Reducing injury risks associated with underground coal mining equipment

A handbook arising from ACARP Project C14016

Robin Burgess-Limerick PhD CPE • Burgess-Limerick & Associates • February 2007

Burgess-Limerick & Associates
Ergonomics and Research Consultants

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Foreword

This handbook is an outcome of ACARP project C14016, undertaken from March 2005 to February 2007. The project was initiated by Xstrata Coal NSW through the Industry Monitor, Dave Mellows, and has involved cooperation and contributions from many other people in the industry. Project staff (Robin Burgess-Limerick, Suzanne Johnson, Gary Dennis, & Jenny Legge) collectively visited 14 Australian underground coal mines (Ulan, Beltana, United, Baal Bone, West Wallsend, Oaky North, Kestrel, Dartbrook, Denbrobium, Metropolitan, Angus Place, Douglas Park, Newlands and Appin mines). Visits were also made to manufacturing sites in Australia and the USA including Hydramatic, VA Eimco, Joy Haulage, Waratah Engineering, and Specialized Mining Vehicles. Part of this work was completed while the author was a National Academy of Sciences Senior Research Associate in the Mining Injury Prevention Branch of the National Institute for Occupational Safety and Health, Pittsburgh Research Laboratory. A one day seminar was held on October 17, 2006 in Pokolbin, and was attended by 100 people from mining companies, contractors and manufacturers. The proceedings of this seminar, and the final project report (incorporating this handbook) are available via *www.burgess-limerick.com*.

Introduction

The objectives of the project were: (i) to identify injury risks associated with the ergonomics of underground mining equipment through analysis of the full-text description of incidents involving underground equipment and audits of participating sites; (ii) to identify and evaluate existing control solutions through audits of participating sites; (iii) to identify and evaluate potential controls for outstanding issues through collaboration with all stakeholders; (iv) to develop a generic ergonomics risk assessment tool for application to new equipment; (v) to communicate the consolidated views of diverse mine sites to manufacturers; and (vi) to disseminate the results of the project to mine sites, engineering students, and manufacturers.

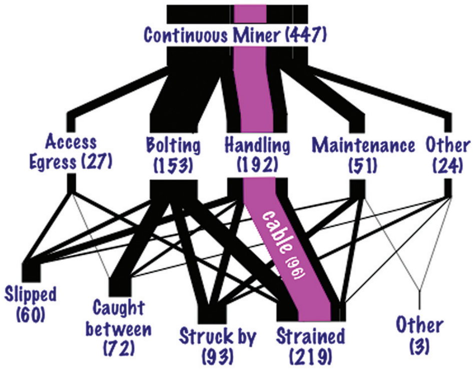
This handbook aims to collate this information in two parts. Part one draws on the information obtained to provide a snap shot of current best practice for the management of underground equipment injury risks. The focus of this section is restricted primarily to roadway development equipment. Part 2 of the handbook provides a generic ergonomics risk assessment tool which aims to improve the assessment of injury risks related to the ergonomics of underground mining equipment generally. This part of the handbook is supplemented by a DVD based training module.

PART 1

CURRENT BEST PRACTICE IN EQUIPMENT INJURY RISK MANAGEMENT

Continuous miner

Of 4169 injuries reported to Coal Services during the three years to June 2005, 23% (959) were associated with development equipment. 447 of these injuries were associated with continuous miners.



Injuries associated with continuous miners in NSW mines during the 3 years to June 2005

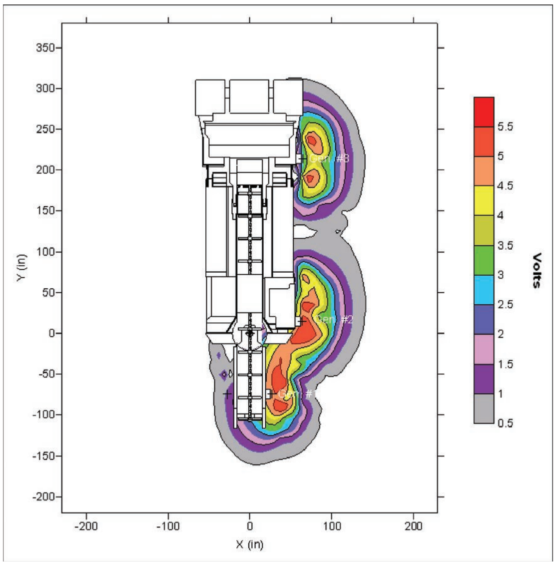
The most common injury mechanisms associated with continuous miners are: (i) slips during access/ egress or working on the platform; (ii) caught between/struck by injuries while bolting; (iii) strain during bolting; and (iv) strain during handling continuous miner cable.

Analysis of the frequency of injuries under-emphasises the risk of high consequence, low frequency events. For the continuous miner, such risks include potential injuries associated with inadvertent or incorrect remote control operation; the risk of entrapment between the continuous miner and the rib during tramming, and the risk of interaction between the shuttle car and the continuous miner operator during coal loading.

The risk of inadvertent operation of the remote control is reduced by recessed switches rather than toggle switches, however potential exists for operation of incorrect switch, particularly activating the conveyer instead of cutting heads (or vice versa).

The proximity of conveyer and cutter switches creates an risk of incorrect operation

The prevention of injuries caused by interaction between the continuous miner operator and the shuttle car relies on soft controls, although the use of proximity devices may be possible. Similarly, soft controls are relied upon to prevent entrapment between rib and continuous miner. 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 NIOSH (Schiffbauer, 2001; see also *www.msha.gov/regs/complian/PIB/2006/pib06-18.asp*).



NIOSH proximity detection system

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

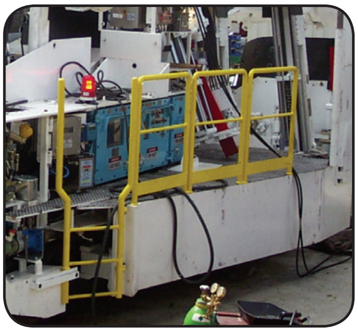
SLIPS DURING ACCESS/EGRESS OR OPERATION

Slipping off the continuous miner platform, whether during access or egress, or during operation 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, 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. Cut-out foot holds provided on some miners are problematic during egress because the location of the cut out can not be seen from above. In this situation, miners are very likely to jump off, with potential injury consequences.

