Injuries Associated with Underground Coal Mining Equipment in Australia

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Abstract: In the 3 years to June 30, 2008, 4,633 injuries occurring underground at NSW (Australia) coal mines were reported to the insurer. Equipment was involved in 2149 of these injuries (46%). The narrative field accompanying these reports was examined to determine opportunities for controlling injury risks. The most common equipment types involved were: Continuous miner (12% of all underground injuries); Bolting machines (6%); LHD (8%); Longwall (7%); Personnel Transport (4%); and Shuttle Car (3%). The most common combinations of equipment and mechanism were: strains while handling items associated with continuous miner or bolting machines; strains, or being struck by, or caught between, while drilling or bolting on a continuous miner or bolting machine; driving or traveling over rough roads in a variety of equipment; being struck by while operating Longwall equipment. Rare, but high potential consequence events reported during the period included: interactions between personnel and mobile equipment; interactions between personnel and Longwall shield movements; transport equipment collisions. A range of potential short-term control measures for these risks have been identified, including monorails for continuous miner services; redesign of continuous miner platforms and bolting rigs to reduce reach distances during drilling and bolting; improvements to guarding of bolting controls; standardisation and shape coding of bolting controls; two handed fast-speed drilling & bolting; improvements in underground roadway maintenance, vehicle suspension, visibility and seating; and proximity detection devices interlocked with mobile equipment controls. Longer term control measures include automated bolting, and mesh placement, in conjunction with either non-line-of-sight remote control of, or automated, continuous mining machines.

Keywords: Occupational injuries, underground coal mining, mining equipment, narratives text analysis, continuous miner, shuttle car, bolting.

1. INTRODUCTION

Working with or near underground coal mining equipment is inherently hazardous due to the multiple sources of injurious energies and adverse environmental conditions. Australian coal mines are acknowledged as having excellent safety records. This has been ascribed, at least in part, to the risk based regulatory framework under which the mines operate [1]. As indicated in Table **1**, the rate of injuries involving lost time decreased considerably in New South Wales mines over the 8 years to the end of June 2006, and remained relatively constant over the next two years. Australian compensation statistics suggest that 22% of all lost time claims in the mining industry are associated with mobile plant and transport [2]. The aim of this investigation is to examine narratives describing equipment related injuries occurring at NSW underground coal mines as a means of identifying opportunities for further reducing injury risks.

A previous analyses of injuries associated with a subset of underground coal mining equipment types has been reported [3]. This paper extends the analysis to include all equipment types, and utilises data from the three years to the end of June, 2008. During this period in NSW there were between 29 and 30 operating underground coal mines, predominantly Longwall mines operated by large companies. The number of employees during the period increased from 6541 to 7030, with raw production increasing from 52.2 to 60.6 million tonnes per annum (Table **1**).

Conventional analyses of injury statistics typically provide tables detailing the breakdown of injuries by body part, nature of injury, mechanism of injury, or agency of injury. Such analyses are appropriate and may especially be helpful in tracking broad trends over time, however further, and perhaps more valuable, information is available in the narrative text field completed for each injury reported to the workers' compensation insurer for coal mines in NSW (Coal Services Pty Limited). The detail contained in these narratives varies, however additional insight is generally into the causes of the injury, such as the activity being performed at the time of the injury. Analysis of injury narratives has previously been undertaken in mining [3-5]; construction [6-8]; welders [9] and truck drivers [10].

Helander and Krohn [4], for example, conducted an analysis of injury narratives for most hazardous underground machinery in hard rock mining, coding the narratives for worker activity, suggested cause of accident; machine part involved, and body part injured. Similarly, Helander *et al.* [5] examined injury narratives from 600 roof-bolter accident reports from mines in the USA and coded each for cause, machine part, and body part injured; concluding that roof bolting was the most dangerous job in US underground coal mines and that rock falls accounted for 25% of roof bolting injuries.

