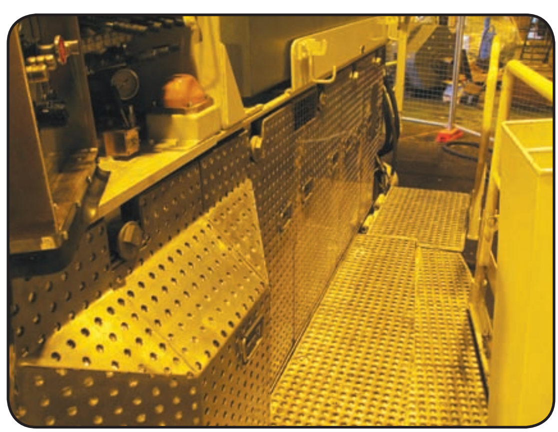
An additional risk highlighted at a focussed recall session, and subsequently observed, is reaching under unsupported roof whilst handling mesh into place on top of the continuous miner. The "mesh-grabber" innovation presented by Kestrel at the 2005 QLD Mining Safety conference (Rio Tinto Australia, 2005) has potential to eliminate this hazard by allowing the mesh to be raised with the canopy.

"Mesh grabber" innovation

Being struck by hydraulic fluid is also an injury mechanism of considerable concern because of the serious consequences of fluid injection injuries. Control measures put in place to reduce this risk include substitution of hosing with piping, and isolation of miners from hydraulic hosing.

Replacing hydraulic hoses with stainless steel piping where possible

Stainless steel covers isolate miners from hosing and include noise attenuation materials



Slips during access/egress or operation

Slipping off the continuous miner platform, whether during access or egress or while working on the platform, accounted for 20 injuries per year in NSW. Injury risks depend in part on platform height, in that higher platform heights increase the potential severity of the consequences. However, given the uneven nature of the floor and the proximity of the rib, even a slip off a low platform can still result in a time lost injury.

The likelihood of a slip during access and egress can be influenced by the access system provided. Cutout foot holds provided on some continuous miners are problematic during egress because the location of the foot hold cannot be seen from above. In this situation, miners are very likely to jump off, with potential injury consequences.

Hinged steps are provided on some miners (and are frequently broken off). Access systems should be designed to comply with AS3868 (bottom step < 400 mm above the ground, three points of contact). Provision of ladder access may preferable for high platforms where compliance with this standard is

Hinged platform and access step

Sandvik MB650 step access

MB650 steps folded for breakaway

otherwise difficult. Such access systems have been retrofitted at some mines, however stairs are more commonly being implemented on new equipment.

The probability of slips and trips while working on the platform are decreased by ensuring platforms are a single level. Improvements to platform lighting and kickboards around platform edges are worthwhile. Flameproof fluorescent lighting has been provided and advances in LED lighting technology are promising for improvements to equipment lighting and for continuous miner platforms and bolting rigs in particular.

Handrails have been retrofitted at some sites and are typically incorporated in new equipment. While MDG 1 specifies handrails should be provided for platform heights above 1.2m, the injury statistics suggest that this is insufficiently protective, and handrails are justified for all platforms.

Step access and handrails

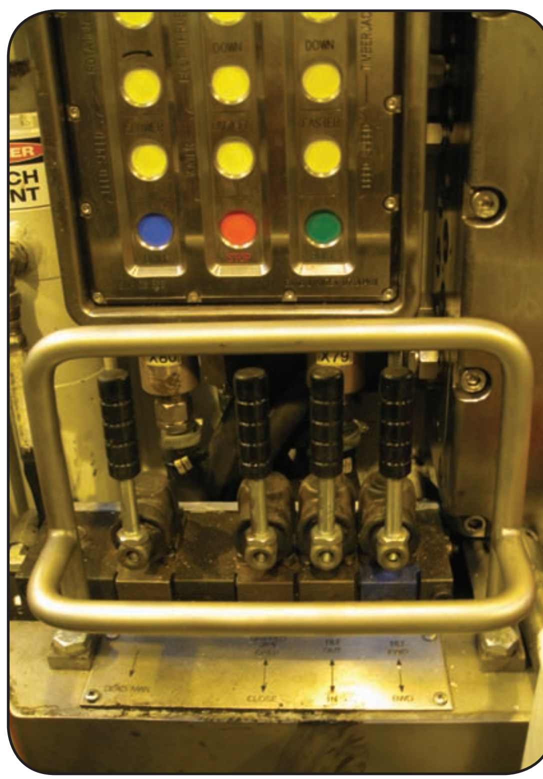
Single level platform and rear step

Continuous miner platform lighting

Caught between/struck by injuries while bolting

A variety of causes of these injuries are evident. Causes include: (i) unintended operation of bolting controls; (ii) operation of the incorrect control; (iii) operation of the correct control, but in the wrong direction; or (iv) operation of the correct control in the correct direction while either the operator or another person had some part of their person in a location where entrapment was possible. Each injury cause requires different control measures.

Unintended operation of controls typically occurs through bumping with a battery, lamp cord, self-rescuer, or through the control being struck by a falling object (eg., drill steel or bolt) or small rock. The probability of unintended operation of bolting controls is reduced by guarding, however care is required to ensure that the guarding does not cause difficulties in operating the controls, or increase the reach distance required to access bolting rigs.



Guarding against inadvertent operation

Requiring operators to perform a task involving the sequential manipulation of multiple controls, especially while looking in a different direction, creates the potential for the wrong control to be selected. The need to standardise bolting machine controls as a way of reducing the risk of such injuries has long been recognised. Miller and McLellan (1973) commented on the "obvious need" to redesign roof bolting machines, suggesting, for example, that of 759 bolting machine related injuries, 72 involved operating the wrong control, while Helander et al. (1983) determined that 5% of bolting machine accidents were caused by control activation errors. 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 has been suggested on numerous occasions over the past 40 years (e.g., Hedling & Folley, 1972; Grayson et al., 1992; Helander et al., 1980; Helander et al, 1983; Klishis et al., 1993; Mason et al., 1980; MSHA, 1994; 1997; Muldoon et al., 1980).

Too much guarding may inhibit access

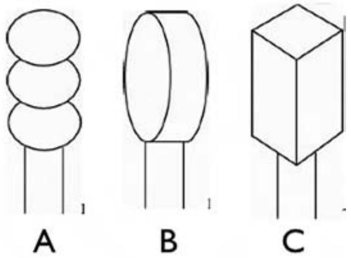
A bank of similar controls increases the probability of operator error

For example, Hedling and Folley (1972) 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." 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" (p. 18). In particular, a lack of standardisation 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 of mirror image and left/right arrangements, and the possibility of inadvertent operation.

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 the US Mine Safety and Health Authority (MSHA) to investigate, and a report released (MSHA, 1994) which determined the causes to be the unintentional operation of controls. Amongst other suggestions, a recommendation included in this report was: "Provide industry-wide accepted distinct and consistent knob shapes." Despite this, it was only with the 2010 revision of MDG35 (DII, 2010) that this issue has been addressed in published guidelines for bolting equipment.

At one site visited during the current project, shape coding had been undertaken by an operator, who had placed a plastic cap over the end of one control. At another site it was observed that one lever was missing a knob, which has a similar effect, although whether this was deliberate or not is unknown. With the inclusion of shape coding in drafts of the MDG35 revision, manufacturers have offered shape coding for retrofit to existing equipment, and new bolting rigs.

Shape coding through a missing knob



Handles shapes stipulated in MDG35 for (A) rotation; (B) feed; and (C) timber jack

The potential effectiveness of shape coding in reducing selection errors was focus of a ACARP project 16013 (Burgess-Limerick, 2009). The results of this project demonstrated that beneficial consequences of shape coding are likely in situations in which the relationship between shape and function is constant, but the location of the controls is altered: either by changing to a different workstation; or a different machine (Burgess-Limerick et al., 2010a). Consequently it is important to ensure that the relationship between shape and function is standardised, and that a means is provided to prevent shaped handles being placed on the incorrect lever.

Shape coding of bolting controls

The importance of these requirements was highlighted by a serious injury which occurred at the Austar mine in NSW in 2008. It is likely that a selection error was involved, and the investigation revealed that although the bolting controls were differently shaped, the shapes were not consistently applied across the bolting rigs (NSW DPI, 2009)

Another potential error in control operation which may lead to injury is operating the control in an incorrect direction. The probability of this error is likely to be reduced by ensuring consistency in control operation across bolting rigs, and ensuring compatibility between the movement of the control and the movement of the device controlled.

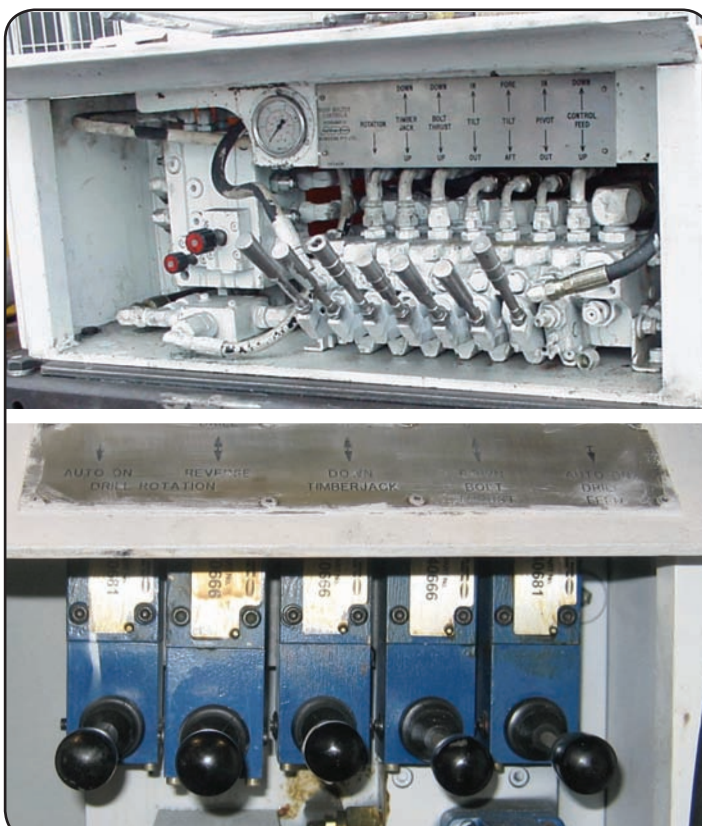
The importance of ensuring "compatible" directional control response relationships is unanimously agreed, that is, the direction which the controlled element moves in response to a movement of a control should correspond to the operators' expectations. Contraventions of this principle increase errors, increase reaction time, and increase the time taken to learn to use equipment proficiently.

NSW inspector Koppe demonstrating the operator's position immediately prior to the serious injury occurring at Austar mine in March, 2008 (NSW DPI, 2009)

Directional compatibility is often expressed as implying that the movement of a control should be in the same direction as the movement of the controlled element which results eg., "The single most important control optimisation is to have controls move in the direction of the component controlled" Muldoon et al., (1980); p 41. This logic leads to the common generic recommendation that a horizontal control lever should be moved upwards to cause an upward movement of a controlled element. This recommendation is reflected in ISO/TS 15077 which applies to controls for tractors and self-propelled machinery for agriculture and forestry, as well as AS4024. AS2956.1 (1988, also ISO4557) hedges its bets, stipulating "The movement of the following controls in relation to their neutral position shall be in the same general direction as the movement they control unless customary usage or combining of controls dictates otherwise."