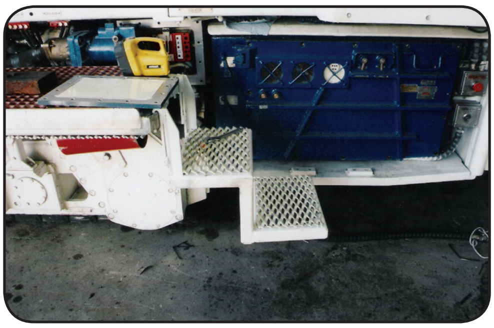
Hinged steps are provided on some miners (and are frequently broken off). Access systems should be designed to comply with AS3868 (bottom step <400 mm above the ground, three points of contact). Provision of ladder access may preferable for high platforms where compliance with this standard is otherwise difficult. Such access systems have been retrofitted at some mines, and the ABM25S provides a retractable stair access.

Hinged platform and access step



Ladder access system and handrail

Retractable steps on ABM25S



Step access

Single level platform and rear step

The probability of slips and trips during operation 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 explored (West Wallsend) and advances in LED lighting technology are promising for improvements to equipment lighting and for continuous miner platforms and bolting rigs in particular.

Tripping hazards caused by changes in platform levels

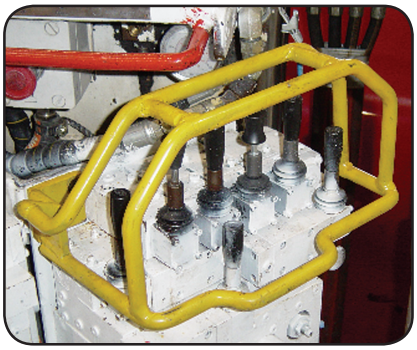
Handrails have been retrofitted at some sites (e.g., West Wallsend, Angus Place) and incorporated in the ABM25S. While MDG 1 specifies handrails should be provided for platform heights above 1.2 m, the injury statistics suggest that this is insufficiently protective, and handrails are justified for all platforms.

Handrail on ABM25S platform

CAUGHT BETWEEN/STRUCK BY INJURIES WHILE BOLTING

A variety of causes of these injuries are evident. Many are a consequence of either: unintended operation of bolting controls; operation of the incorrect control; operation of the correct control, but in the wrong direction; or 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.

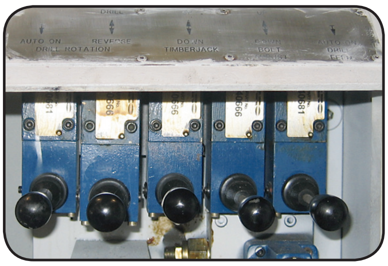
Unintended operation of controls typically occurs through bumping with a battery, self-rescuer, or through the control being struck by a falling object (e.g., drill steel or bolt) or small rock. The probability of unintended operation of bolting controls is reduced by guarding, however care is required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

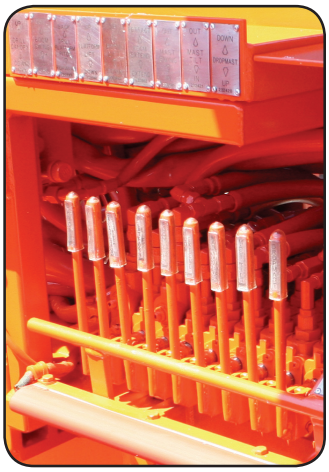


Guarding against inadvertent operation

Too much guarding may inhibit access

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.





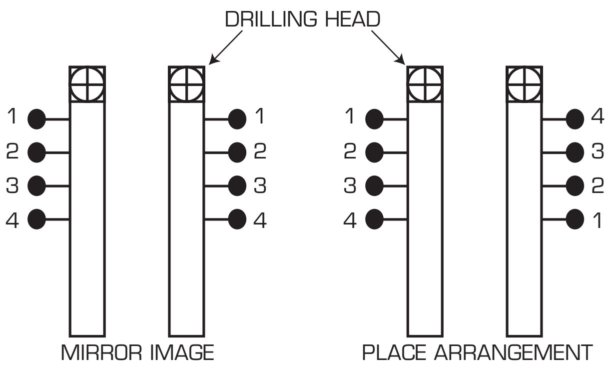
A bank of similar controls increases the probability of operator error

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; 1999; Muldoon et al., 1980).

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 mirror image and left/right arrangements, and the possibility of inadvertent operation.

The probability of selecting the incorrect control may be reduced through consistent location of controls on both sides of miner (known as location coding). Where a machine has dual controls on opposite sides and operated by opposite hands, a question arises regarding the appropriate layout of controls.

One alternative is for the control arrangement to be "mirrored", that is for the controls to be laid out such that controls to be operated by left and right hands are in the same order relative to the chuck, that is the control closest to the chuck on each side correspond to the same machine function. A non-mirrored arrangement, or "place" arrangement has the controls laid out in the same order left-to-right, that is the left-most control on both sides controls the same function, and so on.



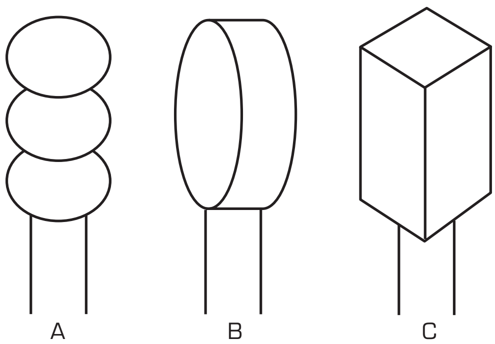
"Mirror" and "Place" alternatives (Helander et al., 1980)

Helander et al., (1980) noted that the question was controversial, and cited a Masters thesis by Pigg (1954) as the best available evidence. This research involved 64 participants learning a four choice reaction time task in which different coloured lights were paired with different levers. After 6 blocks of 8 trials, subjects changed hands and repeated the task with the levers either presented in the same left–right sequence, or in a mirrored sequence. Reaction time was initially delayed in the left–right condition relative to the mirror condition, but the new arrangement was rapidly learned. Fewer errors were also made in the mirrored transfer condition. On the basis of these results, Helander et al recommended a mirrored layout, and this recommendation was contained in the "Human Factors Guidelines for roof drills" proposed by Helander and Elliott in 1982 (Gilbert, 1990).