The information available in injury narratives has potential to aid in prioritising effective control measures. The aim of the analysis was to utilise injury narratives to

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Table 1. NSW Underground Coal Mining Statistics 97/98 to 07/08

Financial Year	97-98	98-99	99-00	00-01	01-02	02-03	03-04	04-05	05-06	06-07	07-08
Number of mines	n/a	n/a	n/a	n/a	n/a	29	27	28	30	29	29
Number of miners	6957	6063	5615	5737	5497	5064	5054	5620	6541	6792	7030
Raw production (million tonnes)	n/a	n/a	n/a	n/a	n/a	46.9	49.3	51.9	52.2	57.2	60.6
Fatalities	1	2	3	2	1	0	2	0	0	1	0
Serious injuries	n/a	n/a	26	34	27	26	43	25	24	27	18
Lost Time Injury Frequency Rate	60.0	43.7	37.9	35.6	37.8	35.5	32.9	27.3	23.9	23.7	23.7

Source: NSW Minerals Council Key Industry Statistics 2008. (www.nswmin.com.au).

identify opportunities for reducing common injury risks associated with underground coal mining equipment. 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 within the results.

2. METHODS

Coal Services Pty Ltd, is the sole workers' compensation insurer for NSW coal mines. De-identified narrative text fields for all incidents reported by underground coal mines in New South Wales during the 3 years to June 30, 2008 were obtained from Coal Services Pty Ltd. These reports included injuries of varying severity, from medical expenses only, to time lost, and serious bodily injury. Narratives describing the injuries occurring underground were manually coded for equipment involvement; activity being undertaken by the injured person immediately prior to the injury; the injury mechanism; and agent of injury, using previously determined codes [3]. Frequencies of cross-tabulated combinations of codes were calculated and presented graphically to aid interpretation. Examples of injury narratives are also provided.

3. RESULTS

The total number of injuries reported by underground coal mines to Coal Services Pty Ltd in the 3 years to June 30, 2008 was 4633 (excludes injuries occurring on the surface at an underground mine, as well as hearing loss 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 graders, stone dusting equipment, dolly cars, road headers, longwall move equipment, and gas drainage drilling equipment.

3.1. Continuous Mining/Bolting Machine

Continuous miner and bolting machines were grouped for subsequent analysis. Table **2** provides a breakdown of the number of injuries by activity and mechanism. These data are illustrated in Fig. (**1**). Consideration of the data presented in Table **2** and Fig. (**1**) reveals that injuries most frequently occurred whilst miners were drilling and bolting, and handling bolting supplies such as drill steels, bolts and mesh. 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 to the operating platform, were also relatively common activities. Examples of each of these injury types are provided in Table **3**. 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" and
>
> "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".

Table 2. Underground Injury Frequency by Activity and Mechanism for Continuous Miner 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**

