ACARP PROJECT C28034
PUBLISHED 01/02/2021

MINING EQUIPMENT HUMAN FACTORS DESIGN FOR WORKFORCE DIVERSITY

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CREATE CHANGE

ACARP project C28034: Mining equipment human factors design for workforce diversity

Final report

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Executive summary

The objectives of the project were: (i) to identify and describe design issues with current mining equipment that are a barrier to workforce diversity; (ii) to document and evaluate remedial control measures currently undertaken at sites; and (iii) to communicate the results of the investigation to equipment designers and mine sites.

Visits were undertaken to seven surface coal mines in Queensland and NSW to conduct focus group workshops and task observations. Additional information was obtained from previously documented assessments of manual tasks associated with earth-moving equipment maintenance, including attempts to reduce manual tasks risks undertaken by a range of mine sites.

The information gained during the project was used to populate an EMERST control framework for equipment design for diversity. Two required operating states were defined:

(1) Earth-moving equipment can be safely and comfortable operated by people of a maximum range of anthropometric diversity

(2) Earth-moving equipment can be safely and comfortable maintained by people of a maximum range of anthropometric diversity

A range of credible failure modes were identified including:

1.1 Small operators have difficulty reaching isolation points, fire suppression and emergency stop.

1.2 Small operators find access systems initial step height uncomfortable

1.3 Height and weight of refuelling hose and attachments makes refuelling difficult

1.4 Location of displays requires excessive neck extension and/or shoulder extension

1.5 Controls difficult or uncomfortable to operate for smaller operators

1.6 Equipment operation requires extended periods of neck rotation

1.7 Seat suspension cannot be adjusted sufficiently to suit the mass of small operators

1.8 Seat height cannot be adjusted to suit leg length of small operators

1.9 Routine maintenance or inspection tasks performed by operators require excessive reach

1.10 Seat belt height cannot be adjusted to be comfortable for small operators

1.11 Mirrors do not provide the field of view required by small operators

1.12 Truck handrail impedes vision for smaller truck drivers

2.1 Maintenance tasks require manual manipulation of heavy masses, or exertion of high forces

2.2 Maintenance tasks require awkward postures

Presentations regarding the preliminary findings of the project were presented to the EMESRT advisory committee, the ACARP Research Committee, and to the Standards Australia mirror committee responsible for earth-moving equipment (ME-063). The preliminary findings were subsequently circulated within a major manufacturer of earth-moving equipment.

Recommendations:

That EMESRT promotes earth-moving equipment design improvements to reduce barriers to workplace diversity through communication of these results to Original Equipment Manufacturers, and standards committees (ME-063 and ISO TC127 / SC 2).

That mine operators put participatory ergonomics programs in place that: assess hazardous manual tasks associated with equipment operation and maintenance; and implement a combination of design and administrative controls to reduce risks as far as reasonably practical.

Introduction

The minerals industry is a complex system in which procedures, equipment and people need to interact safely and efficiently in order to achieve operational requirements. A number of challenges arise including a diversity of company cultures which is reflected in different procedures, rules and practices at mines; a variety of national laws, regulations and guidelines; many different equipment manufacturers and suppliers; differences in the mining environment, and significantly, diversity (including anthropometric diversity) of the workforce employed across mine sites.

The design of mining equipment may unnecessarily restrict the range of potential employees who can operate and maintain the equipment, and in turn create elevated risks of injury for those who currently undertake tasks associated with operating and maintaining the equipment. A variety of standards and guidance materials currently exist to assist equipment designers accommodate workplace diversity. This material may include, for example, guidance on visibility; noise measurements; whole body vibration assessments; ergonomics and human factors; controls and displays; manual tasks risk analyses; and audits against relevant standards and Mining Design Guidelines (MDGs). However designers of equipment for mining operations face significant challenges in applying this information.

It is important to understand how the design of mining equipment restricts the range of potential employees who can safely and comfortably operate and maintain the equipment to provide additional assistance to equipment designers. The objectives of the project were: (i) to identify and describe design issues with current mining equipment that are a barrier to workforce diversity; (ii) to document and evaluate remedial control measures currently undertaken at sites; and (iii) to communicate the results of the investigation to equipment designers and mine sites.