However, while not citing any evidence, a contrary recommendation was made by Muldoon et al (1980) – "Once an operator learns that rotate is to the left of feed, he should not have to relearn that rotate is to the right of feed on the right boom." … "Since mirror image controls confuse the operator and do not increase efficiency, they should not be used" p. 41. The proposed "Human Factors Guidelines for Mobile Underground Equipment" provided by Essex Corporation in 1984 (Gilbert, 1990) also recommended against mirror image control configurations for drill stations, and this is also consistent with AS4024. This question will be addressed during an ACARP funded project (C16013) to be conducted in 2007–2008.

Another potential way of reducing the probability of operators selecting the wrong control is to reduce the similarity of the controls through, for example, changing the shape of knobs (shape coding), or the length of control levers (length coding). Similar recommendations were made more than 30 years ago (Hedling & Folley, 1972).

Shape coding through a missing knob



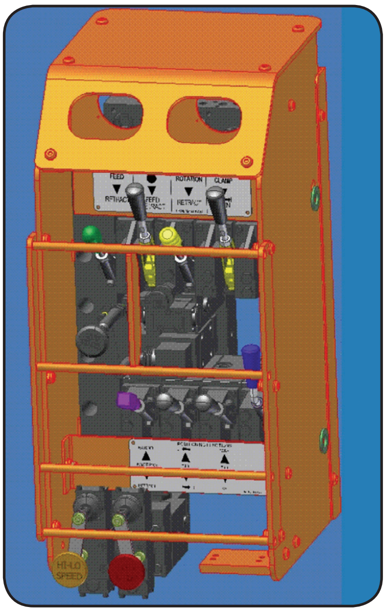
Handles shapes stipulated in MDG35 for (A) rotation; (B) feed; and (C) timber jack

At one site visited during the current project, shape coding had been undertaken by an operator who had placed a placing 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. The recently revised MDG 35 includes shape coding recommendations, and consequently shape coding will be introduced in new bolting rigs. While shape coding and length coding are both likely to be desirable, the relative magnitudes of benefit associated with shape, length and location coding is unknown, and will be assessed in the subsequent ACARP project. This is necessary before evidence based recommendations may be made regarding the relative importance of each type of coding, and whether all methods should be employed, or whether a subset is sufficient to reduce the risk of operating the wrong control to acceptable levels.

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.

Shape coding employed in mast mounted bolting controls (Hydramatic)



Shape coded controls

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 e.g., "The single most important control optimisation is to have controls move in the direction of the component controlled"(emphasis in original) 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, although no evidence is provided to justify this recommendation. 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".

A recent "Proposed Standard for Actuator Lever Movements" (Hydramatic Engineering, 2005) similarly argues against the use of any generic directional relationships for bolting rigs on the basis of the range of potential combinations of orientation of bolting rigs and controls given that with current drilling machines the orientation of the drill rig may change through 90 degrees to allow both rib and roof bolting. Instead, the following control response relationships are proposed: Forward rotation, advance drill feed, bolt thrust, extend timber jack, extend canopy = lever down, back, pull out or rotate clockwise.

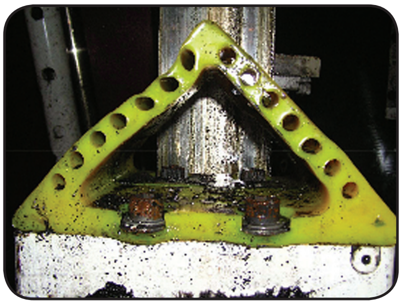
The issue is not straight forward. A number of authors have noted the relatively common practice to reverse this situation on bolting rigs where downward movement of horizontal control is associated with upward movement of controlled element such as boom or a timber jack. While some reports note this as a violation of directional control-response relationships, Chan et al., 1985 noted that response may be compatible if the operators assume a "see-saw" mental model of the situation where moving the near end of the control downward causes the far end (and the controlled element) to move upward.

Chan et al. (1985; Simpson & Chan, 1988) investigated this situation through an experiment in which 144 people reported the direction they would move a control lever to achieve a specified effect, using a 1/10th model of a drill loading machine. The results indicated that the while the majority of people reported responses consistent with a "see-saw" mental model, the stereotype was far from universal, and up to 33% of people reported expectations for "up=up". Extremely strong expectations were reported for the movement of vertical controls however, with more than 90% of people expecting a backward movement of a vertical lever to cause an upward movement of a controlled element, and this is consistent with common generic recommendations. Consequently, it may be better to use forward and backward movements of vertically mounted controls to cause vertical movements of controlled elements.

This is consistent with both the proposed "Human Factors Guidelines for Roof Drills" provided by Helander and Elliott, where vertical controls are preferred over horizontal controls, and implicit in the proposed "Human Factors Design Guidelines for Mobile Underground Mining Equipment"

which provided recommendations for vertical lever directions, but no recommended directions for horizontal levers (Gilbert, 1990). Chan et al (1985) suggested that "conflicting recommendations and gaps in the literature would need to be resolved before any standardisation of control-response relationships for mining machines was possible". The subsequent ACARP project aims to address these issues to allow justifiable recommendations to be made.

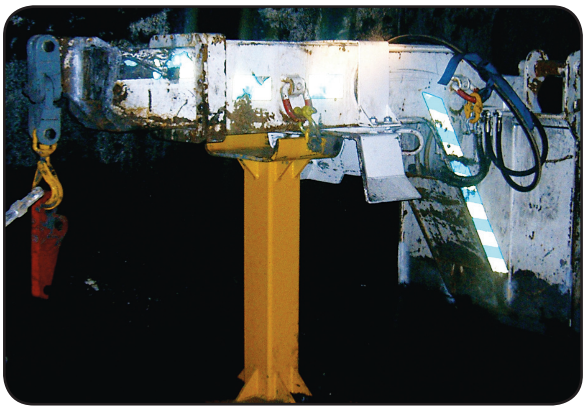
Injury may also occur when the correct control is operated in the correct direction, but while the operator or another person has a body part located in a location where entrapment is possible. A variety of control measures are employed to such injuries, as well as those associated with control error. 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 headplates 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)

STRAIN DURING BOLTING

Manual handling of bolting supplies, mesh and vent tubes poses risks of both acute and cumulative injury. With only one exception, all sites visited during the project were 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 adjacent to bolting rigs further reduces handling of these items.