The issue is not straight forward. It is relatively common on mining equipment to find situations in which downward movement of horizontal control lever causes upward movement of the controlled element such as a boom, timber jack or drill steel. While some authors (e.g. Helander et al., 1980) have suggested that this is a violation of compatible directional control-response relationships, Simpson and Chan (1988) suggested that the response may be compatible if the operators assume a "see-saw" mental model of the situation, where moving the near end of the control downwards causes the far end (and the controlled element) to move upwards.

This suggestion is not consistent with previous results however (see Loveless, 1962 for a comprehensive review). For example, Vince (1945, as cited by Mitchell & Vince, 1951) reported that participants' expectations are for an upwards movement of a linear control to result in an upward linear movement of an associated display. This principle might be called the "principle of consistent direction" and is generally reflected in current standards. Vince & Mitchell (1946) were similarly reported to have examined relationships between linear movements of control and displays in different planes, finding



Variations in directional relationships for bolting.

that a forward movement of a vertical control placed in front of participants was expected to cause an upward movement of an associated linear display.

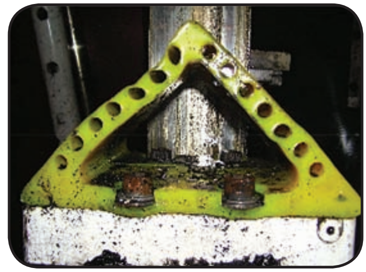
Of relevance to the design of bolting controls, Humphries (1958) noted that directional expectations were influenced by operator position with respect to the control and displays. Participants were reported to expect a control movement to the right of the body to produce a display movement to the right of the field of view, and for a control movement away from the body to produce an upward movement of the display.

More systematic investigations of the effect of operator orientation with respect to the display were undertaken by Worringham and Beringer (1989, 1998). The general principle of consistent direction was modified to accommodate situations in which an operator uses a control located to one side, or behind, while looking straight ahead. In this case (and consistent with Humphries, 1958) the compatible directional relationships were reported to be ones in which the movement direction of the control in the virtual visual field (as if the participant was looking at the control) was consistent with the movement of the controlled element. This principle is referred to as "visual field compatibility".

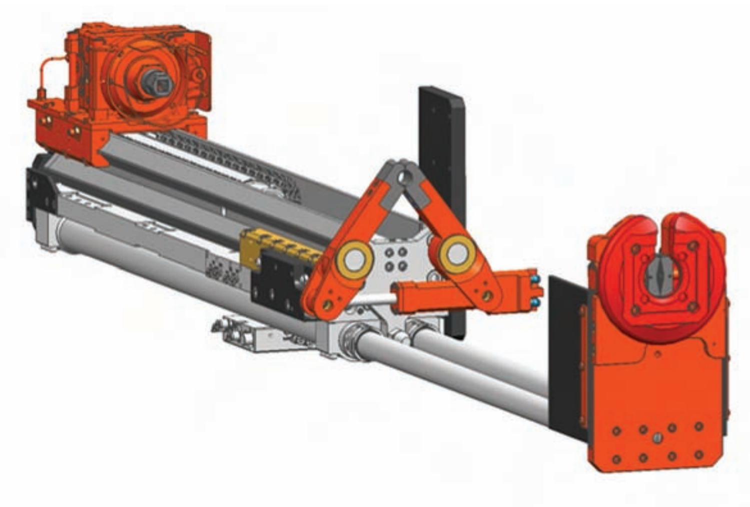
Despite the definition of principles of "consistent direction" and "visual field compatibility", there remain combinations of lever movement and response direction for which designers have no evidence base upon which to make design decisions. These directional compatibility issues were a subject of investigation in ACARP project 16013 (Burgess-Limerick, 2009). The principles of consistent direction and visual field compatibility were found to be predictive of the results obtained in the majority of combinations of control placement, orientation and device response examined (Burgess-Limerick et al., 2010b).

The exception was the strong compatibility between an upward movement of a horizontal lever, and the away movement of a vertical lever, to cause extension (lengthening) of the controlled device, regardless of whether the direction of movement of the control is consistent with the direction in which the extension occurs. This finding suggests that another dimension of "lengthening/shortening" or "extension/retraction" directional compatibility exists. The effects of the different dimensions are likely to be additive, in that error rates were lowest when the upward or away movement of the control was also congruent with the direction of the extension. The results also indicated that the control of left/right slew by horizontally oriented control levers; and the control of clockwise/anti-clockwise elevation in a frontal plane with vertically oriented control levers; were associated with relatively high rates of directional errors, and these situations should be avoided.

Injury may also occur when the correct control is operated in the correct direction, but while the operator or another person has a body part located in a location where entrapment is possible. A variety of control measures are employed to such injuries, as well as those associated with control error. These include the use of a "Panic bar" to isolate bolting rig before placing drill steel and bolts, fitting of "Keeper plate" to drill mast, rubber insertion warning plates between head plates of adjacent bolters, guarding to prevent access between rigs, and guards on gripper jaws, spacers between top plate & intermediate plate, rubber "early warning" guards and requiring two handed operation for full power operation. "Crush cones" were presented at the 2006 NSW mining safety conference as an innovation with the aim of reducing the risk of entrapment between timber jack and drill mast.



Crush cone innovation (Newstan & ABTROV Pty. Ltd.)

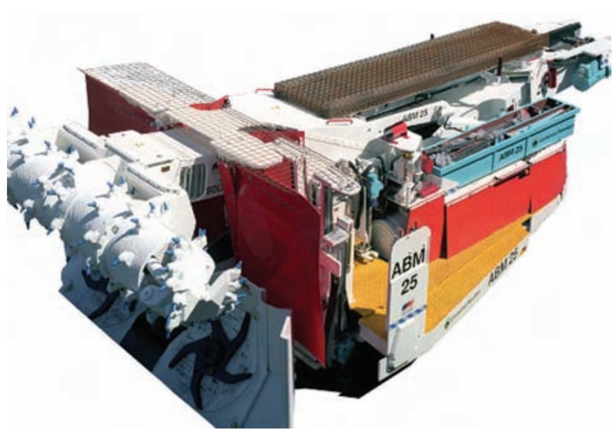


Provision of drill guides on rib bolters to reduce the need to hold drill steels

Strain during bolting

Manual handling of bolting supplies, mesh and vent tubes poses risks of both acute and cumulative injury. Most mines are aiming to reduce the injury risks associated with the handling of bolting materials by loading materials in a pod on the surface, which is in turn loaded onto the continuous miner by some form of attachment to an LHD, either a jib, or a "racker" system. Providing storage for drill steels, dolly and bolt plates near bolting rigs further reduces handling of these items.

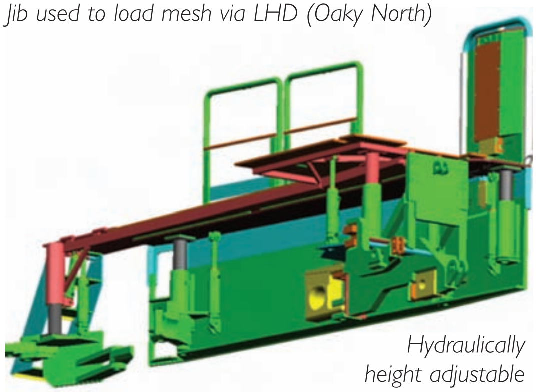
Handling of mesh may be facilitated by single or dual "ski jumps" on top of the continuous miners, however new miners feature integrated mesh carriers, with mesh being loaded by LHD and jib. Work is underway to examine the potential for the use of a polymer spray to replace mesh.



Bolting supplies pod and mesh carrier

Handling mesh into position typically involves awkward postures

Jib used to load mesh via LHD (Oaky North)



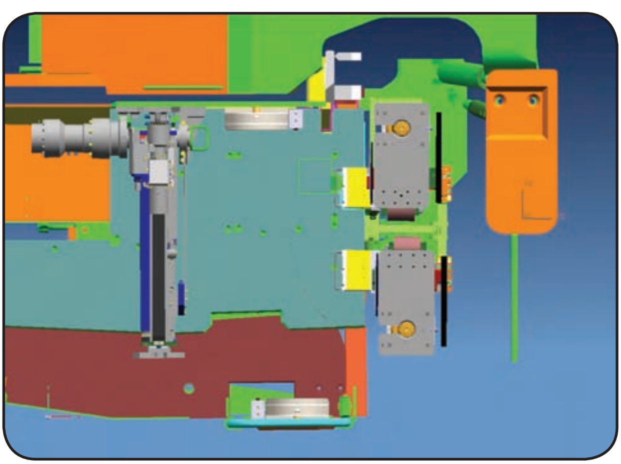
Hydraulically height adjustable platform on Sandvik miner bolter to reduce reach distance for supplies and mesh

The risks associated with handling vent tubes were not satisfactorily controlled at any sites visited during the project. Reductions in the length and weight of the tubes and adding webbing handles to fibreglass vent tubes are positive steps. Miners which have a flexible vent ducting (elephant's trunk) bring additional handling risks. The height adjustable platform implemented on some Sandvik Miner Bolters may reduce handling issues associated with mesh and vent tubes. Vent tube handling risks may also be reduced through the use of flexible ducting and a monorail system.

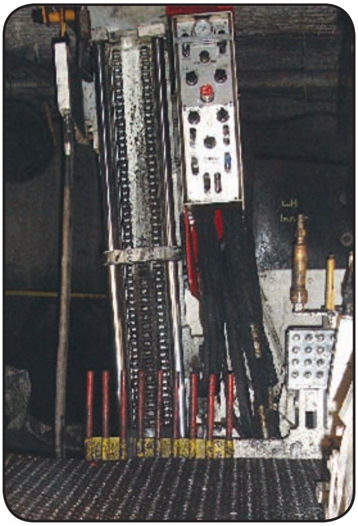
Installing vent tubes requires awkward postures and forceful exertions

Strains during bolting are likely to occur because of prolonged exposure to high shoulder load moment (mass x distance). Shoulder load can be reduced by reducing the reach distance required to access the drill pots. This reach distance varied considerably across continuous miner models observed. Redesign of platforms and bolting rig controls has been undertaken to improve access and mast mounted drill rig controls and rotation of the drill pots also reduce injury risks.

Handling drill steels and bolts at a distance from the body increases the risk of shoulder injuries.

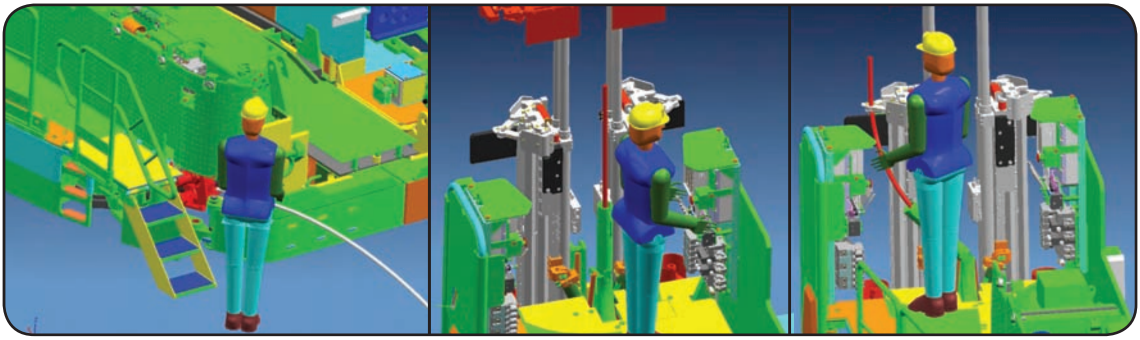


Increased platform space has potential to reduce reach distances during bolting.



Mast mounted control and rotated drill pots reduces reach distance.