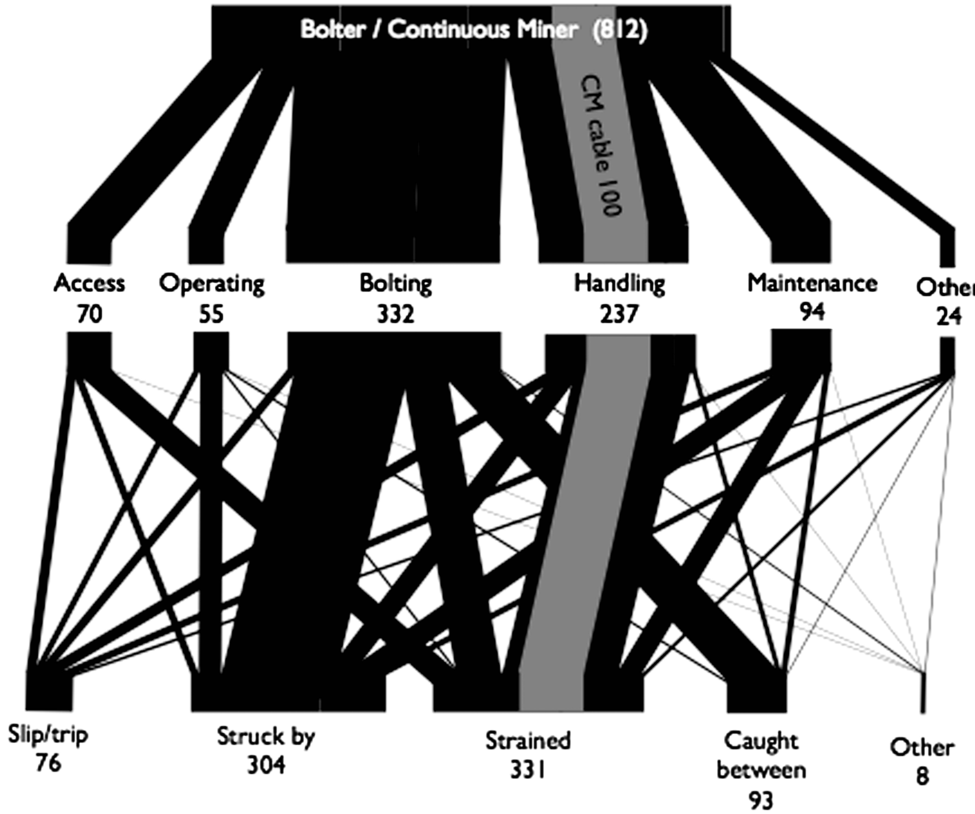

Fig. (1). Underground injury frequency by Activity and Mechanism for Continuous Miner and Bolting Machine for NSW mines during the 3 years to June 30, 2008.

3.2. Load-Haul-Dump

Table **4** provides the frequency of injuries for each combination of activity and mechanism for injuries associated with Load-Haul-Dump (LHD) equipment. Fig. (**2**) presents these same data graphically. Consideration of these 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 in Table **5**. 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", and

> "While reversing Eimco pushing power tram he stood up to see where he was going his head got caught between the machine & gas drainage pipe causing closed head injury".

3.3. Longwall

Injuries associated with Longwall equipment are presented in Table **6** and Fig. (**3**). 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 also including striking the head on the Longwall supports. Slipping or tripping was also relatively frequent. Examples of injury narratives are provided in Table **7**. 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", and

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

3.4. Transport

Injuries associated with personnel transport are presented in Table **8** and Fig. (**4**). Consideration of these data reveals

Table 3. 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 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

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 in Table **9**. Infrequent, but potentially high consequence events associated with transport included:

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

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

3.5. Shuttle Car

Injuries associated with the operation of shuttle cars are described in Table **10** and Fig. (**5**). Consideration of the data presented in Table **10** and Fig. (**5**) reveals that injuries associated with shuttle cars most frequently occurred to drivers as a consequence of traveling over rough roads or being struck by. Injuries also occurred during maintenance. Examples of injury narratives are provided in Table **11**. Infrequent, but potentially high consequence events associated with shuttle cars included:

> "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"

Table 4. Underground Injury Frequency by Activity and Mechanism Associated with Load-Haul-Dump 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**

Table 5. 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

"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".

4. DISCUSSION

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) or while drilling or bolting on continuous miner or bolting machine (70 injuries); injuries involving being struck by, or caught between, while drilling or bolting on continuous miner or bolting machine (175 injuries and 69 injuries); injuries occurring while driving or traveling over rough roads in a variety of equipment such as LHD, shuttle car and transport (164 injuries); and injuries arising as a consequence of being struck by falling rock or other material while operating Longwall equipment (98 injuries). While the majority of the injuries documented in these narratives are relatively minor, the potential for serious injuries and fatalities is ever present, particularly when large mining equipment is operating in close proximity to people.

Continuous mining and bolting machines are powered by long and very heavy trailing electrical cables. One common cause of strains associated with these equipment is the manual handling of cables. 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