Bolting supplies pod and mesh carrier

Handling of mesh is typically facilitated by single or dual "ski jumps" on top of the continuous miners. One site visited loaded cassettes of mesh manually onto the top of the miner, while an LHD and jib are used to load mesh cassettes at Oaky North. A height adjustable platform to improve the postures adopted to handle mesh while bolting features in the design of the ABM 25S. This model also includes a system for loading mesh cassettes mechanically.

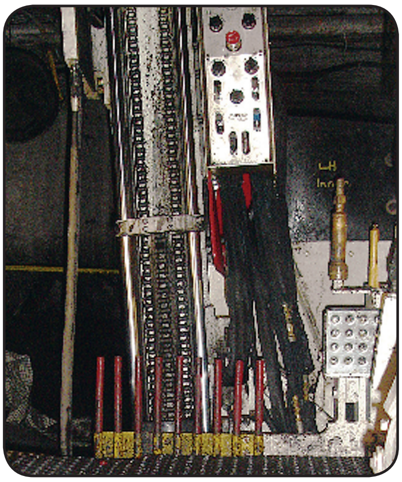
Jib used to load mesh via LHD

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 the ABM25S may reduce handling issues associated with mesh and vent tubes. Vent tube handling risks may also be reduced through the use of a monorail system.

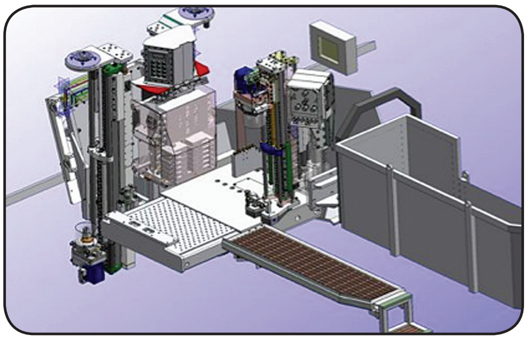
Installing vent tubes

Strains during bolting are likely to occur as a consequence of prolonged exposure to high shoulder load moments (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



Mast mounted control and rotated drill pots reduces reach distance



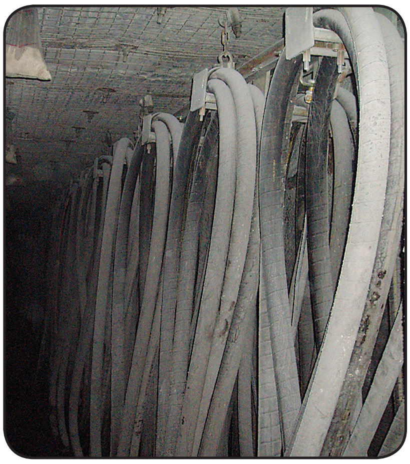
Redesigned bolting rig controls increases space available on platform

A hand operated rib borer is in use at some sites. This is a high risk manual task. Fitting a miner mounted rib borer is the preferred control.

HANDLING CABLE

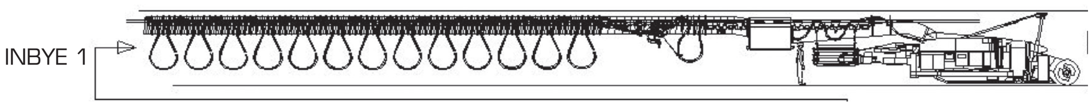
Strains while handling was the most frequent cause of injury associated with continuous miners. The majority of these injuries involved handling continuous miner cable (32 injuries per year in NSW). The severity of injuries associated with handling cable varies from relatively minor shoulder strains 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, there is no doubt that 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).

Handling cable is a common cause of shoulder and back injuries



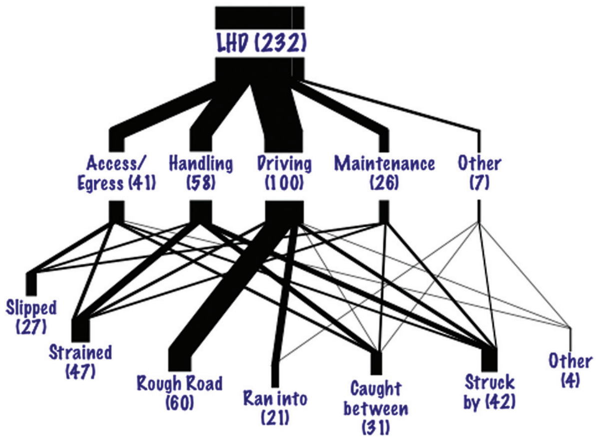
Development monorail
(Macquarie Manufacturing)

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).



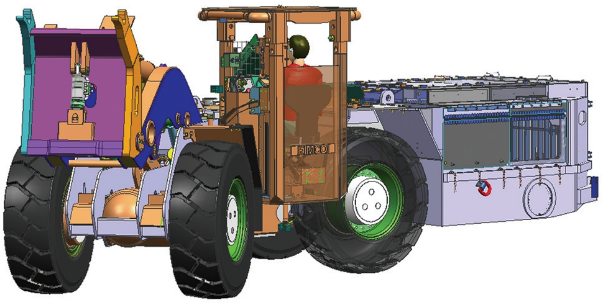
Load–Haul–Dump

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.

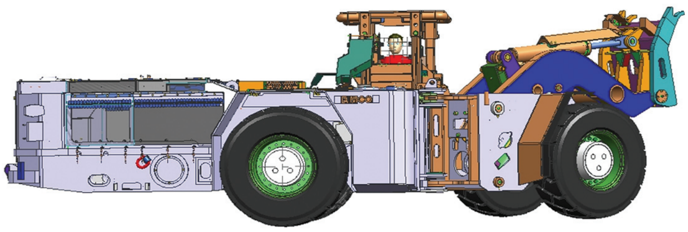


Injuries associated with LHD vehicles in NSW mines during the 3 years to June 2005

Some cab modifications have been carried out to address these issues, however the major current development is the height adjustable cab redesign undertaken by VA Eimco in conjunction with Xstrata Coal NSW and BHP Billiton.



Height adjustable cab fitted to Eimco LHD



Enlarged LHD cab (Kestrel)

Existing cabs have been modified to increase door size and provide anti-skid surface (Kestrel) to reduce the risk of injury during access/egress. The height adjustable cab redesign improve access with cab in lowered position. Existing cabs have also been modified to increase cab space.

While roadway maintenance is critical to prevent jarring and reduce exposure to whole body vibration, controls can also be implemented at the seat. "Jel" seat padding is provided at Beltana, and weight adjustable ISRI seats will be fitted to the new Eimco LHD cabs. Improvements may be required in the adjustment mechanism.