The increasing requirements for cable bolting caused by adverse geological conditions creates additional injury risks associated with handling and inserting cable bolts. Sandvik have proposes an integrated cable bolt handling system which would reduce these risks by allowing cable to be fed from the rear of the continuous miner and under the platform to the bolting rig.



Proposed integrated cable bolting system

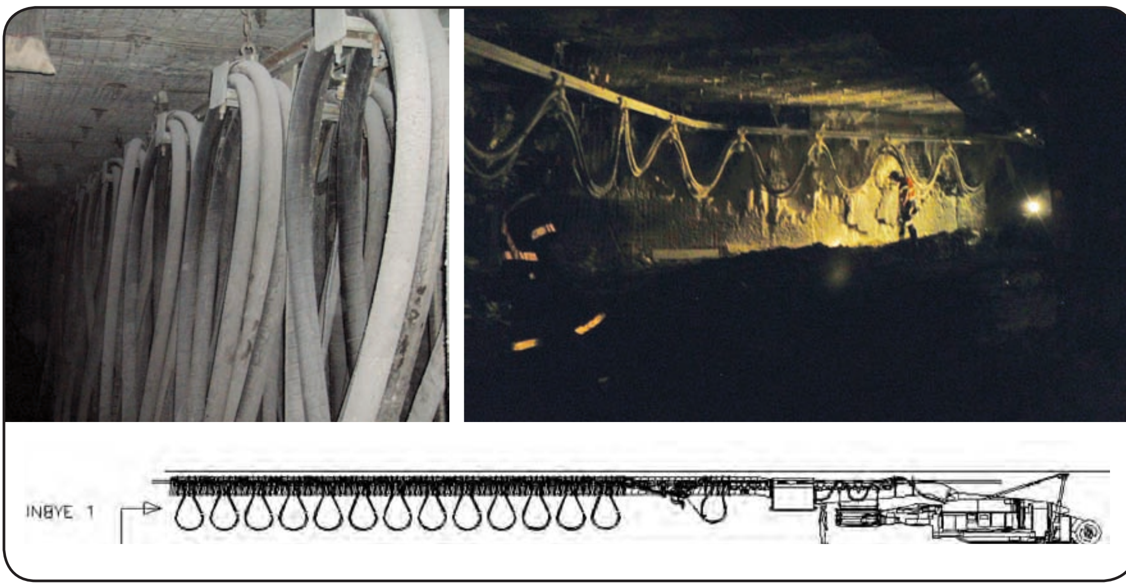
Handling cable

Strains while handling was the most frequent cause of injury associated with continuous miners. The majority of these injuries involved handling continuous miner cable (32 injuries per year in NSW). The severity of injuries associated with handling cable varies from relatively minor shoulder strains to serious back injuries. Whilst the cumulative nature of most musculoskeletal injuries implies that other manual tasks are likely to have also contributed to these injuries,

Handling cable is a common cause of shoulder and back injuries

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., 2001; 2002).

Engineering controls are required to eliminate or reduce manual cable handling. Manual cable reelers are used with a cable boat at some sites, however a hydraulic cable reeler attached to a LHD reduces manual cable handling, as does the provision of a monorail. Installation and retrieval of monorails may bring additional manual tasks risks, however these are likely to less than those associated with current methods. Integration of cable and other services with continuous haulage has been suggested in the context of remote control (Schnakenberg, 1997).



Development monorail

As Gibson (2010) put it "Whilst ever continuous miners are required to operate within a 5.0–5.4m wide 2.5–3.5m high operating envelope, provide effective roof and rib support within metres of the face, be able to break away and mine cut throughs between adjoining roadways, and cut coal at instantaneous rates of 30–40tpm, it is unlikely that designers and manufacturers will be able to incorporate the concurrent operation of manually operated bolting and meshing systems within an ergonomically acceptable on board work environment". Consequently, considerable work is currently underway by both researchers and mining equipment manufacturers to achieve automated bolting. When this is feasible, the introduction of automated bolting will result in a marked decrease in injury risk through the elimination of a range of hazards.

Automation of continuous miners and shuttle cars is also being investigated by the CSIRO with ACARP funding. Although this may be further away, once automated bolting is achieved, non-line-of-sight remote control will also be a feasible means of removing pedestrians from the vicinity of the continuous miner to a large degree.

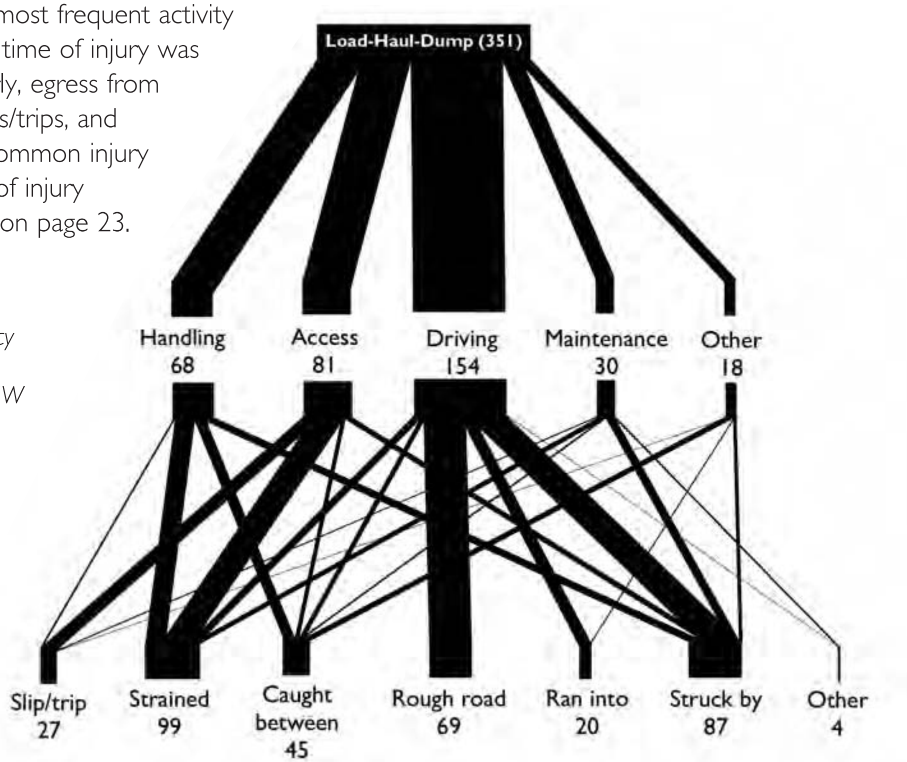
Load-Haul-Dump

The frequency of injuries for each combination of activity and mechanism for injuries associated with Load-Haul-Dump (LHD) equipment is presented below.

Underground injury frequency by Activity and Mechanism associated with LHD equipment.

	Caught between	Ran into	Rough road	Slip/ trip	Strain	Struck by	Other	Total
Access	7	0	0	21	44	9	0	**81**
Driving	8	18	69	0	12	46	1	**154**
Handling	18	0	0	3	35	12	0	**68**
Maintenance	3	0	0	2	8	14	3	**30**
Other	9	2	0	1	0	6	0	**18**
Total	**45**	**20**	**69**	**27**	**99**	**87**	**4**	**351**

Consideration of the data reveals that injuries most frequently occurred to the drivers of LHDs, and that the most frequent injury mechanisms were associated with rough roads, being struck by, and ran into. The next most frequent activity being performed at the time of injury was access to, and particularly, egress from LHDs in which case slips/trips, and strains were relatively common injury mechanisms. Examples of injury narratives are provided on page 23.



Underground injury frequency by Activity and Mechanism associated with LHD for NSW mines during the 3 years to June 30, 2008.

Example injury narratives for the most frequent combinations of activity and mechanism associated with LHDs.

Activity and Mechanism	**Example Narratives**
Driving: Rough road	While driving Eimco hit a big hole in road seat bottomed out jarring his neck and lower back While driving Eimco struck holes at 20CT MG23 causing him to strike his head on roll bar causing neck pain While driving an Eimco outbye to pick up a bucket machine hit a piece of timber on the road straining his neck & lower back.
Driving: Struck by	While driving Eimco mucking out cut through a piece of rib struck his l/ring finger – amputation While driving Eimco LHD under pipe range the pipes fell over on back of cab & slipped off hitting his head jarring his neck and l/shoulder While driving Eimco with 11 mesh modules on the top mesh caught on a roof bolt causing the mesh to swing around & strike his r/cheek causing laceration.
Driving: Ran into	While driving Eimco he hit his head on a roof bolt injuring his neck While driving LHD Eimco past a parked Eimco a forklift tyne from parked Eimco entered the drivers cab crushing the first three toes on his r/foot While driving Eimco out of 940 run into bolting pods that were side by side in the rib making LHD bounce and jarred his lower back.
Access: Strain	While hopping out of Eimco 913 battery cord caught door handle pulling his head back quickly and straining his neck While hopping out of Eimco cab he twisted to get out and stepped down straining his lower back When he stepped out of Eimco he rolled his l/ankle causing sprain
Access: Slip/trip	While getting on Eimco he slipped under the brake pedal and fell over straining his r/knee

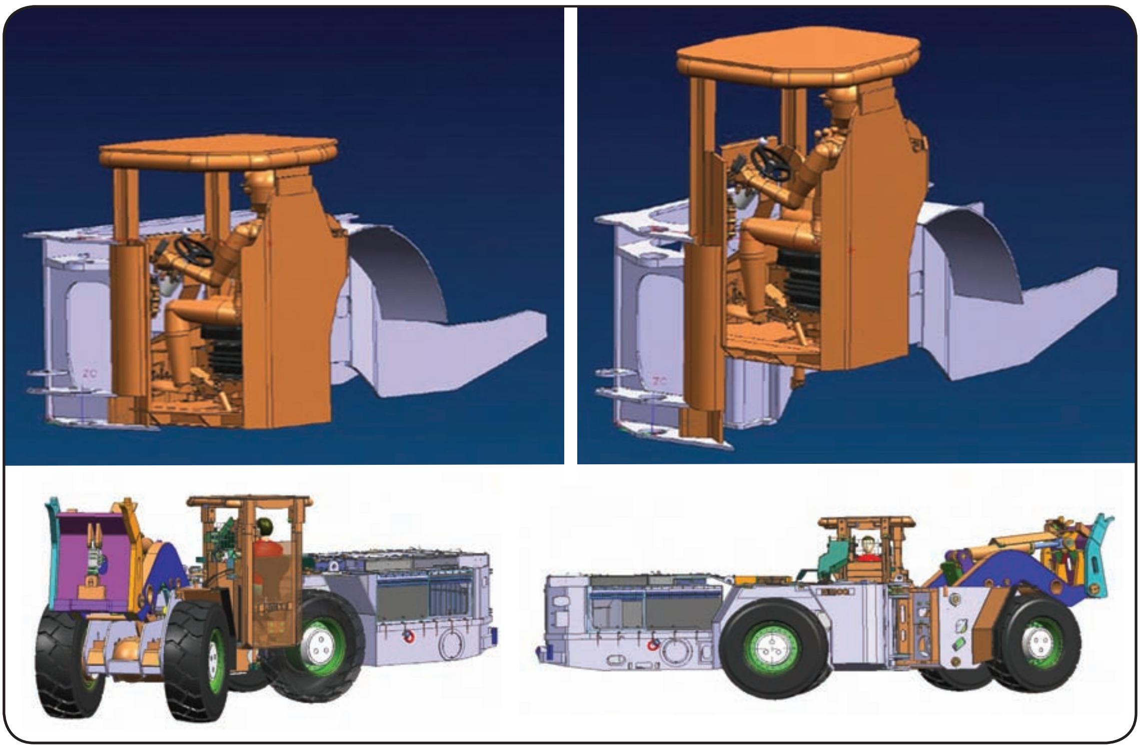
Pedestrian interactions

Infrequent, but potentially high consequence events associated with LHD included

> *He was at the hydrant washing c/m remote when a front loader heading outbye suddenly came back inbye and ran into him spun him around the wheel passed over his lower leg and fractured L/tibia*
>
> *While standing behind Eimco observing the gear being unloaded the Eimco reversed & pinned him between work platform & bucket spraining his L/ankle*

Load-Haul-Dump vehicles are associated with a range of injury mechanisms. Injuries associated with hitting a pot hole or other roadway abnormality are most common, however slips or strains during access/egress, and collisions with rib, other vehicles or objects also occur. Restricted cab space, poor seat suspension, the sideways seating posture, and restricted visibility contribute to these injury risks.