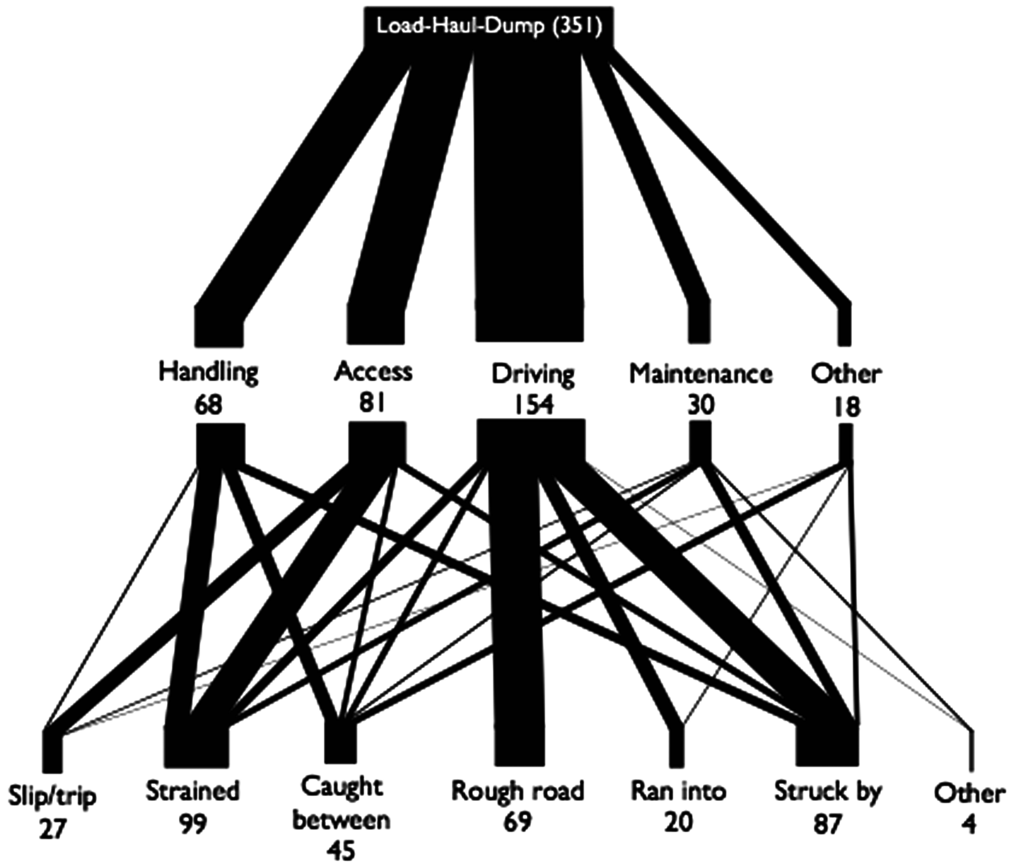

Fig. (2). Underground injury frequency by Activity and Mechanism associated with LHD for NSW mines during the 3 years to June 30, 2008.

Table 6. 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**

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 [11]. Engineering controls are required to eliminate or reduce manual cable handling. One control which has been developed to reduce the requirement to manually handle continuous miner cables is the installation of a monorail to which services, including electrical cables are fastened. Additional sections of monorail are added as the continuous miner advances. This control measure has great potential to reduce injury risks, and is beginning to be adopted in Australian mines.

Handling of drilling and bolting supplies, and roof support mesh, is a second common cause of strain injuries, although loading supplies (bolts, resin, plates) onto pods on the surface and loading these *via* mobile plant has become more common. Manual handling of the supplies and drill steels, is still undertaken during the drilling and bolting process itself however, and the prolonged and repeated performance of a task which commonly involves awkward shoulder postures to place drill steels and bolting in a chuck located at some distance from the miner's body is, unsurprisingly, associated with musculoskeletal injuries to the back, shoulder, and wrist. More recent designs of bolting workstations have been successful in reducing the reach distances required (and thus the shoulder loads), however, the risk will remain as long as drilling and bolting is

Table 7. 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

undertaken manually. Considerable efforts are underway to achieve automated bolting [12] and marked injury reductions in musculoskeletal injuries are anticipated when this is achieved and implemented widely. The handling of mesh will simultaneously be replaced by an automated manipulator, or replaced with a spray on polymer [13].

Another serious injury risk which arises as a consequence of the current manual drilling and bolting procedures is the risk associated with being struck by or caught between the moving equipment components. Some injuries occur as a consequence of inadvertent operation of drilling/bolting controls while the operator or another person is in a hazardous position. This can occur, for example, by rock or rib, or drill steel, falling onto an unguarded control; another common cause of inadvertent control operation is a miners' self-rescuer, or cap lamp cord bumping or catching on a control lever. Additional guarding is being employed by designers to reduce this risk.