The first stage of this project was a review and evaluation of available anthropometric design requirements for mobil plant and equipment as documented in relevant ISO standards and Mining Design Guidelines (MDGs) to provide a context for the subsequent investigations. The second stage of the project was to facilitate small focus groups of operators and/ maintainers/individual one on one discussions with a representational cross section of the current site workforce at the participating sites.These sessions aimed to identify equipment, tasks and situations in which the range of potential operator or maintainer characteristics were not accommodated, including situations which had been resolved by design changes made onsite. Situations which were currently managed through administrative controls, as well as any situations for which no solution had been identified were also documented.

Information was gathered during focus groups, individual operator and maintainer discussions, and task observations at seven Queensland and NSW surface coal mines to gain an improved understanding of the limitations of current equipment designs with respect to accommodating diversity in operator and maintainer physical characteristics (static anthropometric variability); and with equipment operation and maintenance tasks which require combinations of high exertion, awkward or static postures, repeated similar movements and long duration which do not accommodate potential variability in operator and maintainer strength, flexibility and reach distances (dynamic anthropometry). Additional information was sourced from previously documented assessments of manual tasks associated with earth-moving equipment maintenance, including attempts to reduce manual tasks risks undertaken by a range of mine sites.

The information obtained was used to construct an EMESRT Control Framework for equipment design for diversity, and these findings are in the process of being communicated to industry. Presentations regarding the preliminary findings of the preliminary findings of the project were made to the EMESRT advisory committee, the ACARP Research Committee, and to the Standards Australia mirror committee responsible for earth-moving equipment (ME-063). The preliminary findings have been circulated within a major manufacturer of earth-moving equipment.

Existing design guidelines

A number of standards and guidance materials currently exist to assist equipment designers. The ISO standards process is formal and change often lags behind technology development. In some cases this may result in weak or ineffective standards that need to be written in general terms to accommodate future technology developments. In this way the general nature of some standards may only establish minimum requirements and not be overly helpful to equipment designers, in particular when designing for diversity and inclusivity within the workforce. Mining Design Guidelines (MDG) produced by the New South Wales regulator are able to respond more quickly to changes in technology. Standards do however have a safety and productivity focus, and provide design consistency between equipment manufacturers. Standards provide a basis for auditing purposes, and assist in mining regulation, compliance, and the development and application of safety management systems.

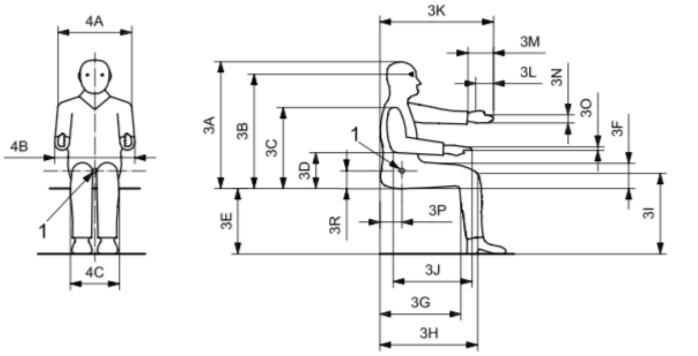
ISO12100 (2010) “Safety of machinery- General principles for design - Risk assessment and risk reduction, provides a general framework approach to equipment design, including basic terminology, principles and a method for achieving safety in the design of machinery. More specifically, IS0 9241-210 (2010) proposes a human-centred design approach to design that has substantial economic and social benefits for users, employers and suppliers. It provides a set of principles based on explicit understanding of of users, tasks and environments; users are involved throughout design and development; the design is driven and refined by user-centered evaluation; the process is iterative; the design addresses the whole user experience; and the design team includes multidisciplinary skills and perspectives (Horberry et al 2018).

ISO3411 “Earth-moving machinery-Physical dimensions of operators and minimum operator space envelop” provides data approximating the 5th, 50th and 95th percentile of the “earth-moving machinery operator population”, for numerous static dimensions relevant to the design of earth-moving equipment (eg., Figure 1) and these data are utilised in ISO6682 to provide recommendations regarding the location of controls (eg., Figure 2).

There are considerable limitations to the use of such data. The standards notes, for example, that: “In some areas of the world, more the 5% of the operators have leg lengths less than the value given for the smallest operators”, and suggests that “special adjustments may be provided”, without specifying the nature to these adjustments. This note highlights an example of one area in which current equipment designs limit the diversity of the potential workforce by providing insufficient seat adjustment to accommodate short leg lengths. It is noteworthy that the limitation will disproportionately effect potential female employees.