Some cab modifications have been carried out to address these issues. A height adjustable cab redesign was undertaken by Sandvik in conjunction with Xstrata Coal NSW and BHP Billiton, however this does not seem to have been widely adopted.



Height adjustable cab fitted to LHD

While roadway maintenance is critical to prevent jarring and reduce exposure to whole body vibration, controls can also be implemented at the seat. Weight adjustable suspension seats have become standard in new vehicles, although improvements may be required in the adjustment mechanism, and ideally weight adjustment should be automatic.

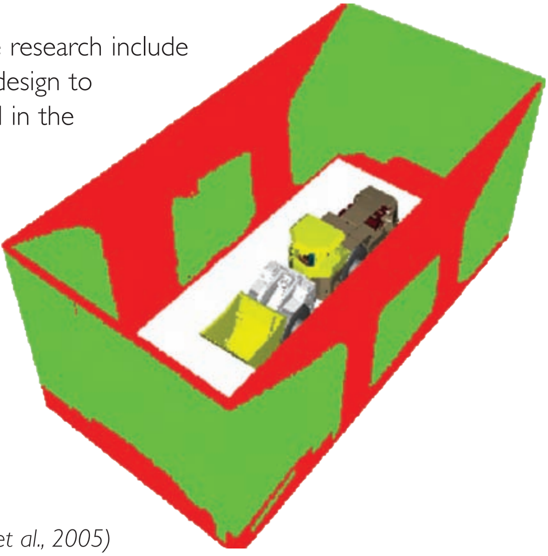
The sideways seating position used in LHDs requires prolonged exposure to a rotated neck posture (Eger et al., 2010). This can be reduced by providing some degree of seat rotation. 30 deg rotation in seat has been provided in some refits, and in new vehicles. Dual seats allowing the driver to face the direction of travel are provided on an MPV. The SMV Brumby provides a permanent 20 deg seat rotation to reduce neck rotation during the predominant travel direction.

Rotated neck posture caused by side-one seating

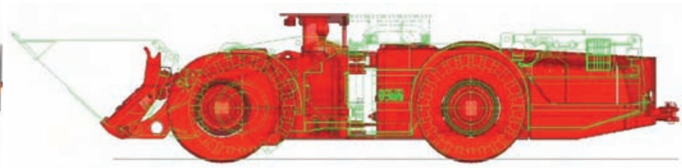
The restricted visibility inherent in current LHD designs has been the subject of considerable research, and implicated in a number of serious injuries. Reports by Kingsley et al. (1980), then Pethick and Mason (1985), described the visibility difficulties associated with the design of free-steered vehicles and Simpson et al. (1996) suggested that many underground vehicle collisions are at least in part a consequence of restricted driver visibility.

The research has predominantly focussed on documenting the extent of the problem and providing methods for assessing the lack of visibility associated with current designs (eg., Kingsley et al., 1980; Eger et al., 2004; 2010; Tyson, 1997), but has also examined the potential benefits of design modifications to remove visibility obstructions (Godwin et al., 2008) and the provision of video cameras (Godwin & Eger, 2009).

Recommendations for LHD redesign arising from the research include raising the sitting position where possible and cab redesign to remove visual obstructions. Visibility will be improved in the raised cab position of the height adjustable LHD cab redesign. Improved cabin ergonomics are also a feature of Bucyrus loaders. These loaders feature joystick steering controls, however the industry has been slow to embrace the change.



Visibility Box Plot for an LHD (West et al., 2005)



Next generation Sandvik LHD (LS151) improves visibility in comparison to previous Eimco 913 model

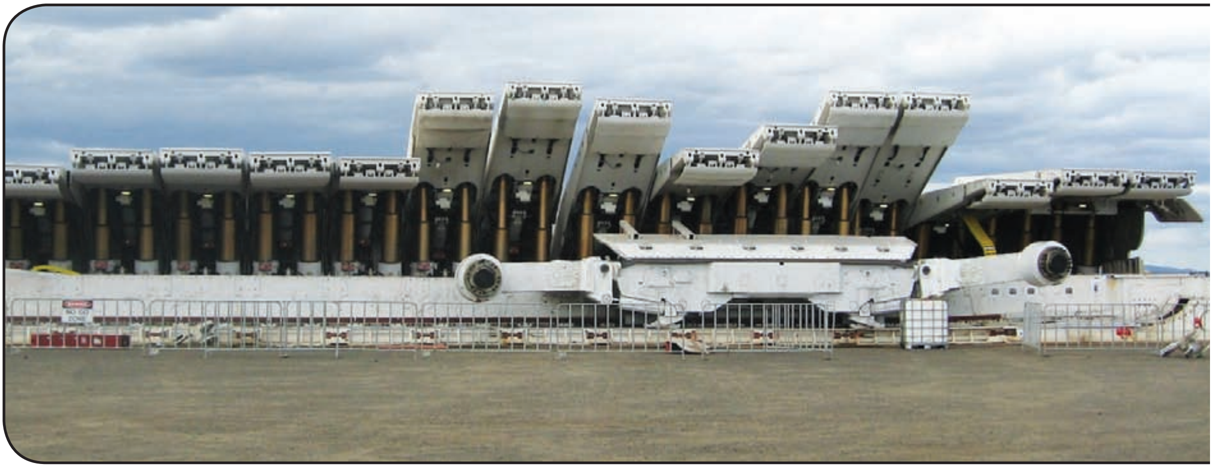
Improved LHD cab ergonomics

Improved maintenance access

Bucyrus "ergo cab" designed for compact loader range

Other controls to reduce pedestrian interaction risks include transport rules, pre-start alarm, directional lighting, and the use of proximity detection systems.

Longwall

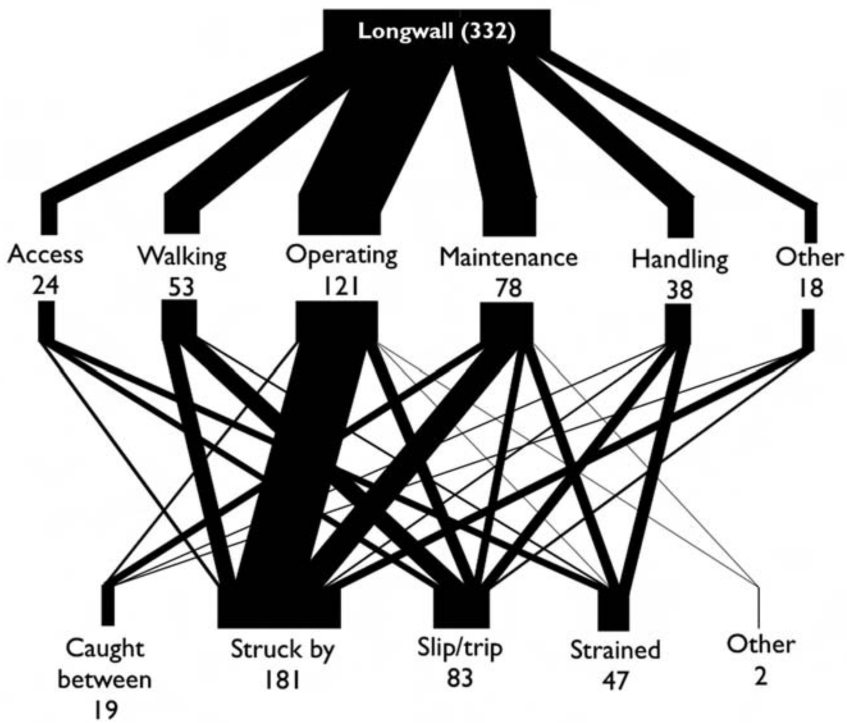


Longwall mini-build

Injuries associated wi\th Longwall equipment are presented on the following page.

Underground injury frequency by Activity and Mechanism for Longwall equipment.

	Caught between	Slip/trip	Strain	Struck by	Other	Total
Access	0	9	10	5	0	**24**
Walking	0	26	3	24	0	**53**
Handling	2	15	18	3	0	**38**
Maintenance	11	12	15	39	1	**78**
Operating	4	17	1	98	1	**121**
Other	2	4	0	12	0	**18**
Total	**19**	**83**	**47**	**181**	**2**	**332**



Underground injury frequency by Activity and Mechanism associated with Longwall equipment for NSW mines during the 3 years to June 30, 2008.

Consideration of these data reveals that injuries associated with longwall equipment most frequently occurred during operation, maintenance and walking on the face, and that the most frequent injury mechanism was being struck by – typically by coal or rock from the roof or face, but also by hydraulic oil (57 instances), and including striking the head on the longwall supports. Slipping or tripping was also relatively frequent. Examples of injury narratives are provided on the following page.

Example injury narratives for the most frequent combinations of activity and mechanism associated with Longwall equipment.

Activity and Mechanism	Example Narratives
Operating: Struck by	While operating shearer cutting towards the TG he was struck on his L/ear by fly rock causing laceration While operating shearer a piece of rock flew from shearer & struck his chest causing him to fall between supports straining his R/shoulder & injured chest and back While he was activating shield a lump of stone fell between shield striking his hand causing a fracture While operating 18 roof support with 17 roof support mimic he walked on 18 roof support & a hose burst spraying oil on his R/thigh causing high pressure injury While operating hydraulic directional control valve on 92 L/W shield to retract DA RAM a hose retaining staple worked loose releasing valve bank causing pressurized hydraulic fluid to release hitting his L/thigh
Maintenance: Struck by	While changing picks on shearer in LW407 a slab of coal fell and smashed his L/leg causing fracture While adjusting BSL chain when high pressure fitting blew out and fluid wet his leg & pressure hit his bottom – possible high pressure fluid injection
Walking: Struck by	While walking along L/W face he struck his head on a chock & fell backwards straining his neck While walking past chock a high pressure fitting blew out spraying him with emulsion bruising legs trunk & head
Walking: Slip/Trip	While walking along pontoons of shields from T/G to M/G he slipped off the pontoon twisting his knee While walking along LW face his foot slipped between chock feet & rolled over on his R/ankle causing sprain
Operation: Slip/Trip	While operating L/W shearer he slipped on the chock pontoon straining his lower back
Maintenance: Slip/Trip	While assisting to clean out cable tray he slipped & fell backwards when his L/leg was caught between chock leg and baselift RAM injuring his L/knee – medial ligament tear While standing on pontoon of a chock he was using a pinch bar to lever a hose the bar slipped causing him to fall backwards & strike his head on cable tray of AFC jarring his neck & felt pain to his shoulder & lower back

Infrequent, but potentially high consequence events associated with longwall included:

When operating shearer he slipped on a cobble of coal on 116 chock which started to advance catching him between a chock & pantech causing fractured pelvis & ruptured bladder

While setting up for maintenance a longwall support advanced knocking him over pinning his R/lower leg causing puncture wound medial right ankle & bruised calf

While advancing chock his L/foot was caught underneath a shield causing amputation of his L/2nd and L/3rd toes

Proximity detection has potential to prevent injuries of this type also.