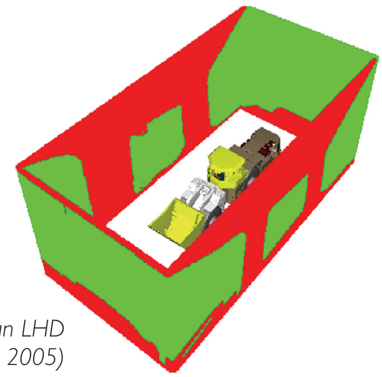
The sideways seating position used in LHDs requires prolonged exposure to a rotated neck posture. This can be reduced by providing some degree of seat rotation. 30 deg rotation in seat has been provided in some refits, and will is included in the Eimco LHD cab redesign. Dual seats allowing the driver to face the direction of travel are provided on an MPV (United). 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 visibility restrictions while driving Load-Haul-Dump vehicles (LHD) 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 (e.g., Kingsley et al., 1980; Eger et al., 2004; Tyson, 1997).

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 Eimco LHD cab redesign.

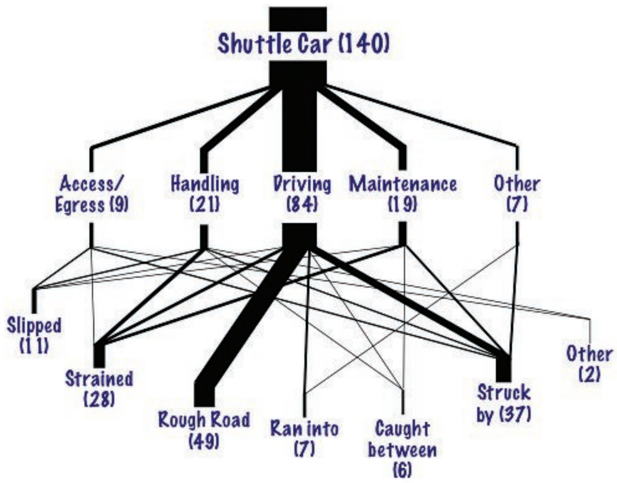


Visibility Box Plot for an LHD (West et al., 2005)

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

Shuttle car

The most common injuries associated with shuttle cars are those caused to the driver when the shuttle car hits a pot hole or some other roadway abnormality.



Injuries associated with shuttle cars in NSW in the 3 years to June 2005

While some current models of shuttle cars provide suspension, the vast majority of shuttle cars currently in service do not. The seating provided in many shuttle cars also provides little or no protection from unexpected high amplitude perturbations (jarring) or lower amplitude whole body vibration.

Poor shuttle car seat suspension

Roadway maintenance is a primary control measure to be implemented, in conjunction with improvements in vehicle suspension and seating. Injury risks are also increased by restricted cab space.

The risks of pedestrian interaction with the shuttle car is increased by the poor visibility when driving towards the continuous miner, combined with an incompatible steering relationship (Zupanc et al., 2005).

Restricted visibility returning to the face

A number of sites have made minor modifications to shuttle car cabs (e.g.,Pendlebury, 2003). The likelihood of falls during access or egress has been reduced by providing steps and hand holds have been added as part of cab refits at a number of sites, and the space in the cab has also been enlarged as part of these refits. Weight adjustable suspension seating is sometimes found in refurbished shuttle cars, however the mechanisms are so difficult to adjust that it seems unlikely they ever would be.

Improved seating and access (Pendlebury, 2003)

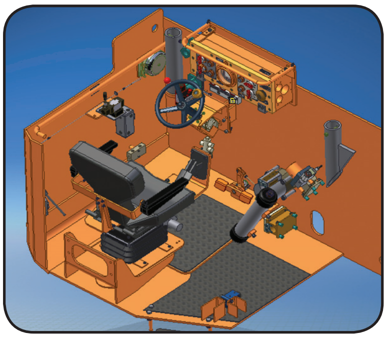
A road-levelling bar is fitted to some cars to aid in roadway maintenance and air-filled tyres are preferred at others to reduce jarring.

Beltana have undertaken a more radical redesign in a cab refurbishment, increasing the size of the cab considerably and reorienting the driver perpendicular to the direction of travel.

East–west cab fitted to shuttle car (Beltana)

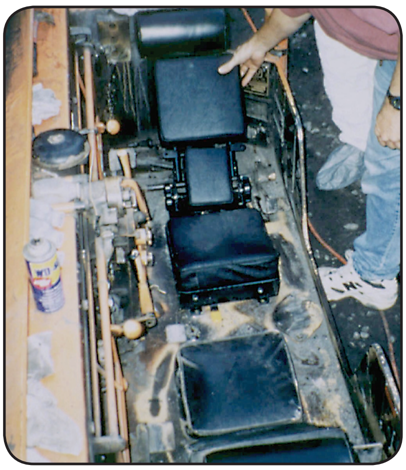
East–west seating is also a feature of Joy 10SC32BC shuttle cars purchased by Beltana from Joy South Africa. These cars also have a suspension system based on a strut of elastomeric pucks and urethane dividers on a steel rod (Joy, 2005).

Joy shuttle car suspension



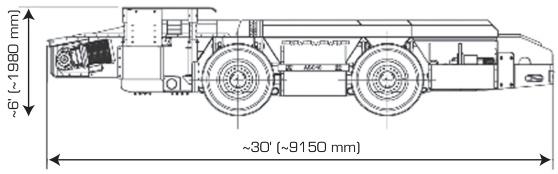
Joy 10SC32BC shuttle car

Hydraulic suspension has also been used in the US by Consolidated mines, and provides better shock absorbtion than passive systems. However current design are reported to have reliability problems. Foam seats developed by NIOSH are used in US Shuttle cars, especially low seam cars (Mayton et al., 1997; 1999).



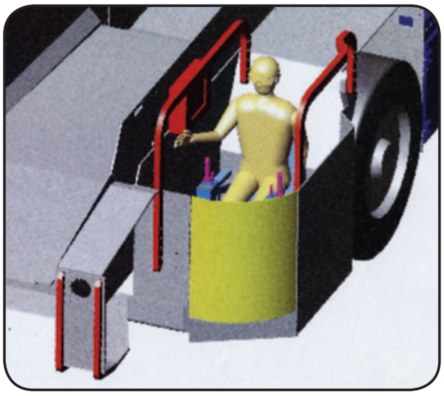
Foam seat developed by NIOSH for low seam shuttle cars

VA Eimco have demonstrated a new shuttle car (ASC18) in the USA which incorporates a fully enclosed cab, a single perpendicularly mounted suspension seat, stick steer, and vehicle suspension.