Attempting to utilise the data provided in ISO3411 (or other sources of static anthropometric data) creates further problems for equipment designers, in that the reference percentiles is problematic for design purposes. There is no “5th percentile operator” or “95th percentile operator”. Individuals vary along each dimension (Robinette and Hudson, 2006) and although dimensions have some degrees of correlation, when multiple dimensions are considered, the range of individuals which fall within a given range on all dimensions reduces substantially. For example, only about 82% of individuals in a population will fall within the 5th to 95th percentile ranges for both height and weight. The more dimensions are considered, the smaller the range of people who actually “fit” the description. Looking at this issue in another way, Figure 3 provides a representation taken from whole body scans of two people with the same sitting height; and also illustrates a hypothetical person generated case using all 95th percentile male dimensions.

ISO 3411:2007(E)



Reference	Designation	Dimension mm		
		Small operator	Medium operator	Large operator
3A	Sitting height [a]	800	894	976
3B	Eye height, sitting	690	780	858
3C	Shoulder height, sitting	530	585	651
3D	Elbow height, sitting	200	239	285
3E	Horizontal sitting surface height [c]	400	449	495
3F	Thigh clearance [c]	120	146	170
3G	Buttock to calf distance [c]	420	474	525
3H	Buttock-knee length	530	601	670
3I	Knee height, sitting (with shoes)	500	558	627
3J	Forearm-fingertip length [c]	410	464	515
3K	Anterior arm reach [c]	750	832	909
3L	Decrement for control grasp [c]	–65	–73	–80
3M	Hand length	170	190	207
3N	Hand breadth [b, c]	80	87	96
3O	Hand thickness [c, d]	25	30	35
3P	SIP (seat index point) length	113	125	137
3R	SIP (seat index point) height	80	88	97
4A	Shoulder (bi-deltoid) breadth	380	450	514
4B	Elbow-to-elbow breadth [c]	385	454	521
4C	Hip breadth, sitting	320	378	456

1 seat index point (SIP)

NOTE These columns represent the measured size range of the world population. Small is approximately the 5th percentile measurement, medium is approximately the 50th percentile measurement, and large is approximately the 95th percentile measurement. Small operator = 51,9 kg, medium operator = 74,4 kg, large operator = 114,1 kg

Figure 1: Example of static anthropometric data currently available with ISO3411 "Earth-moving machinery - Physical dimensions of operators and minimum operator space envelope".

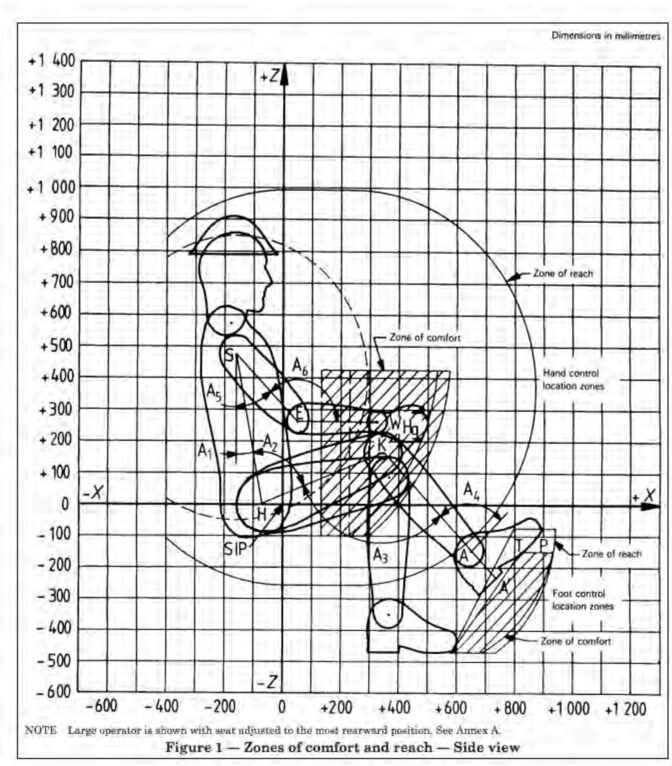


Figure 2: ISO6682: Earth-moving machinery - Zones of comfort and reach for controls.