Other bolting related injuries are attributable to an operator making either a control selection error (where the incorrect control is operated); or a direction error (where the correct control is operated, but in the incorrect direction). 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 as a means of addressing perceived inadequacies [14-18]. (Hedling & Folley, 1972; Grayson *et al.*, 1992; Helander *et al.*, 1980; Klishis *et al.*, 1993; Muldoon *et al.*, 1980).

In 1972, Hedling and Folley [14] 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" and proposed that "Each control knob is designed to resemble (at least symbolically) the equipment it represents". Similarly, Helander *et al.* [16] suggested in the context of bolting machines that "poor human factors principles in the design and placement of controls and inappropriately designed workstations contribute to a large percentage of the reported injuries" (p. 18). In particular, a lack of standardisation of controls was noted, with more than 25 different control sequences being identified, differences existing even on similar machines produced by the same manufacturer. Helander *et al.* also noted the lack of control coding, violation of direction stereotypes, a mixture mirror image and left/right arrangements, and the possibility of inadvertent operation. Klishis *et al.* [17] made similar observations 10 years later, noting a lack of standardisation even among machines from the same manufacturer and commenting on the potential for operating the wrong control. Evidence for the potential effectiveness of shape coding in reducing selection errors some circumstances has recently been provided [19].

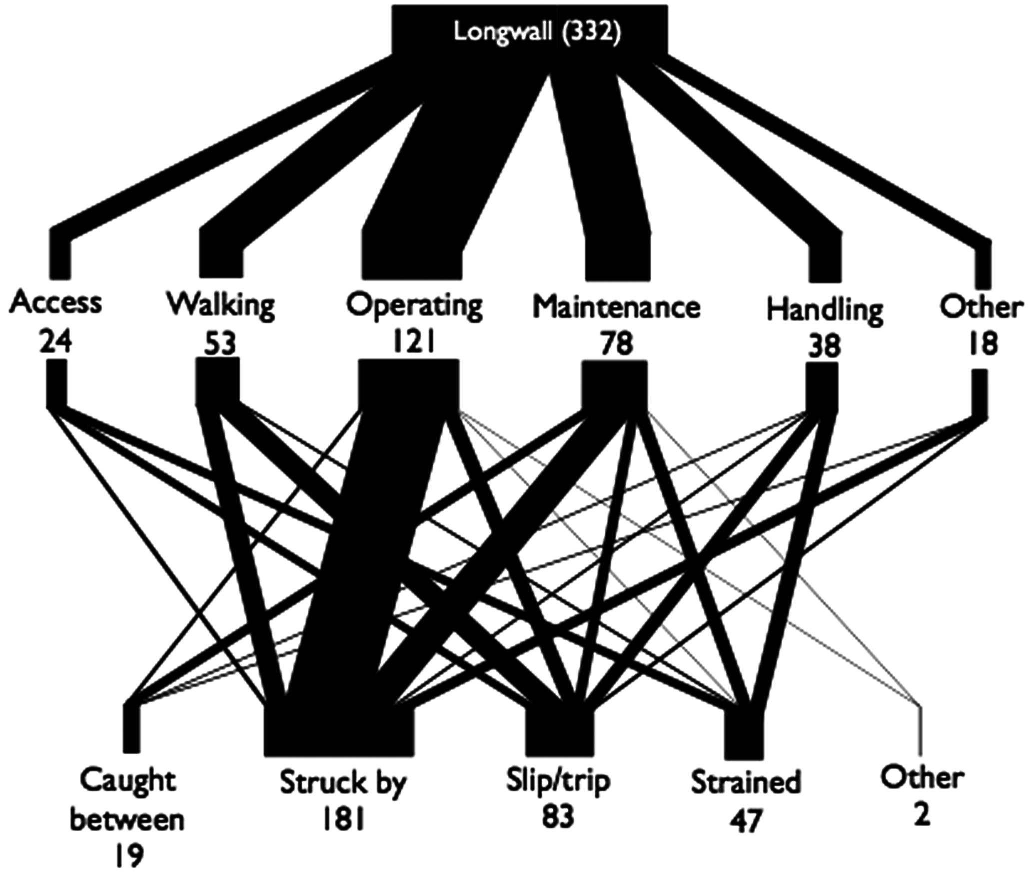

Fig. (3). Underground injury frequency by Activity and Mechanism associated with Longwall equipment for NSW mines during the 3 years to June 30, 2008.