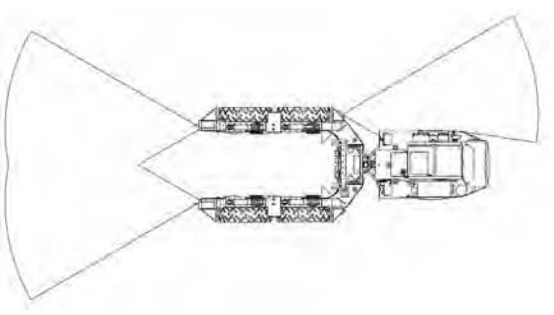
Although difficult, efforts have been made to reduce tripping hazards on the longwall face through, for example, provision of walkway lighting, and placing covers between the toes on the front walkway. Handles have been provided on one face to assist moving from front to rear walkways.

Reduced tripping hazards on front walkway

Handles to assist movement between front & rear walkways

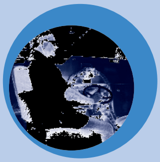
Vehicles provided to move longwall chocks have greatly restricted visibility. Video cameras are being provided to overcome these issues to some degree.

Chock carriers

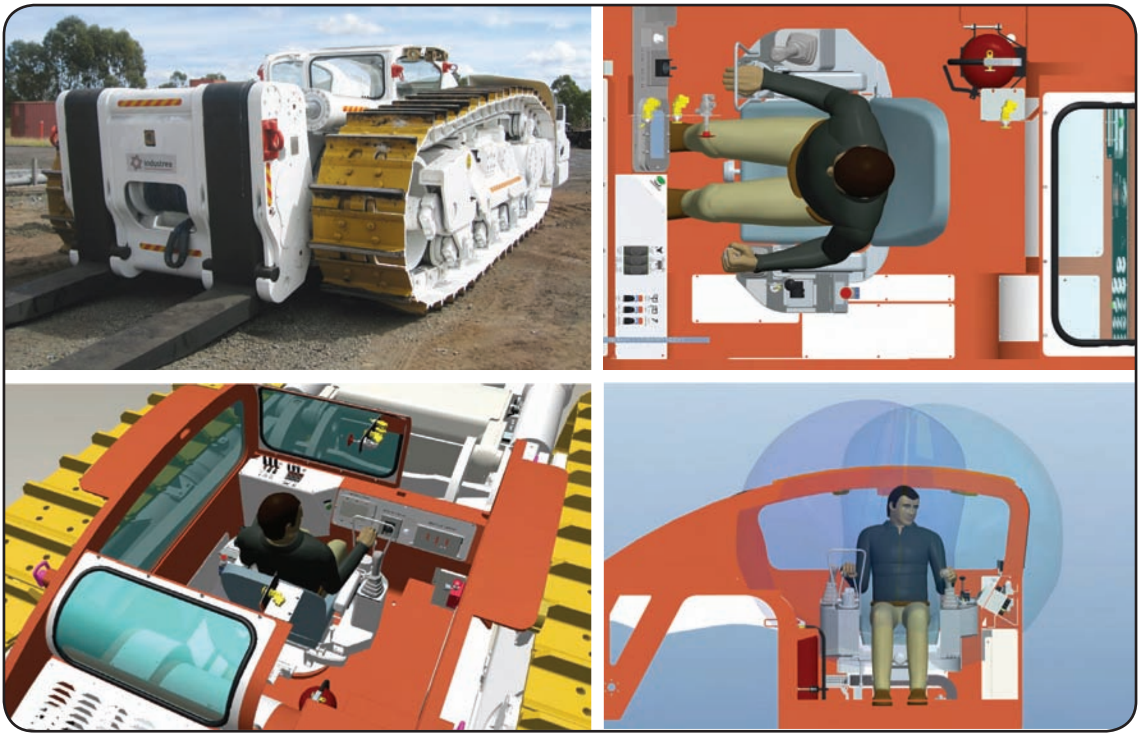


Field of view of video cameras provided for Industrea Chock Carrier

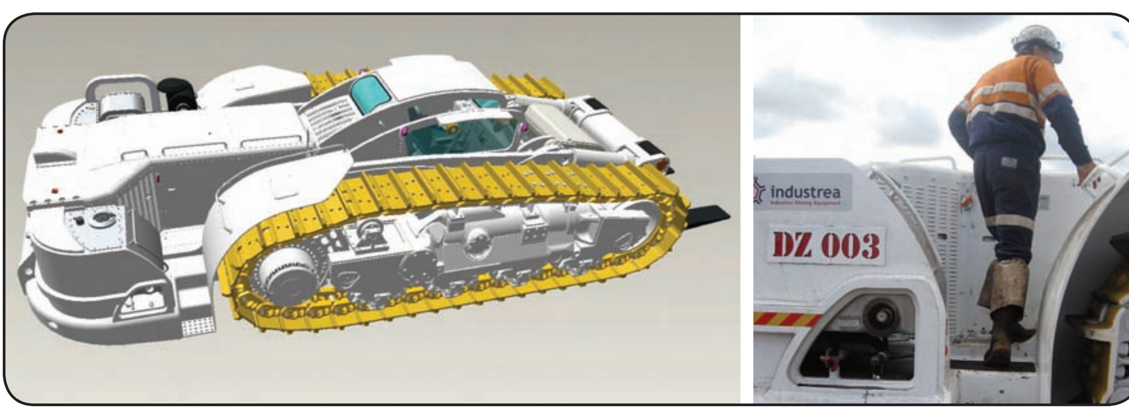
Video displays provided to driver



The Industrea Mining Equipment dozer has a number of innovative features to overcome visibility issues. The cab height is hydraulically adjustable to allow access through low mine sections, while allowing normal operation from a higher position. A rotating seat and controls are provided to allow the operator to face the direction of travel, or at 90 deg. The location of controls and displays has been carefully thought through to ensure all controls and displays lie within normal reach distances, and an excellent access system has been designed as an integral part of the vehicle.



IME dozer with height adjustable cab, rotating seat, & video cameras



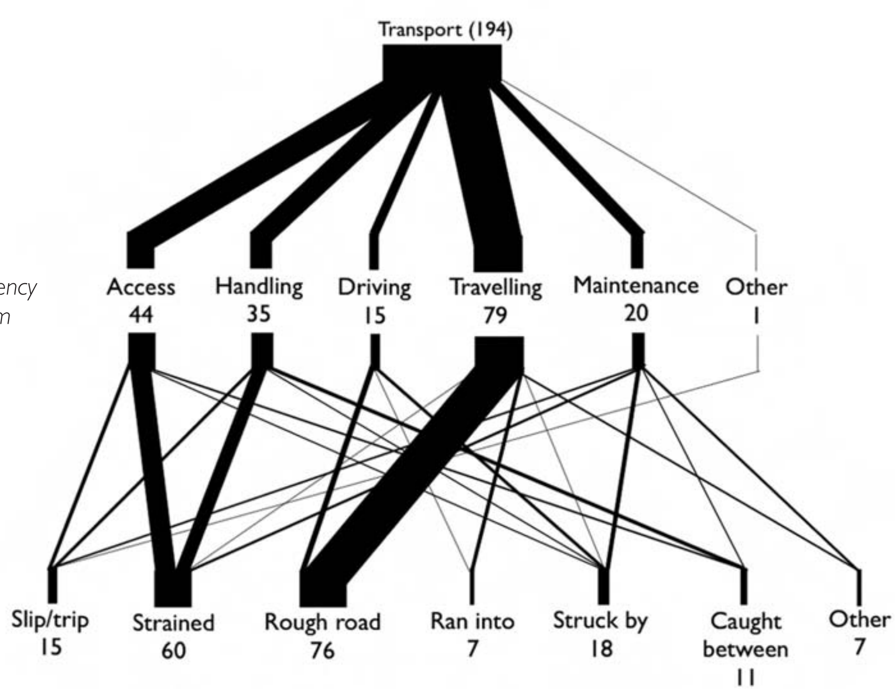
Integrated access to IME dozer

Transport

Injuries associated with personnel transport are presented below.

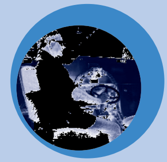
Underground injury frequency by Activity and Mechanism associated with Personnel transport.

	Caught between	Ran into	Rough road	Slip/ trip	Strain	Struck by	Other	Total
Access	3	0	0	6	33	2	0	**44**
Driving	0	1	9	0	0	5	0	**15**
Handling	6	0	0	5	22	2	0	**35**
Maintenance	2	0	0	3	4	7	4	**20**
Traveling	0	6	67	0	1	2	3	**79**
Other	0	0	0	1	0	0	0	**1**
Total	**11**	**7**	**76**	**15**	**60**	**18**	**7**	**194**



Underground injury frequency by Activity and Mechanism associated with Personnel transport for NSW mines during the 3 years to June 30, 2008.

Consideration of these data reveals that injuries associated with personnel transport most frequently occurred to passengers as a consequence of traveling over rough roads. Injuries also occurred during access. Examples of injury narratives are provided on page 34.



Example injury narratives for the most frequent combinations of activity and mechanism associated with Personnel transport.

Activity and Mechanism	Example Narratives
Traveling: Rough road	While traveling from panel to pit bottom sitting in the back of PJB hit rough roads & was thrown in the air landing on his tailbone on edge of seat fracturing his sacrum While traveling in an overcrowded SMV sitting awkwardly the SMV jolted over numerous potholes causing pain in his L/buttock & lower back – lumbar disc injury While sitting in PJB traveling to pit bottom along 642 traveling road hit a large bump launching him into the roof then back down jarring neck & lower back
Access: Strain	While mounting the rear of SMV he dislocated his R/knee After alighting from rear of SMV he twisted his L/knee on uneven floor of road causing strain

Infrequent, but potentially high consequence events associated with transport included:

> *While traveling in transporter it ran into back of another transporter causing him to hit his L/knee on the steel wall of engine compartment*

> *While being transported out of pit driver fell asleep & crashed PJB into rib & got thrown into steel canister spraining his neck.*

The most frequent injuries associated with personnel transport are those caused by hitting potholes or other roadway abnormalities.

Some transport in use has very poor seating, and older vehicles feature seats facing perpendicular to the direction of travel. This is a known risk factor for injury in the event of a collision.

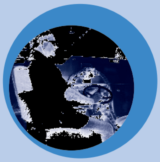
Control measures to reduce this jarring and vibration (in addition to roadway maintenance) include improved shock absorbers and thicker cushions, and complete suspension and seat redesign (Dayawansa et al., 2006). The SMV transport redesign undertaken at Kestrel with ACARP funding has the additional advantage of seating passengers facing forwards and backwards. Either provide superior safety if a collision occurs. Dayawansa et al. also developed concepts for new underground transport vehicles as part of ACARP project C14037.