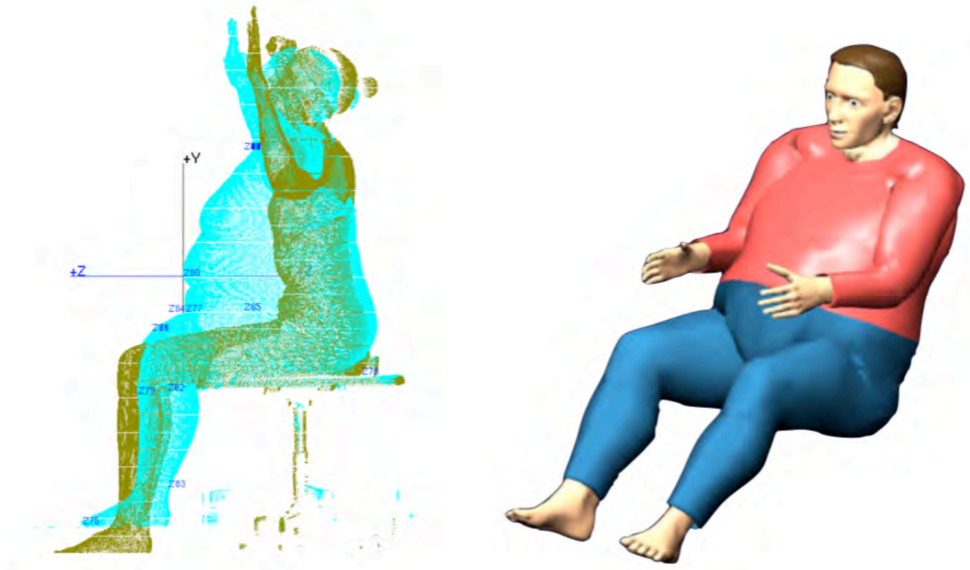


Figure 3: (left) Two individuals with the same sitting height, and (right) a hypothetical 95% male.

BS 6912-19:1996, ISO 11112:1995 (part 19) provides specifications for dimensions and requirements for operator’s seat. This International Standard specifies the dimensions, requirements and adjustment ranges for operator seats on earth-moving machinery as defined in ISO 6165. Additionally, it provides dimensions for armrests when fitted on these machines. Again, whilst nominal values of dimensions regarding seat features, their mutual locations and adjustments are established on the basis of ergonomic requirements taking into consideration operator sizes it is referenced according to ISO 3411, and considers from the 5th percentile through the 95th percentile. The dimensions for the operator’s seat and related adjustments are provided, and include essential dimensions and optional requirements. Seat dimensions and adjustments, if provided, are referenced to the seat index point (SIP) determined in accordance with ISO 5353. Confusion arises as the standard advises “dimensions and adjustments other than those specified in this International Standard may be used only if they provide better accommodation for the operator”.

Seat design, condition and adjustment is known to influence operator whole-body vibration exposure levels (Lewis and Johnson 2012; Paddan and Griffin, 2002), and therefore seat installation needs to suit both the vehicle and its operating environment. Performance differences across seats may have been shown to have significant health implications for drivers and equipment operators (Blood et al, 2010). Seating remains a design problem, in particular where seats fitted to equipment may not accommodate a sufficient range of operator masses and fore-aft adjustability is limited. This highlights another example of an area in which current equipment designs limit the diversity of the potential workforce by providing insufficient seat adjustment to accommodate in particular smaller operators. It is noteworthy that these limitations disproportionately effect potential female employees, typically smaller in stature. For example Figure 4 illustrates a seat that is claimed to be a “standard fitment” for some vehicles. The operator mass range stipulated (80-150 kg) clearly provides a restriction on the diversity of operators who could be employed.

Figure 4: A “standard fitment” seat that restricts operator diversity.

The potential implication of providing a seat that is not matched to an operators mass is illustrated in Figure 5. The data presented in the figure were collected during ACARP project C26026 from a haul-truck being driven at a central Queensland surface coal mine. The top panel illustrates typical recording obtained from accelerometers placed in the seat of the truck, and on the floor under the seat. The acceleration data collected at the operator-seat interface is frequency weighted according to ISO2631.1 to provide an assessment of the whole-body vibration exposure of the driver relative to the Health Guidance Caution Zone provide by the standard. Comparing the magnitude of the accelerations collected on the floor under the seat with these data provides an assessment of the effectiveness of the seat in attenuating biologically relevant accelerations. The 2 hour 13 minute measurement highlighted in the top panel yields a ratio of seat to floor acceleration amplitude of 0.63 when the data are expressed as RMS, and 0.67 expressed as VDV, which indicates that the seat is effectively attenuating the relevant vibration frequencies and as a consequence the vertical whole-body vibration exposure assessment of 0.45 $m.s^2$ RMS lies below the ISO2631.1 Health Guidance Caution Zone for an 8 hour daily exposure, and just within the Health Guidance Caution Zone when expressed as VDV.