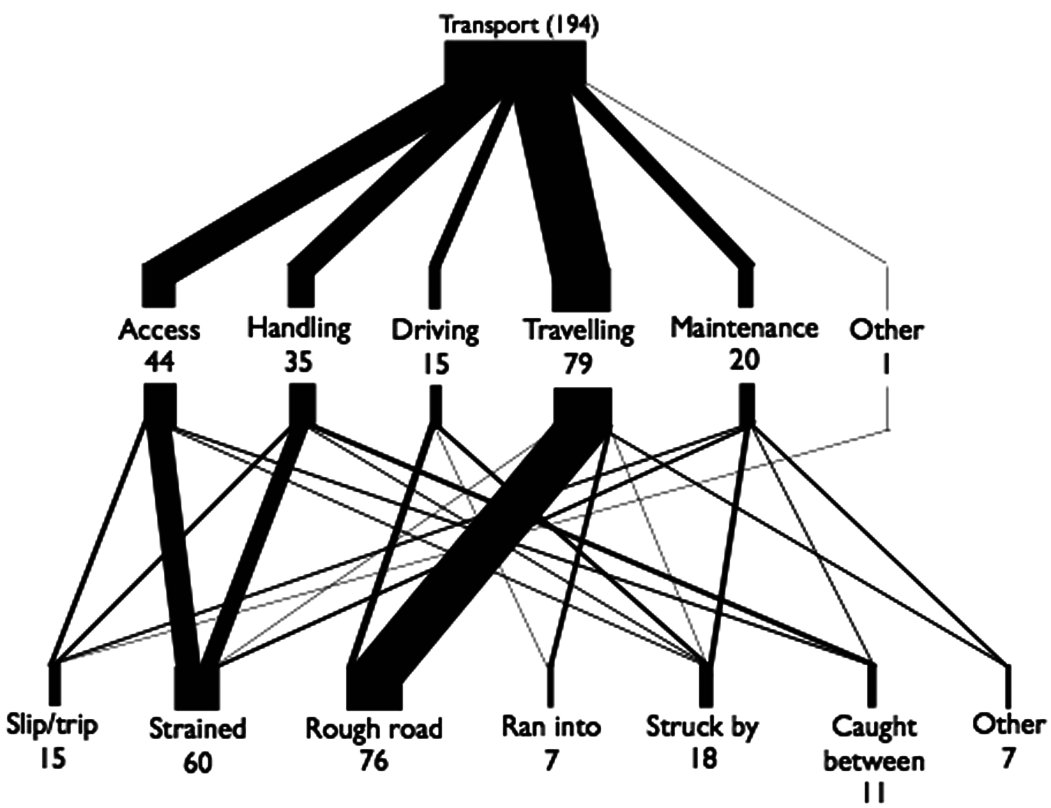

Fig. (4). Underground injury frequency by Activity and Mechanism associated with Personnel transport for NSW mines during the 3 years to June 30, 2008.

Table 8. 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**
Travelling	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**

Table 9. Example Injury Narratives for the Most Frequent Combinations of Activity and Mechanism Associated with Personnel Transport

Activity and Mechanism	Example Narratives
Travelling: Rough road	While travelling 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 travelling 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 travelling to pit bottom along 642 travelling 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