VA ASC18 Shuttle Car with stick steering

Waratah Engineering have incorporated suspension in cars to be delivered in 2007, and has proposed designs for a car which incorporates seat mounted joy stick controls; 180 deg seat rotation; enlarged cab; accelerometers to measure vertical vibration transmitted to the driver; and proximity sensors to prevent hard collisions with continuous miner (or continuous miner operators).



Proposal for rotating seat with joystick steering (Waratah Engineering)

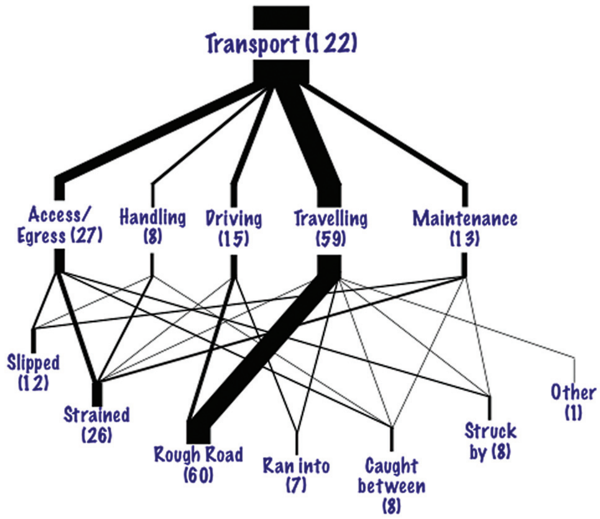
The use of flexible conveyer trains instead of shuttle cars is another option to reduce hazards associated with shuttle cars.

Awkward postures during routine maintenance are reduced by providing external header tanks and grease points. Manual tasks risks associated with tyre changing are reduced by the innovation presented in 2004 by United.

Shuttle car tyre changing innovation

Personnel transport

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



Injuries associated with transport in NSW in the 3 years to June 2005

Some transport in use has very poor seating, and almost all seats face passengers perpendicular to the direction of travel.

Poor seating increases risks of both acute and cumulative injuries

Control measures to reduce this jarring and vibration (in addition to roadway maintenance) include provision of "Jel" seats , improved shock absorbers and thicker cushions, and complete suspension and seat redesign (ACARP project C14037 – Dayawansa et al., 2006). The SMV transport redesign undertaken at Kestrel with ACARP funding has the additional advantage of seating passengers facing forwards. This refit also incorporated seat restraints. Both changes provide superior safety in the event of a collision.

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

Dayawansa et al., have also developed concepts for new underground transport vehicles.

Concept vehicles (Dayawansa et al., 2006)

Portable bolter

Both the use, and manual transport of, portable hand held bolting rigs pose a high risk of injury. Substitution with other bolting devices, or mounting them on LHD via QDS is desirable. A track mounted bolting rig, "ferret" has been developed by Mastermyne.

"Ferret" (www.mastermyne.com.au).

PART 2

GENERIC ERGONOMICS RISK ASSESSMENT TOOL FOR UNDERGROUND COAL MINING EQUIPMENT

Explanatory notes

The aim of this tool is to provide a generic framework for conducting an ergonomics risk assessment of underground mining equipment. The objective is to assist in documenting the effectiveness of current control measures in order to determine where additional control measures may be required.

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 risk assessment form provides the option for both current risk and controls, and proposed controls and consequential risk to be determined.

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

Each hazard is considered in the following structure.

Injury examples

Selected injury narratives from NSW 2002/03–2004/05 compensation claims are provided to orientate the risk assessment to real injury possibilities.

Risk assessment

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. These are coded as follows:

MAXIMUM REASONABLE CONSEQUENCE (MRC)

Multiple Fatalities	Single Fatality Severe Disability	Serious Injury	Time Lost Injury	First Aid
1	**2**	**3**	**4**	**5**

The injury narratives provide an indication of the MRC, especially for relatively common injury events, but may underestimate the MRC for infrequently occurring events.

PROBABILITY

Not Applicable	Almost Certain	Likely	Possible	Unlikely	Rare
NA	**A**	**B**	**C**	**D**	**E**

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)).

The risk is assessed as a combination of consequence and probability according to the matrix below, where matrix cells 1–10 are considered high risk, cells 11–19 medium risk, and cells 20–25 low risk.

RISK MATRIX

Maximum Reasonable Consequence (MRC)	Probability (P): A	B	C	D	E
1	1	2	4	7	11
2	3	5	8	12	16
3	6	9	13	17	20
4	10	14	18	21	23
5	15	19	22	24	25

Issues contributing to hazards

The guidelines provide information about known issues contributing to the identified hazards, and examples of control measures. The aim of control measures is generally to reduce the probability of adverse events occurring. Elimination of the hazard is the most effective control, followed by design controls. Administrative controls are unlikely to have a marked impact on the risk assessment.

Slip/Trip while entering or leaving equipment

Injury examples

While climbing off the roof bolter he slipped off the back step landing awkwardly on the ground spraining his ankle

While returning to C/Miner after crib break he attempted to step onto operator's platform he slipped on the step striking his mouth on bolting pod fracturing the top three incisors

While climbing onto O/D/S drill rig platform he grabbed hold of the drill bed step on bolting mast. The operator was retrieving the drill steel. The drill bed came back catching his L/middle finger – partial amputation

While climbing down off left hand side of C/Miner his foot slipped and fell to the ground hitting his L/Thigh against C/Miner on the way down causing bruising and abrasion and straining his lower back

While climbing into 913 Eimco the tool belt hooked up in the door of the vehicle straining his lower back

While getting onto Eimco 103 when he grabbed hold of the steering wheel the machine articulated causing the door to shut jamming and lacerating his L/Hand – stiches

While returning to Eimco after having crib he grabbed the greasy handle to help enter the Eimco and slipped and fell twisting his knee

While he was getting out of the Eimco his battery caught on the steering wheel causing the Eimco to articulate which made the door close on his L/Hand causing bruising and lacerations