However, the lower panel of Figure 5 illustrates a 2 hour 26 minutes measurement taken from the same truck driving the same circuit earlier on the same day indicates that during this period the seat has provided less effective attenuation and, indeed, when the acceleration are expressed as VDV (a measure more sensitive to high amplitude shocks) the seat appears to be amplifying the floor accelerations. The difference between the two measurement periods is the driver. It is likely that the driver in the earlier shift was relatively light and either did not, or could not, adjust the suspension of the seat to match their mass. The resulting whole-body vibration levels are likely to be associated with detrimental health effects across multiple body systems if exposure is prolonged.

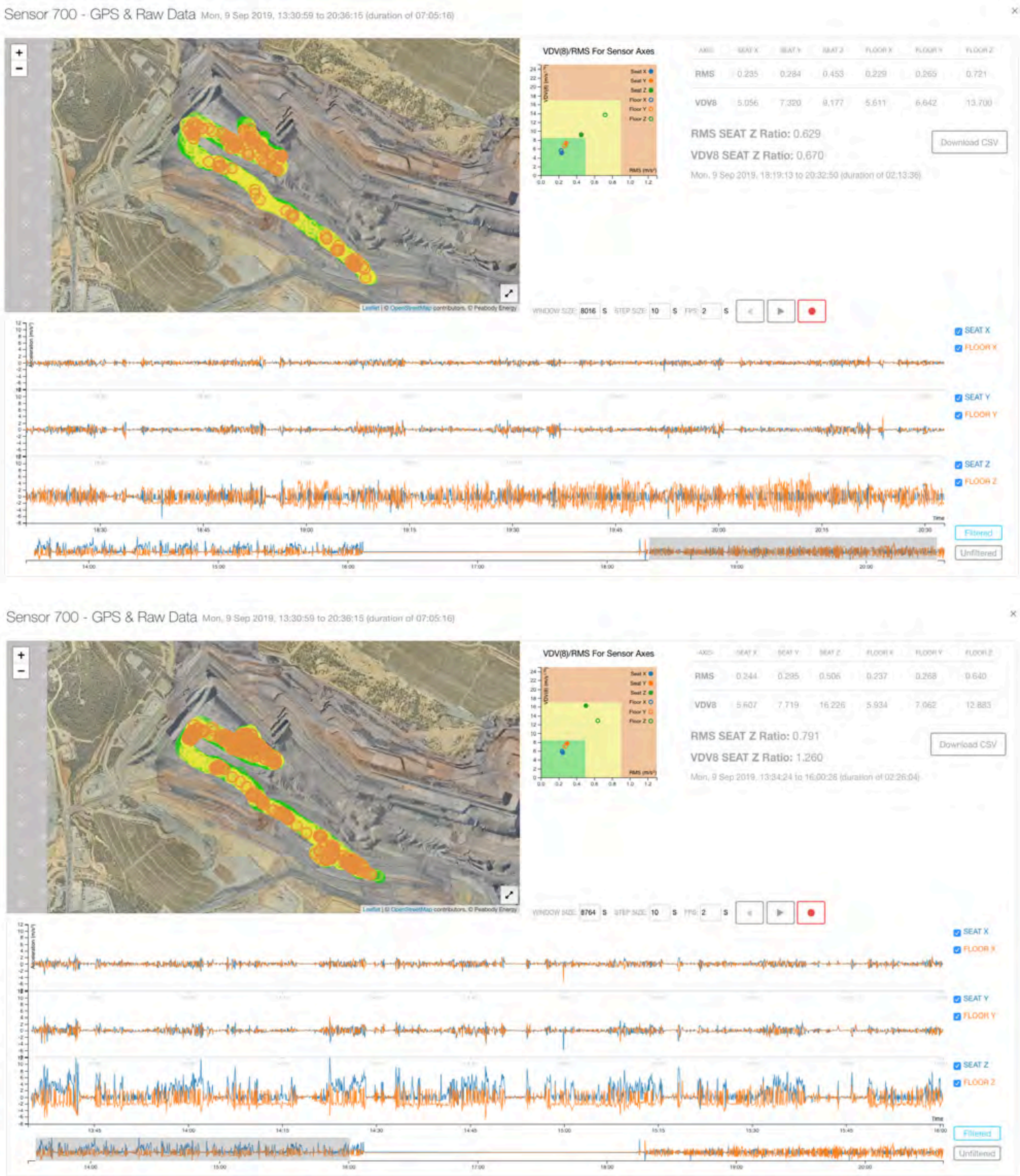


Figure 5: Seat and floor accelerometer measurements taken from a haul-truck during normal operations at a surface coal mine illustrating the potential consequences of seat suspension not accommodating a light operator's mass.

ISO 5006: Earth moving machinery-operators field of view provides a test method and performance criteria to address the operator's visibility in such a manner that the operator can see around the machine to enable proper, effective and safe operation that can be quantified in objective engineering terms. The test method uses two lights placed at the location of the operator's eyes. The test method used does not include all aspects of the operator's visibility, but provides information to assist in determining the acceptability of visibility from the machine. Criteria are included in this document to provide guidance for designers as to the extent of visibility maskings that are acceptable. Allowing for operator capability and the operation mode of the machine, the test method divides the area around the machine into six sectors: the front (sector A), to the front sides (sectors B and C), to the rear sides (sectors D and E), and to the rear (sector F). For each of the sectors, the operator's physical characteristics are considered.

Mine Design Guideline MDG15 (2002) Mobile and transportable plant for use at mines and petroleum sites was developed by the NSW regulator with the aim of improving an unacceptable rate of injury to people operating and maintaining mobile plant, fires on mobile plant and unplanned movement of mobile plant. Whilst not a mandatory compliance document, it includes advice from a number of A/NZ and ISO Standards to inform safe mining equipment design features such as provision of safe access and egress via ladders and stairs, walkways and handrails; location of