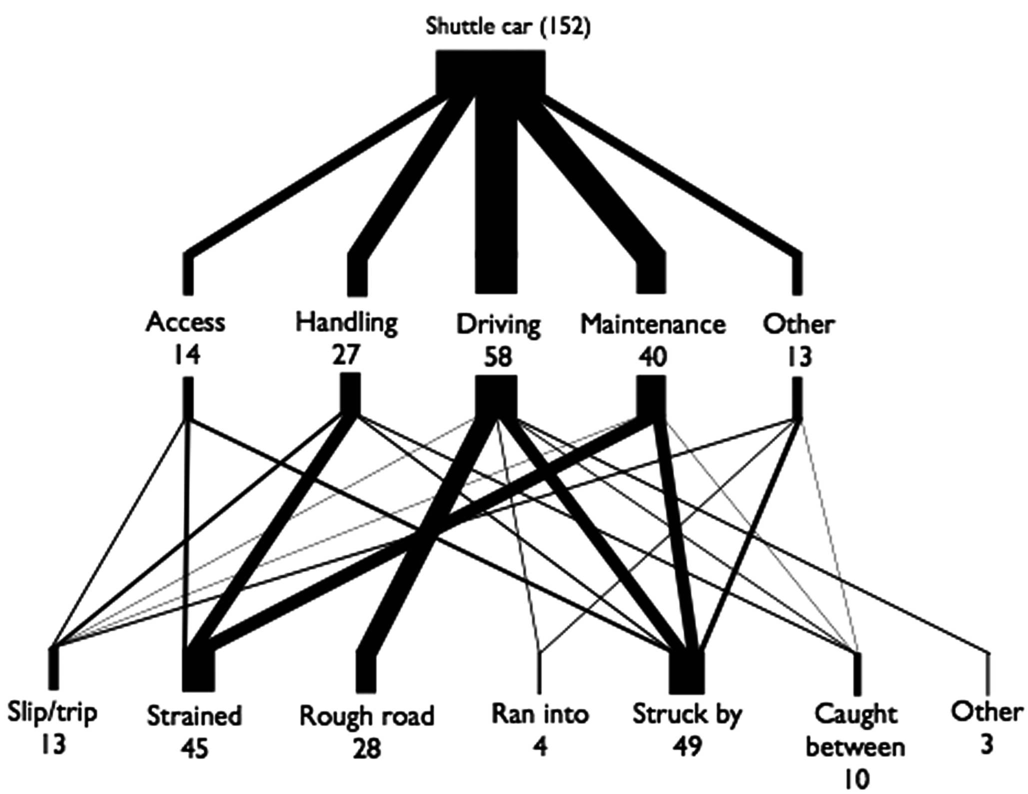

Fig. (5). Underground injury frequency by Activity and Mechanism associated with Shuttle cars for NSW mines during the 3 years to June 30, 2008.

Table 10. 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**

Table 11. 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 travelling 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

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 MSHA to investigate, and a report released [20] which determined the causes to be unintentional operation of controls. The solutions proposed in this report were: 1. Two-handed fast feed; 2. drill head raise shutoff; 3. auxiliary controls; 4. guarding; 5. pinch point identification; 6. self-centering controls; 7. hands-off drilling; 8. insertion/retrieval devices; 9. standardised control layouts; 10. pre-operational inspection. Other suggestions included in this report included: "Provide industry-wide accepted distinct and consistent knob shapes and relative handle lengths to identify corresponding control function" and "Standardize machine control lever movement and corresponding machine function movement." MSHA subsequently called for industry comment on an advance notice of proposed rulemaking titled "Safety standards for the use of roof-bolting machines in underground mines" [21] however no related rule or design criteria were subsequently released.

While bolting machines were not associated with any fatalities in NSW during the time period under examination, an incident did occur in which a drill bit was rotated whilst caught on mesh and a mine workers arm became entangled in the mesh, and subsequently amputated [22]. It is likely that the injured miner intended to adjust the position of the drill steel, but selected the adjacent rotation control (a selection error).

It is clear from the injuries reported by NSW mines in the three years to June 2008 that the design shortcomings previously identified in the context of bolting machines also remain to some extent in the design of controls on the bolting machines, and integrated miner bolters which are predominantly employed in Australian mines. Bolting controls require guarding to prevent inadvertent operation (while still allowing access for intentional operation). Bolting machine controls should be standardised across manufacturers to an appropriate layout (and provide shape and length coding) to reduce the probability of operation of the wrong control. This standardisation must carefully consider direction compatibility principles to reduce the probability of operation of controls in the wrong direction [23]. Improvements to bolting machine design are required to guard pinch points and provide interlocks (eg., two-handed fast feed) to reduce the probability and consequences of intentional or unintentional control operation whilst the operator or other person is in a hazardous location.