While he was stepping down from Wagner on the surface he slipped off stepping rail straining his lower and upper back

While climbing onto shuttle car his L/Foot slipped on wet steel floor twisting his L/Knee

While climbing into S/Car to drive off he struck his head on the protective bar over cabin jarring his neck

While he was stepping up into the S/Car drivers compartment he slipped on the smooth floor and fell out of the S/Car straining his R/Shoulder

While getting out of the shuttle car he slipped and fell hitting his L/Ribs and chest on machine causing contusion

While getting into the SMV transport drivers compartment he lost his footing – he slipped and fell twisting his L/Knee

While stepping down off Eimco scrubber tank he slipped and jarred his lower back

Risk assessment

Based on these injury reports, 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

Injury examples

While bolting he stumbled on loose coal and fell against a bracket protruding from the bolting tray bruising L/Chest

After he had finished a rib bolting cycle he was about to pin the excess rib when he fell over a piece of coal on the platform – abrasion to R/Thigh and Sprained L/Knee

While roof bolting on C/M platform when he walked to get bolts he slipped off the platform straining his lower back

While bolting on the O/D side of C/Miner retrieving the drill steel when he slipped backwards to replace the drill steel onto the rack. He slipped off the side of the C/Miner straining his lower back.

While moving forward to install roof bolts he slipped on C/Miner platform and fell on floor jarring his lower back

While assisting roof bolting, standing on fixed C/Miner platform hear rib bolter when he had to step back out of the other operators way L/Foot went into gap between extendable platforms causing his to fall straining his R/Knee

While reaching up into POD on C/Miner to get washers he slipped and fell on platform landing on his L/Rib cage causing fracture

While using rib bolter on ABM C/Miner one of his feet slipped off the edge of work platform causing him to twist his upper body straining his neck and back.

While standing on top of Eimco washing it down for service he slipped over straining his lower back and R/Hip

While standing on the C/Miner head assisting the crew to hang and tie up hoses he slipped when stepping off the C/Miner landing on the C/M pick lacerating L/Upper calf – stiches

While standing on bumper of SMV tying up telephone cables his feet slipped off bumper and fell to the ground.

While inspecting continuous miner head extension hoses for leak he slipped and fell on C/Miner head cutting picks causing grazes and bruising to his chest wall

While standing on protection bar of bulk stone duster cutting bag of dust he slipped jarring his lower back.

After checking fuel and water on diesel loco he slipped off the machine hitting the ground heavily spraining his R/Ankle

Risk assessment

Based on these injury reports, if miners are required to perform duties which involve standing on equipment of machinery, 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 1.2 m, 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

Injury examples

While shunting trailer with 913 Eimco hit a pile of rock on floor causing Eimco to jump hitting his head on roll bar straining his neck

While driving into the mine the Eimco hit a hole in the road causing it to bounce straining his lower back

While driving brumby machine struck a hole in the road causing his head to hit the roof straining his neck

While driving PET machine over rough roads he felt lower back pain

While driving a S/Car to the C/Miner he drove into a hole causing him to be thrown into the air when he landed in the seat he jarred his lower back – Sciatica

While he was driving a S/Car towards the face he drove over a large bump throwing him into the air landing on his self-rescuer bruising his lower back

While driving a S/Car a piece of stone in wheel track run over by car causing it to buck. His head hit the roof jarring his neck and concussion.

While driving a S/Car he struck a bump in road jarring his lower back – disc injury

While travelling in the driftrunner it struck a large hole in the road throwing him off his seat striking his head in driftrunner roof injuring his neck and upper and lower back

While sitting in PJB hit a bump of coal in swilly causing him to be thrown airborne from his seat landing on his self-rescuer fracturing his L/10th and 11th ribs

While travelling out of the mine SMV struck large hole in road and was thrown from the bench seat landing heavily on edge of the sear jarring his lower back and Coccyx

While travelling in PJB the machine struck an object on the road causing the machine to bounce throwing him upwards against the roof of the machine causing neck pain and mild concussion

Risk assessment

Miners driving, or travelling in, vehicles on underground mine roads are exposure to both low frequency/high amplitude forces (jolts and jars) and relatively high frequency/low amplitude force (vibration). The jolts and jars occur as a consequence of the vehicle driving into pot holes, over stone or coal, and other roadway abnormalities and cause a variety of acute injuries as described in the injury narratives. 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

Exposure to this hazard can be 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

Injury examples

While operating a Fletcher roofbolter he was bent over reaching to remove a drill steel from the chuck straining his lower back

While roofbolting on ABM20 LHS outer rig overstretching with chemical in R/Hand and roof bolt in left hand installing a bolt he strained his L/Shoulder – Rotator cuff

While operating Joy C/Miner pushing 8m bolt into roof he strained his lower back

While operating a roofbolter on ABM19 on the work platform he turned to receive roof bolt plates turn back and recommenced bolting he felt L/Knee pain and fell onto the platform – Strain.

While lifting mesh onto the bolter on C/Miner he strained his lower back

While standing on C/Miner trying to lift a 600mm vent duct T-Piece by himself he strained his L/Shoulder

While advancing face ventilation he had vent tube lifted above his head trying to match tubes together straining hisR/Shoulder – supraspinatus tear.

While setting roof bolt at face on ABM46 inserting roof bolt reaching out with L/Arm he strained his lower back

While bolting on C/Miner rigs caused rotator cuff tendonitis R/Shoulder – Sprain

While lifting C/Miner cable into rollers during the flit he strained his lower back

While lifting C/Miner cable onto the hook of the boom of the C/Miner above shoulder height he felt pain to his L/Shoulder

While using a hand held bolter to install mega bolts in roof he strained his lower back

While he was standing on C/M Platform using the WASP to drill the top hole to secure tensar mesh as he was pushing the borer he strained his lower back.

While he was operating roofbolter on L/W face and carrying it to a new position he strained his lower back and felt pain in his abdomen

While changing S/Car tyres when undoing wheel nuts with a 3/4 ratchet he strained his lower back

While operating C/Miner removing cover to allow access to an electrical panel he strained his lower back

While levering the wheel off the hub of an LHD strained his lower back

While crouching down greasing points of C/Miner he strained his lower back

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 as a consequence of 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 below provides one means of accomplishing this and integrating the outcome within the risk management matrix.

The above injury examples make it clear that, in the absence of specific controls, some continuous miners and bolting machines are associated with high risk 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 Eimco 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.