controls within the zones of comfort and reach of intended users. It does not provide specific design information regarding diversity within the population of equipment operators and maintainers. It does however, in a very general statement, indicate a person competent in ergonomics should provide an assessment of the equipment, which should take in to consideration the intended use of the equipment and the operating environment, and consider "all relevant ergonomic matters relating to human factors".

Additionally, whilst not specific to the design of mining equipment, ANSI Z590.3 (2011) Prevention through Design Guidelines for Addressing Occupational Hazards and Risks in Design and Redesign Process, provides guidance on the avoidance, elimination, reduction or control of occupational safety and health hazards and risks in design and redesign process.

Overall, these standards and guidelines have limited utility for designers in that they can only consider a limited range of typical tasks, such as those undertaken while sitting in a driver's seat, rather than the complete range of tasks associated with the operation and maintenance of equipment. Taking all tasks into account requires a task-based assessment to be undertaken during the design process, such as that provided by the Earth Moving Equipment Safety Round Table (EMESRT) Design Evaluation for Equipment Procurement (EDEEP) process (Burgess-Limerick, et al., 2012). As well as differing in static dimensions, potential employees differ in terms of dynamic capabilities such as strength, flexibility and reach distances. The most common manifestation of the failure to accommodate such diversity is the design of equipment such that hazardous tasks are required to operate and maintain the equipment.

Maintenance tasks in particular are a frequent source of exposure to musculoskeletal injury risks, and in general, design inadequacies associated with these tasks typically relate to poor access, inadequate provision of lifting points, inappropriate tooling, and the need for excessive manual forces. For example, the task described in Figure 6 involving the manipulation of a heavy hydraulic pump was identified as a high risk task maintenance requiring excessive exertion which would restrict the range of people able to undertake the task. The lower section of the document demonstrates manual task assessment of the task following development of a control design developed by the site to remove this requirement. Task documentation of such issues, highlighting the remedial actions taken by sites and communicating these to the manufacturer will accelerate the improvement of future designs.