Poor seating increases risks of both acute and cumulative injuries

Redesigned SMV transport vehicle (Dayawansa et al., 2006)

Forward & rear facing seating

Concept vehicles (Dayawansa et al., 2006)

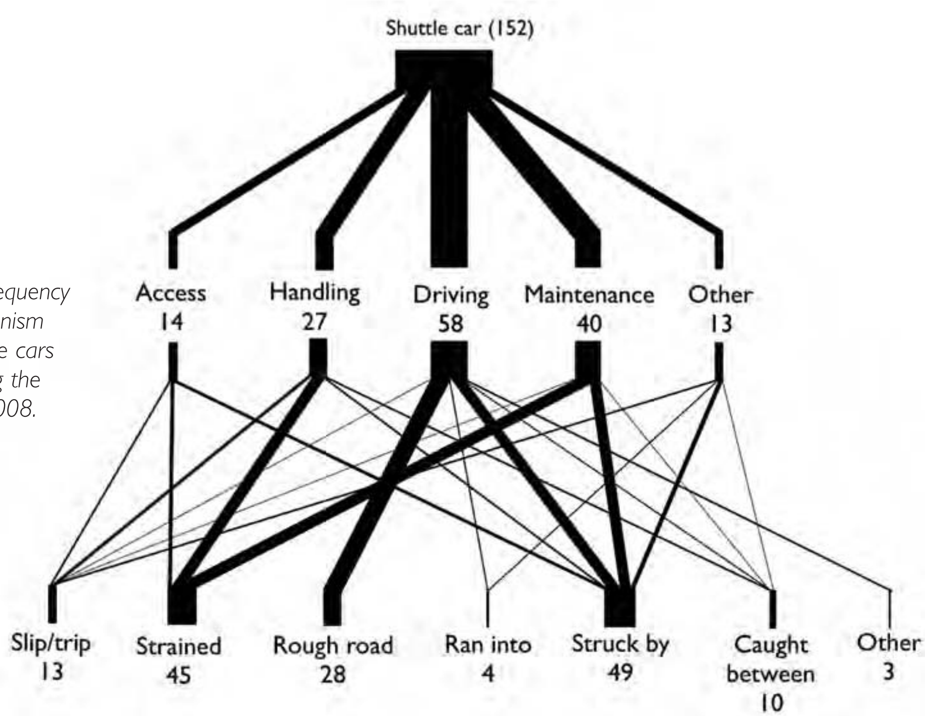


Shuttle Car

Injuries associated with the operation of shuttle cars are described below.

Underground injury frequency by Activity and Mechanism associated with Shuttle cars.

	Caught between	Ran into	Rough road	Slip/ trip	Strain	Struck by	Other	Total
Access	0	0	0	3	6	5	0	**14**
Driving	4	2	28	1	3	17	3	**58**
Handling	1	0	0	5	18	3	0	**27**
Maintenance	4	0	0	1	18	17	0	**40**
Other	1	2	0	3	0	7	0	**13**
Total	**10**	**4**	**28**	**13**	**45**	**49**	**3**	**152**



Underground injury frequency by Activity and Mechanism associated with Shuttle cars for NSW mines during the 3 years to June 30, 2008.

Consideration of these data reveals that injuries associated with shuttle cars most frequently occurred to drivers as a consequence of traveling over rough roads or being struck by (typically falling) objects or material. Injuries also occurred during maintenance. Examples of injury narratives are provided on page 37.

Example injury narratives for the most frequent combinations of activity and mechanism associated with Personnel transport.

Activity and Mechanism	**Example Narratives**
Driving: Rough road	While operating shuttle car he hit a bump on road causing him to hit head on roller bar spraining his neck While driving shuttle car traveling along haulage road constant jarring of back on bumpy roads he felt lower back pain
Driving: Struck by	While sitting in shuttle car drivers cab a piece of stone came out of boom on c/miner into the s/car striking his chest and throwing him out of the cabin causing bruising and pain While driving s/car along wheeling road in low roof area because of rib spall he hit his head on a roof bolt causing neck pain
Maintenance: Strain	While bending to change a shuttle car tyre he strained his upper back While working on a S/car replacing bearings in drivers side steering arm he was applying force to the seized parts in a confined space he experienced pain to his lower abdomen

Infrequent, but potentially high consequence events associated with shuttle cars included the following:

> *While working as a cable hand on c/miner he turned to see a s/car approaching he slipped into s/car wheel rut & L/foot was run over by s/car causing crush injury*
>
> *While training to drive s/car from bootend to c/miner he was crushed between the s/car & the rib causing crush injury to his l/hand*
>
> *While standing in the rib as a s/car was passing he slipped on loose surface his r/foot went under s/car wheel causing bruising.*

In each case the miners concerned were fortunate to escape fatal injury. However, the USA experience suggests that fatalities resulting from with collisions between people and shuttle cars do occur with some regularity. For example, on May 10, 2010, a continuous mining machine operator, received fatal crushing injuries when he was pinned between a shuttle car and a coal rib (www.msha.gov/fatals/2010/FAB10c36.asp) and on July 1, 2010, an electrician was fatally injured when he was run over by a shuttle car (www.msha.gov/FATALS/2010/FAB10c40.asp).

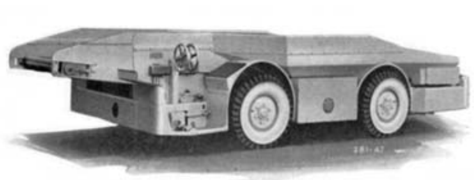
In April 2007 at Moranbah North mine, Jason Blee was operating a continuous miner which broke down. Mr Blee approached the shuttle car driver and instructed him to take the car out of the heading. When the shuttle car was driven out of the heading, the end moved sideways, pinning

Mr Blee against the rib. Mr Blee yelled to the shuttle driver to drive the shuttle car back towards the face to release him. The shuttle car driver attempted to do so, however Mr Blee was crushed against the rib by the shuttle car and subsequently died.

The subsequent coronial enquiry canvassed a range of issues associated with the design of the shuttle car including shuttle car control design. One of Coroner Hennessy's recommendations of September 2009, was "That a working party comprising the Department, coal mine operators, workers, Union representatives and other interested organisations form to meet with manufacturers of shuttle cars to review and discuss, with the intention of designing out or improving the design of some of the concerns related to the ergonomic and/or safety factors and control surfaces of shuttle cars" (Hennessy, 2009). In June 2010, a Queensland shuttle car operator crushed his hand, and a fitter standing next to the shuttle car sustained a fractured pelvis when caught between the shuttle car cabin and rib. These incidents collectively highlight the shuttle car as equipment item requiring particular attention.

Shuttle car designs

Shuttle cars were first introduced to coal mines in 1938. Early designs are illustrated below.



Early shuttle car designs (www.coaleducation.org)

A range of cab designs and steering mechanisms are currently in use in Australia. The majority feature two seats and a steering wheel. The driver moves between seats with each change of direction and remains always facing the direction of travel. The foot switch arrangement in these cars typically follow MDG9 specifications of left foot tram, right foot brake. This differs from the USA which changed to right foot tram by the 1980s.

The steering mechanism in use in these cars features an incompatible directional control relationship. When driving out-bye (sitting in the

Typical shuttle car cab currently in use seat illustrated above), if the driver wishes to turn the car to the right, he rotates the steering wheel clockwise, pushing the top of the steering away from the body. To turn left, the driver pulls the top of the steering wheel back towards the body, an anti-clockwise rotation. This relationship between control direction and vehicle response is "compatible" because it corresponds to the driver's natural expectations, and is executed without difficulty. However, when the driver returns in-bye to the continuous miner, the task is more difficult. In this case, if the driver wishes to execute a right hand turn, he must push the top of the steering wheel away from himself (anti-clockwise rotation), and to turn left he must pull the top of the steering wheel towards from his body (a clockwise rotation). This is an "incompatible" control-response relationship in that it is contrary to the driver's natural expectations.

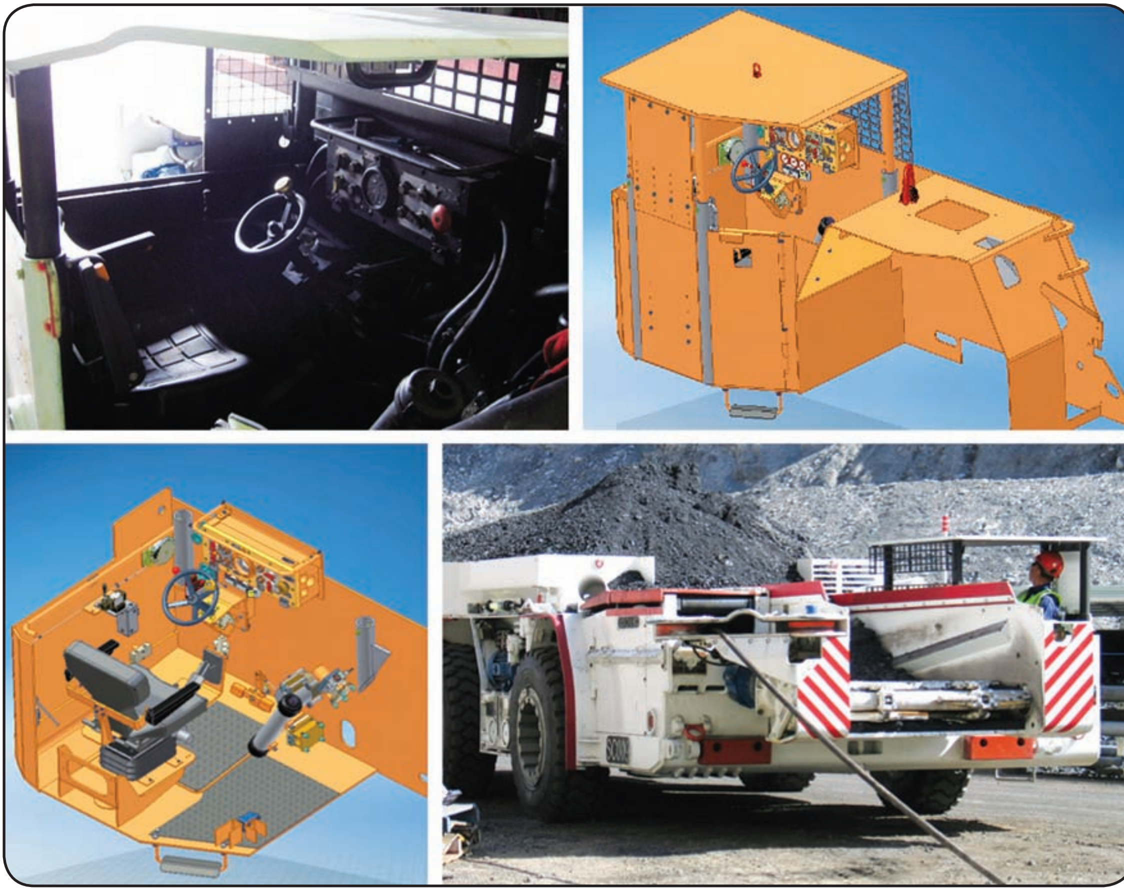
The consequences of incompatible control-response relationships are an increase in the probability of directional errors, and/or a reduction in the speed with which tasks can be performed. This has been confirmed in a series of experiments in a virtual simulation analogous to the shuttle car in which novices made more steering direction errors in the incompatible steering arrangement when presented with an obstacle avoidance task (Zupanc et al., 2005; 2007). Steering direction errors are especially likely in this situation when time pressure is increased, or under stress.

Removing the steering incompatibility while retaining a steering wheel is possible, however it may be important to ensure that the new controls are obviously different from current controls to ensure negative transfer does not occur (that is, to avoid the situation where operators accustomed to the incompatible relationship whilst driving in-bye are temporarily more error prone when driving an always compatible shuttle car).