Simplified matrix for assessment of manual tasks risks

TASK: **DATE:**

ASSESSED BY:

IN CONSULTATION WITH:

COMMENTS
(Why was the task assessed?)

Determine the body region which may be at risk of injury. (Alternately, assess the task for each of the following regions: lower limb, back, neck/shoulder, elbow/wrist/hand).

Assess the tasks characteristics for a body region using the table. Use a different colour pen for each body region to develop a risk profile for the task. Determine whether any of the environmental risk factors listed are present. The sum of codes for a body region provides an estimate of the risk of injury for that body region (range 4–24).

The use of the matrix may be sufficient to assist in determining opportunities for reducing injury risks associated with manual tasks. Alternately, the results of this assessment may be integrated within conventional safety management systems by equating scores of less than 8 as low risk, scores of 9–15 as medium risk, and scores of 16 or above as high risk.

	Green 1	Yellow 2	Orange 4	Red 8
Exertion	Low force and speed	Moderate forces or speed, but well within capability	High force or speed, but not close to maximal – "hard work"	Forces or speeds are close to the maximum the person is capable
Exposure	Performed infrequently for short periods	Performed regularly, but with many breaks or changes of task	Performed frequently, without many breaks or changes of task	Performed continuously for majority of shift
Posture	Comfortable postures, within a normal range about neutral	Uncomfortable postures, but not involving postures at the extreme of the range of motion	Postures at the extreme of the range of motion	
Movement and repetition	Dynamic and varied patterns of movement	Little or no movement, or repeated similar movements	Repeated identical movements	

Body region	Exertion	Exposure	Posture	Movement	**Sum**
Neck, shoulders and upper back					
Elbow, wrist and hand					
Low back					
Leg, knee and foot					

❑ Whole body vibration
❑ Hot or cold environment
❑ Lack of control over work
❑ Hand–arm vibration
❑ High stress environment
❑ Lack of opportunities for social interaction
❑ High time pressure

Caught between moving parts

Injury examples

While removing drill steel from Fletcher hit isolation bar and put fingers near the jaws when he accidentally pushed on the lever jamming his R/Index and middle fingers fracturing finger tip

While roof bolting attempting to line his drill up and drop rig timber jack back from rib he jammed his R/Hand and wrist between guide support and top of valve bank cover – crush injury

While being trained on the Fletcher roofbolter trying to get 4 foot drill steel to start hole in the roof when he activated the rotation with R/Hand his glove was wrapped around the steel lacerating his L/little finger

While operating L/hand side rib bolter on ABM20 the nut spun tightening he attempted to guide spanner back onto bolt L/hand became jammed between timber jack and rig slide – crush injury

While operating Joy 12CM30 hydraulic rib bolter holding dolly directing it onto the rib bolt his R/wrist was caught between chuck and head of bolter – crushing injury.

While using C/Miner 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 L/hand and fracture L/5th finger

While extending C/Miner platform he pulled the diversion lever to push platform out the rib bolter came down jamming his l/foot causing fracture to L/5th toe

While operating RB01 installing roofbolts he placed his l/hand on the dolly to remove it he pulled the wrong lever jamming his l/ring finger – crush injury

While roofbolting putting roof bolt to the roof he pulled the wrong lever which brought the timber jack down trapping his r/arm between the timber jack and manifold lacerating r/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 lever pushing timber jack out crushing l/hand against the rib

While installing roof bolt steel he went to raise timber jack pulling handle the wrong way pinning his r/arm between timber jack and top of rig

While doing 103 inspection on Eimco he stepped into Eimco compartment sat down with one hand on steering wheel the other holding the door. When he turned the steering wheel the door shut jamming his L/middle finger – crush fracture

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

As is evident from the above injury narratives, some entrapment injuries occur as a consequence or 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

Injury examples

VEHICLE–OBJECT

While driving LHD the canopy hit a compressed air line clamp breaking the line pipes came apart with force hitting his head causing fractured skull

While driving domino 59 down the drift he turned the vehicle the wrong way and ran into the rib. A piece of timber lagging sticking out came into the compartment hitting lower back and fractured ribs

While driving eimco along a low height roadway he struck his head on a roof bolt forcing his upper body backwards over the side of the drivers compartment before being able to stop the vehicle causing neck injury

While driving away from the c/miner the s/car bumped the rib and it came over the top of the canopy pinning him inside lacerating his face, neck and chest

While driving PJB out of the panel at the end of the shift he had a head on collision with a PET injuring his neck, l/wrist and r/foot.

While sitting in the back of PJB heading towards pit bottom PJB collided with PET 128 bruising his l/3rd rib

VEHICLE–PERSON

Getting off inbye s/car to talk to co-worker operating outbye s/car it started moving outbye the inbye end of s/car swung into rib catching him and forceing him to rib causing contusion his lungs fracturing left shoulder dislocation AC joint

While he was standing in timber pod waiting to load props into s/car the car inched around corner jamming his legs between s/car and props fracturing his lower legs

While removing pipes along roadway MPV was reversing past him and slid sideways. The wheels of the MPV struck his r/foot causing contusion

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

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 in the vicinity of 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 have been demonstrated to be effective. Where seam height allows, raising the operators seat is also effective. A prototype of a height adjustable cab for an LHD provides a mechanism for maximising visibility.

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 practise 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.

Generic ergonomics risk assessment tool for underground mining equipment

Hazard	Current controls	C	P	R	Additional controls	C	P	R
Slip/Trip during access/egress								
Slip/Trip during operation								
Slip/Trip during maintenance								
Jarring and WBV								
Manual Tasks during operation								
Manual Tasks during maintenance								
Caught between moving parts								
Equipment-object collision								
Equipment-person collision								
Struck by falling rock								

MAXIMUM REASONABLE CONSEQUENCE (C)

Multiple Fatalities	Single Fatality Severe Disability	Serious Injury	Time Lost Injury	First Aid
1	**2**	**3**	**4**	**5**

PROBABILITY (P)

Not Applicable	Almost Certain	Likely	Possible	Unlikely	Rare
NA	**A**	**B**	**C**	**D**	**E**

RISK MATRIX

Probability (P) across; **Maximum Reasonable Consequence (MRC)** down

	A	B	C	D	E
1	1	2	4	7	11
2	3	5	8	12	16
3	6	9	13	17	20
4	10	14	18	21	23
5	15	19	22	24	25

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