These conclusions are consistent with a safety alert issued in 2005 by the NSW Department of Primary Industries [24] which noted serious injuries occurring as a consequence of unintentional and intentional bolting control activation and recommended that roof and rib bolting systems should comply "as far as practical" with AS4024.1 "Safeguarding of machinery – General principles". The safety alert included the following as potential control measures: two handed control for fast speed operation; minimisation of pinch points; guarding to reduce inadvertent operation; shape coding; and standardised control layouts.

These measures, including specified shapes for primary bolting controls, are also included in a revision of a Mining Design Guide addressing the design of bolting equipment [25]. Manufacturers of bolting equipment have responded to the revised Mining Design Guide for bolting equipment and these features are being incorporated in new equipment. While these design improvements may be expected to have some benefits, the implementation of automated bolting will be the most effective way of reducing these injury risks.

Drivers and passengers in vehicles in NSW underground coal mines suffered 173 injuries in the three years to June 2008 as a consequence of the vehicle encountering potholes or other roadway abnormalities. These injuries highlight the importance of maintaining roadway standards, because control at this level is most likely to be effective. Provision of vehicle suspension for shuttle cars, and improved seating in all vehicles [26-28], has potential to reduce the likelihood of these acute injuries. These improvements will also reduce exposure to whole body vibration, which is strongly associated with the development of back pain [29].

A further cause for concern is the number of potentially high consequence events involving being struck by hydraulic fluid. Extremely serious injuries, or even fatalities, can arise from being struck by hydraulic fluid under high pressure. The equipment involved included longwall; continuous miner & bolting machine; and LHD. Improvements in equipment design to reduce the risks of hydraulic fluid injection was the aim of Mining Design Guide 41 which was revised in 2006 [30]. While manufacturers are adopting the requirements of this standard, other potential design improvements being implemented are the replacement of hydraulic hosing with piping where ever possible, and removing miners from proximity to hydraulic hoses.

Rare, but high potential consequence events reported during the period included interactions between personnel and mobile equipment such as continuous miners, LHD, and shuttle car; and transport equipment collisions. Many items of underground mobile equipment provide limited visibility for the operator, and improvements to equipment design to reduce these limitations have been proposed [31]. The use of video cameras has also been proposed [32], and are being implemented, particularly in large vehicles such as chock carriers.

Proximity detection systems have also been highlighted as a potential control measure to reduce the risk of interactions between pedestrians and mobile equipment, and between mobile equipment [33]. A continuous miner operator was crushed against the rib by a shuttle car at a Queensland mine in 2007, and died as a consequence. The coronial inquest [34] canvassed a number of issues related to the design of the equipment which may have contributed to the incident, and the recommendations made by the coroner included the future use of proximity detection.

The explosion risks associated with underground coal mines create additional barriers to the adoption of such technologies, and at the time of writing, there is no system currently certified for use in underground coal mines in Australia. While, proximity detection, especially if interlocked with vehicle controls, has potential to reduce pedestrian - mobile equipment interaction injury risks, greater reductions will be achieved by removing people from the vicinity of the equipment, and particularly the area around the continuous mining machine. These machine are currently remotely controlled, however the operator holding the remote does so *via* direct line-of-sight, standing adjacent to the equipment. Non-line-of sight remote control of the continuous miner is achievable in the short term (and has been undertaken as a control measure for when mining in outburst conditions) especially if combined with automated bolting. Fully automating the continuous miner is the next step. Efforts to achieve this have been underway for considerable time [35-37] and remains the aim of substantial current research [38].

CONCLUSION

Analysis of narratives describing equipment related injuries occurring in underground coal mines was an effective way of identifying high frequency combinations of equipment, activity and injury mechanism. Rare, but potentially high consequence events were also identified. The analysis provided valuable information for identifying opportunities for reducing injury risks associated with underground coal mining equipment. Potential short term controls include: monorails for continuous miner services; redesign of continuous miner platforms and bolting rigs to reduce reach distances during drilling and bolting; improvements to guarding of bolting controls; standardisation and shape coding of bolting controls; two handed fast-feed; improvements in underground roadway maintenance, vehicle suspension, visibility and seating; and proximity detection devices interlocked with mobile equipment controls. Longer term control measures include automated bolting, and mesh placement, in conjunction with either non-line-of-sight remote control of, or automated, continuous mining machines.

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CONFLICT OF INTEREST

None declared.

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