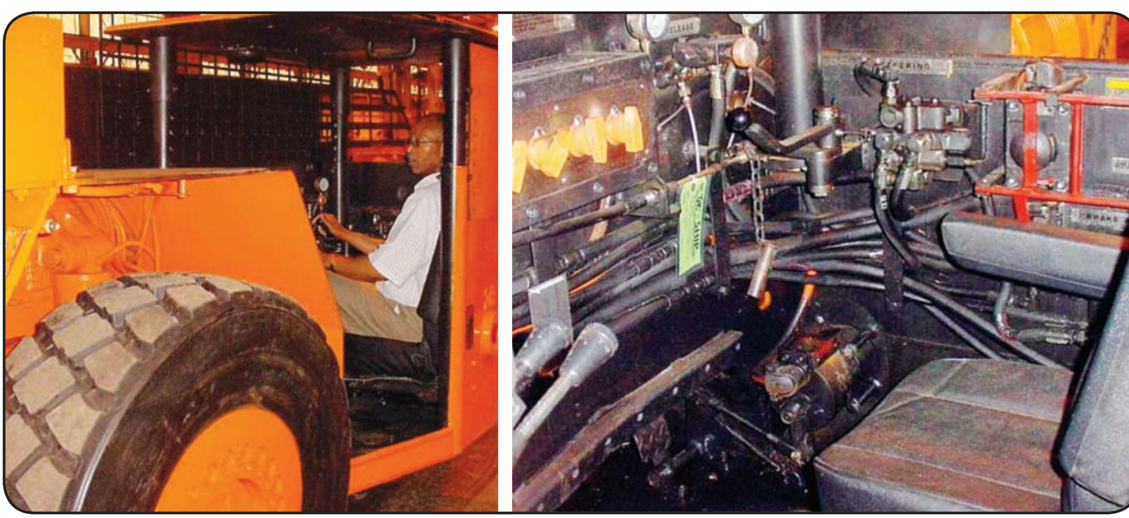
East-west cab fitted to shuttle car (Beltana)

Arising from initial work undertaken by Beltana, Joy 10SC32BC shuttle cars feature a single "east-west" facing seat (above) and enclosed cab. In these cars a left foot brake, right foot tram arrangement is used, with a single rocker throttle used to control tram direction and acceleration. The directional steering incompatibility remains. Side facing seating has the disadvantage of exposing operators to an awkward neck posture for prolonged periods, a likely cause of discomfort and a risk factor for neck injury. These cars featured a suspension system based on a strut of elastomeric pucks and urethane dividers on a steel rod (Joy, 2005). More recently, a patented "joyride" strut has been incorporated to provide improved dampening.

The majority of shuttle cars in use in high seam mines in the USA similarly feature a single east-west seat. A lever steering arrangement is used rather than a steering wheel, however this does not overcome the directional steering incompatibility.



Joy 10SC32BC



US Joy shuttle car steering

The steering mechanism used in US shuttle cars is also unusual in that it is non-proportional. While the lever is deflected from neutral, the wheels deflect to turn to steer the car in the direction indicated, and continue to turn as long as the lever is held away from neutral. When the lever is returned to neutral, the wheels remain turned. Returning the car to straight travel requires deflection of the lever in the opposite direction until the wheels are again straight (and the lever is returned to neutral).

A conventional proportional steering control such as a steering wheel of a car is defined as a zero-order control for steering angle, meaning that the displacement of the control (in this case a steering wheel) is directly proportional to the angle of the wheels. For any constant steering deflection the wheel displacement from straight remains constant, and given constant vehicle speed, the heading of the vehicle will change at constant angular velocity.

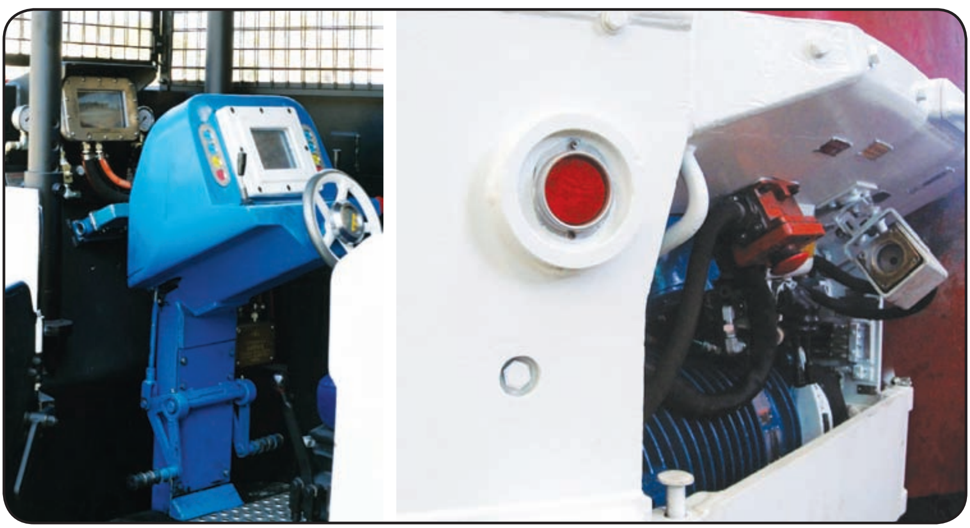
In contrast, the non-proportional steering mechanism is a first order control of steering angle. While the lever is deflected from neutral, the steering angle continues to change with constant angular velocity, and given constant vehicle speed, the heading changes with increasing angular velocity.

Higher order controls are more complex to control in that more steering operations are required to perform any given vehicle maneuver. For example, turning a corner requires one steering input with a steering wheel (away from neutral and return). Turning a corner with the non-proportional steering

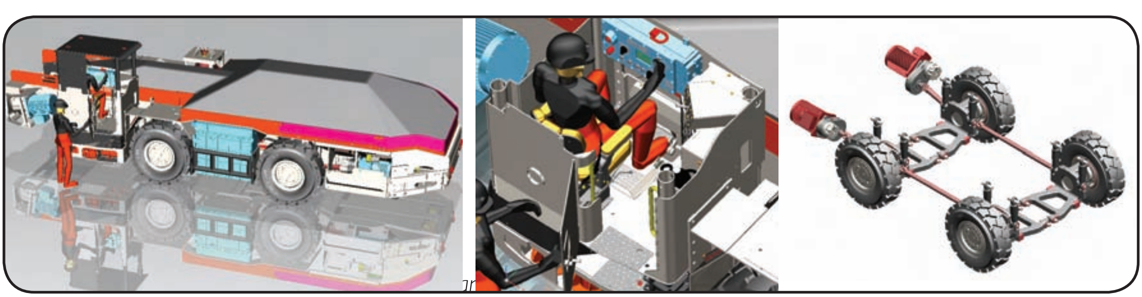
"Ergocab" shuttle car, designed by Highlander Engineering, now owned by PWG Kings & Sons.

requires two steering inputs (away from neutral in one direction and return, then away from neutral in the other direction and return). To achieve a change in lateral position on the roadway with a conventional steering control would require two steering commands. Achieving the same result with the non-proportional control requires four discrete steering commands. While there is no doubt that such complex controls can be learned, it is not clear that there is any benefit for the user in providing a higher order control.

One current shuttle car design available in Australia does overcome the directional steering incompatibility issue. This "ergocab" shuttle car features a single rotating seat and steering wheel console and pedals. The directional steering relationship remains consistent regardless of the direction of travel, and awkward neck postures are avoided. The cab is, however, 200-400 mm wider than the shuttle car body to provide the cab space required.These cars also feature a video camera to compensate for the restricted visibility. Video cameras have also been added to Joy cars at the request of at least one Australian mine.



Shuttle car video camera and display



Sandvik TC790 shuttle cars are in use in South Africa, and will be available in Australia. This car features independent suspension and a variable cab height which can be located to improve visibility where conditions allow.

Although a large capital expenditure, the use of flexible conveyer trains instead of shuttle cars is another option to reduce hazards associated with shuttle cars.

Portable Bolter

Portable hand held bolting rigs are typically used to undertake secondary support, including cable bolting. Injury narratives reported describing the 115 injuries associated with hand-held bolting equipment occurring at NSW underground coal mines in the 3 years to June 2008 included:

> *While roofbolting work with r/shoulder above head height caused pain – rotator cuff tear*
>
> *While drilling a hole in the roof the drill steel jammed in roof & straining his lower back*
>
> *While mega bolting with a co-worker when feeding 8M mega bolt into the roof he strained his lower back*
>
> *While pushing roof bolt into a hole he strained his shoulder and neck*

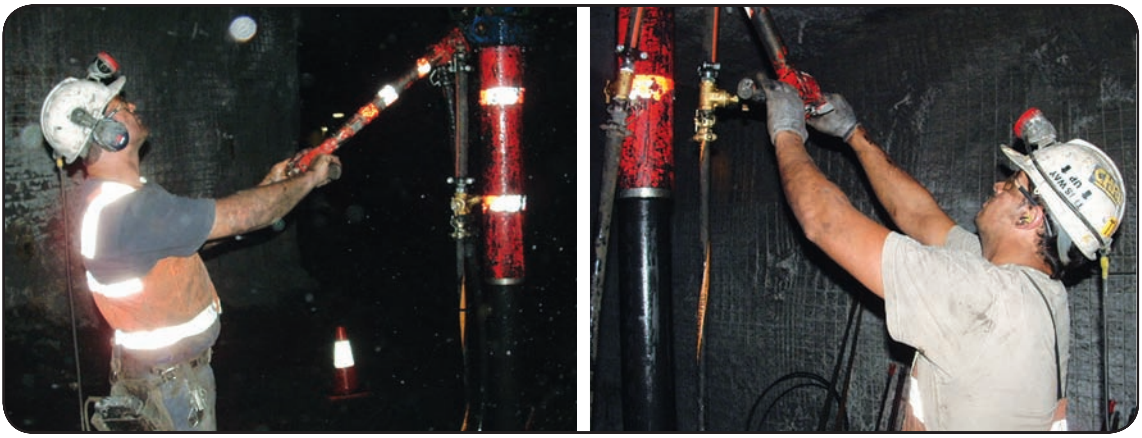
Handheld bolting rig, typically used for secondary support including cable bolting

The handling of these rigs (which can weigh up to 45 kg), and carrying into position over uneven group is a high risk manual task, even when undertaken as a team lift. The use of the bolter requires relatively high back exertion to resist the reaction torque applied by the rig, particularly when the drill bit meets unexpected resistance. Awkward and static postures are also involved, and this task should also be considered a high risk of injury.

The drill operator is assisted by an offsider. This person's tasks include retrieving drill steels, breaking steels (using a hammer) to insert new drill steels whilst holding sometimes very heavy drill strings up, inserting chemical, bolts, cables into the drilled hole, assisting the driller control the rig. Collectively these task components require high exertion, particular of the shoulder, combined with awkward shoulder postures.

Moving handheld bolter into place

The use of hand held bolting rigs should be reduced as far as possible. Substitution with other bolting devices, or mounting them on LHD via QDS is desirable. Track mounted bolting rigs have also been developed, and these should be utilised where possible in preference to hand held bolters.

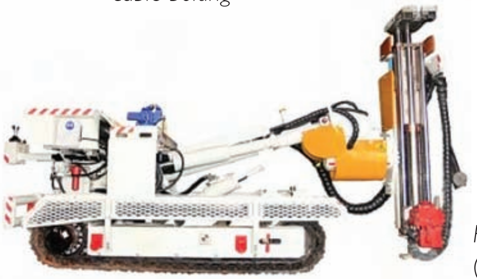


Drilling with hand held rig

Offsider holding drill string during cable bolting

(www.mastermyne.com.au)

QDS mounted bolting platform (alfabs.com.au)



Highlander series 3 (www.highlandsmining.com.au)

GENERIC ERGONOMICS RISK ASSESSMENT FOR UNDERGROUND COAL MINING EQUIPMENT

The aim of this section of the handbook is to provide a generic framework for conducting an assessment of the ergonomic aspects of underground mining equipment. Generic hazards associated with underground equipment have been identified on the basis of injury records and task observation. Not all hazards identified will be present for all items of equipment. Further, the specific nature of the hazards will vary with the equipment, and additional hazards may exist; however the aim of the tool and these explanatory notes is to ensure that the most common hazards are considered.

The hazards identified for assessment are:

- Slip/Trip while entering or leaving equipment
- Slip, trip or fall during operation and/or maintenance of equipment
- Acute jolts and cumulative whole body vibration
- Manual tasks during operation and maintenance
- Caught between moving parts
- Vehicle-object collisions and vehicle-pedestrian collisions
- Struck by falling rock from roof or rib

A discussion of the assessment of the hazard is provided both in terms of the maximum reasonable consequence of the hazard, and the probability of an adverse event occurring. In the case of assessing equipment to determine what additional control measures may be required, the appropriate probability to consider is not the probability of injury to an individual, but rather the probability of injury to any person working with the equipment. (cf HSE doc www.hse.gov.uk/research/rrpdf/rr151.pdf (p. 15).

Slip/Trip while entering or leaving equipment

Risk Assessment

An injury involving lost time is the maximum reasonable consequence of slipping during access or egress. This hazard, and maximum reasonable consequence, will remain while miners continue to access equipment. Given the frequency with which access and egress from equipment occurs (hence a very high exposure to the hazard), the probability of an injury is almost certain if access systems are poor.

Issues contributing to hazards

Unless remote control can be employed to remove the hazard, the best that can be achieved is to reduce the probability of such injuries through improving the access systems provided.
The probability of an injury can be reduced by ensuring access systems comply with relevant standards, and particularly that the height of initial step is 400 mm or less above the ground and the points of contact are possible at all times. Cut-out footholds are not satisfactory to ensure safe egress. Non-slip access surfaces should be provided, which may include non-slip coverings for ladder rungs.

Cab dimensions should be sufficient to ensure than movements are not restricted during access and egress. The dimensions must allow for largest operator wearing self-rescuer and cap lamp battery.

Adequate access systems should also be provided for routine maintenance tasks (or equipment design allow maintenance tasks to be completed without accessing vehicle).

Slip, trip or fall during operation and/or maintenance of equipment

Risk Assessment

If miners are required to perform duties which involve standing on equipment, the maximum reasonable consequence of slipping, tripping or falling from that equipment is an injury involving lost time. The probability of an injury depends on the frequency with which duties are performed which expose miners to the hazard. Exposure is very high for continuous miners with integrated bolting rigs, and is also increased by the need to perform manual tasks including bolting and handling bolting supplies, mesh and vent tubes whilst standing on the continuous miner platform. In this situation, the probability of an injury by this mechanism is almost certain unless specific control measures are in place.

For other equipment types, the probability of injury of this type is low during equipment operation (although increased if miners stand on inappropriate parts of the equipment). This probability is elevated if miners are required to stand on equipment to perform inspections or routine maintenance.

Issues contributing to hazards

For continuous miners with integrated bolting, and indeed for any other equipment type which involves working from an elevated platform, the probability of injuries of this type is reduced by avoiding changes in platform levels, and providing kick boards and handrails. Provision of appropriate platform lighting is desirable, and attention to house keeping to reduce slipping/tripping hazards on the platform is also warranted. MDG1 specifies handrails for platform higher than 1.2m, however the injury experience in NSW mines suggests this is insufficiently protective.

Training and enforcement of the importance of not standing on equipment other than elevated work platforms to perform overhead work is important. This in turn implies a concern with ensuring that alternate means of performing tasks requiring this overhead work are provided.

For all equipment it is important to consider access for maintenance, especially routine maintenance. All pre-start checks and regular maintenance tasks should be able to be performed while standing on the ground.

Acute jolts and cumulative whole body vibration

Risk Assessment

Miners driving, or travelling in, vehicles on underground mine roads are exposed to both low frequency/high amplitude forces (jolts & jars) and relatively high frequency/low amplitude force (vibration). The jolts and jars occur because of the vehicle driving into pot holes, over stone or coal, and other roadway abnormalities and cause a variety of acute injuries. Long term exposure to whole body vibration is strongly associated with the development of back pain, although this link is rarely made in compensation claims.

For equipment such as LHD, Shuttle cars and transport which miners drive or travel in for long periods each shift, the probability of exposure to jarring and whole body vibration is certain, and this probability will be difficult to modify. The aspect of risk which may be modifiable is the maximum reasonable consequence. The severity of injuries resulting from exposure to jolts and jars will depend on a number of modifiable factors including the roadway standards, vehicle speed, vehicle suspension, seating, and cabin space. In the absence of controls relating to these factors, the maximum reasonable consequence is a time lost injury.

Issues contributing to hazards

Eliminated through remote control. Where elimination is not undertaken, factors determining the maximum reasonable consequences are the standard of the mine roads, the speed with which the vehicle travels, the quality of the vehicle suspension and seating, and the space in the compartment (particularly head room).

Administrative controls such as roadway standards and travel rules are important to reduce the exposure to high amplitude impacts, as is allocation of resources to ensure roadway standards are able to be enforced. Travel rules rely on the safety culture of the mine.

Having controlled vibration at the source as far as practicable, the injury consequences of exposure to both high and low amplitude vibration can be further controlled through provision of appropriate vehicle suspension and seating. For Shuttle cars and LHD vehicles, provision of weight adjustable suspension seating is appropriate, although care is required to ensure that the range of weight adjustability is suitable for the population, that the adjustment is easily made; and that miners are trained in the need for, and means of, making the adjustment. The maximum reasonable consequences can be further reduced through ensuring the head room in the compartment is adequate.

Manual tasks during operation and maintenance

Risk Assessment

All equipment requires the performance of manual tasks. Risk factors for musculoskeletal injury are the performance of tasks involving combinations of forceful exertions, awkward postures, repetition and duration. Musculoskeletal injuries can occur from either acute or cumulative loading, and often as a combinations of both. The maximum reasonable consequence of the loading associated with manual tasks depends on the nature of the tasks associated with specific equipment, and similarly, the probability of injury will depend on the frequency with which tasks are performed. For many equipment items a separate task analysis and task based risk assessment will be necessary. The tool provided as Appendix B of the "Procedure for Managing Injury Risks Associated with Manual Tasks" (Burgess-Limerick, 2008) provides a method for assessing manual tasks risks.

In the absence of specific controls, continuous miners and bolting machines are associated with high risk manual tasks (almost certain probability of lost time injuries) including bolting and cable handling.

While the duration of exposure to maintenance tasks is less than tasks associated with operation, and consequently the probability of injury is less, a task analysis of routine manual tasks should be undertaken to ensure manual tasks risks are minimised.

Issues contributing to hazards

Where significant manual tasks are associated with equipment use it is necessary to undertake a detailed task analysis and risk assessment of the specific tasks undertaken. This risk assessment should consider the degree of exposure to the known risk factors of forceful exertions, awkward postures, repetition and duration. The injury risks associated with these physical risk factors may be exacerbated by exposure to environmental and psychosocial risk factors including heat or cold, high stress or time pressure, and cognitive over or under load.

Elimination or substitution of manual tasks injury risks is commonly undertaken through the provision of mechanical aids, such as loading of pods of bolting supplies and mesh onto CM via LHD and jib, or a monorail to reduce cable handling. Risk reduction is also achieved through redesign of workstations and workplaces to improve access and reduce reach distances, such as the redesign of bolting rigs and controls to allow closer access. The design of control layout should ensure that primary controls lie within the normal reach envelope of the smallest potential user.

Routine inspections and maintenance tasks should be able to be performed without exposure to forceful exertions or awkward postures.

Caught between moving parts

Risk Assessment

The maximum reasonable consequence associated with entrapment hazards will vary depending on the specific equipment under consideration, however for much underground equipment the consequences can be severe, and certainly include serious injuries. A task analysis and more detailed risk assessment is warranted where multiple entrapment risks exist. The probability of entrapment occurring will vary depending on the frequency with which tasks or activities with which the hazards are associated are performed. Design controls such as guarding and shape coding of controls may reduce the probability of injury occurring.

Issues contributing to hazards

Entrapment injuries occur as a consequence of inadvertent control operation, operation of an incorrect control, or of the correct control in the wrong direction. Guarding of controls may reduce the probability of inadvertent operation. Reductions in the probability of operating the incorrect control may be achieved through standardisation of control location and ensuring that primary controls have different shapes and lengths. Standardisation of directional control response relationships may reduce the probability of operating a control in the wrong direction. Provision of emergency stop may allow recovery from error on some occasions.

Other entrapment injuries are associated with deliberate operation of a control while the operator, or another person, has some part of their body in a hazardous location. Here guarding or other design controls (two handed operation, etc) should be employed to reduce the probability of this occurring. Training on its own will not be an effective control and should only be considered an adjunct to design controls.

Vehicle-object collisions and vehicle-pedestrian collisions

Risk Assessment

Collisions between vehicles and objects (including other vehicles) have the reasonable potential to cause serious injuries, while a fatality is a reasonable consequence of collisions between vehicles and pedestrians. These risks should consequently be considered independently although there are shared causal mechanisms.

Given the high exposure of vehicles driving through the cluttered underground environment with reduced visibility, the probability of vehicle-object collisions is relatively high, and specific controls are required to reduce both the probability, and potential consequences, of these collisions.

Where vehicles operate near pedestrians, the possibility exists of collisions between vehicles and pedestrians and, unless controlled, the risk is high.

Issues contributing to hazards

The restricted visibility afforded to drivers of many underground vehicles is a known contributor to the risk of collisions and has been the subject of considerable investigation. Redesign of vehicles to minimise obstructions to the line of sight has been demonstrated to be effective. Where seam height allows, raising the operators seat is also effective.

Other control measures which have potential to reduce the probability of collisions include: pre-start alarm; speed limits; vehicle lighting which indicates vehicle travel direction; proximity detection devices; travel rules which stipulate vehicles stop while pedestrians pass; ensuring steering control-response relationship are always compatible; and physical separation of pedestrians and vehicles. Control measures which may mitigate the consequences of vehicle-object collisions include cab enclosures, seat restraints, and forward or rear facing seating.

Struck by falling rock from roof or rib

Risk Assessment

The maximum reasonable consequence of this hazard is a fatality. The probability depends on where and how the equipment is operated, and what controls are employed.

Issues contributing to hazards, and specific control recommendations

The probability of adverse events is dramatically reduced by the practice of roof meshing. In mines where mesh is not routinely applied (many mines in Eastern USA) injuries due to falling material are the most common equipment related injury. In some cases however, the placement of mash during the bolting process requires miners to briefly extend their bodies under unsupported roof to manipulate mesh sheets into place before the temporary roof support is extended. This practice creates a possibility of fatal injury and requires a design control to ensure mesh placement can be undertaken without exposure to unsupported roof. The provision of protective cabs on vehicles reduces the probability of injury from falling materials further.

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NOTES

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Dr. Burgess-Limerick has published 50 papers in refereed journals and received more than $3.9M in competitive research funding from diverse funding agencies including the National Occupational Health and Safety Commission, the National Health and Medical Research Council, Workcover Queensland, Coal Services Health and Safety Trust, and the Australian Coal Association Research Program (ACARP). Robin has acted as the project leader for 4 ACARP projects (C11058, C14016, C16013, C18012) as well as making a significant contribution to C14045. Robin has received numerous awards for research including an ACARP Research Excellence Award for project C14016, and a 2006 National Academy of Sciences (USA) Senior Research Associateship within the Mining Injury Prevention Branch, National Institute for Occupational Safety and Health, Pittsburgh Research Laboratory.

Dr. Burgess-Limerick's publications include a book titled "Human Factors for the Design, Operation and Maintenance of Mining Equipment" (with Tim Horberry & Lisa Steiner) published by CRC press in 2010.