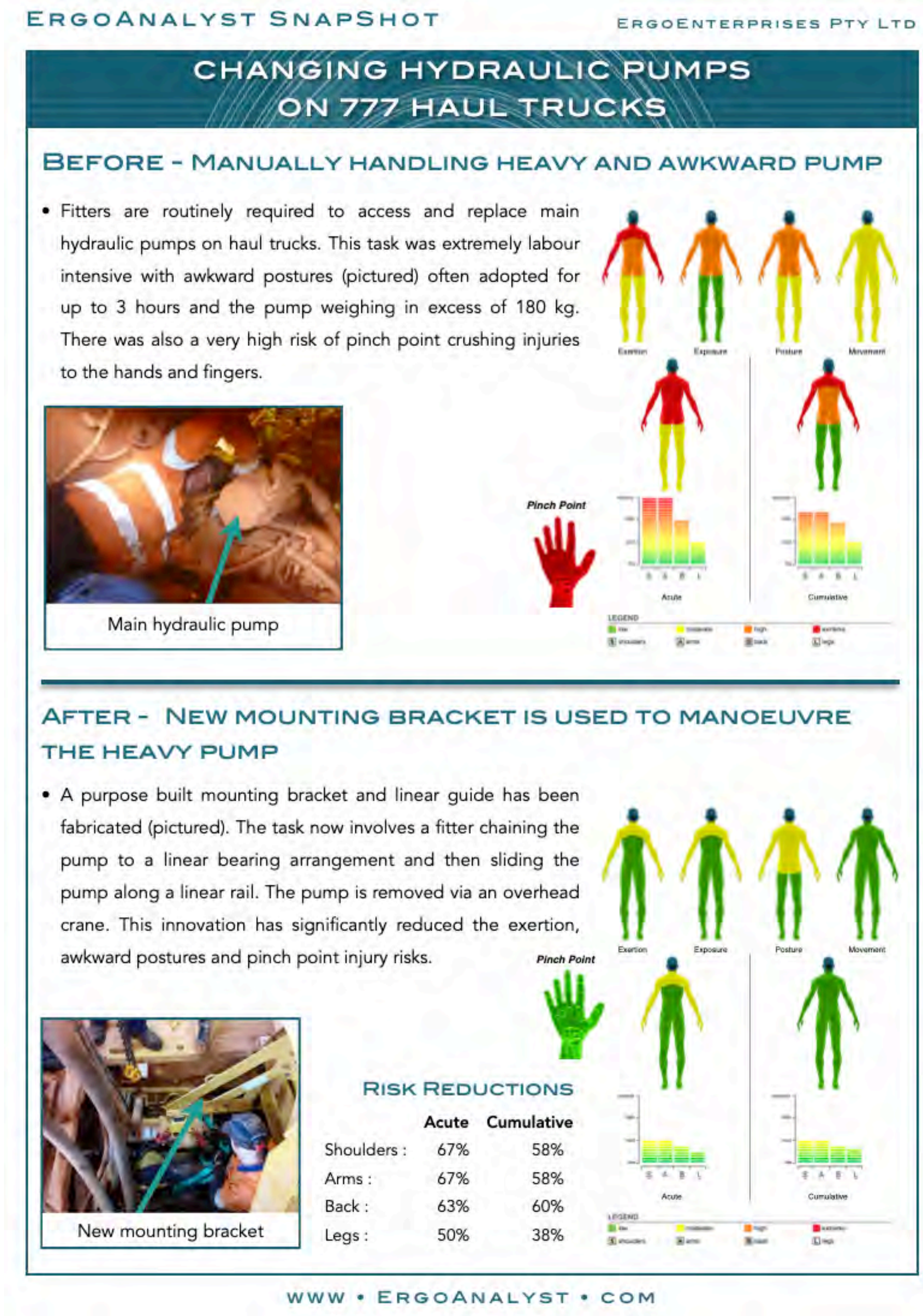


Figure 6: Example of a maintenance task identified as requiring excessive exertion which would restrict the range of people able to undertake the task, and a control measure developed by the site to remove this requirement.

An EMESRT control framework approach to equipment design for diversity

Visits to seven surface coal mines were undertaken during the project to gather information regarding operational and maintenance tasks associated with earth-moving equipment and limitations to workforce diversity associated with these tasks.

Four BHP central Queensland surface coal mines were visited from 29 April to 2 May 2019 in conjunction with the BHP Industry Monitor (Iain Curran) and other BHP staff (Figure 7). Three focus group workshops were undertaken involving 17 surface mine operators and maintainers, as well as task observations at each site. A Glencore New South Wales surface coal mine was visited 11-12 September, 2019. Extensive time was spent with equipment maintainers in the workshop and in the field. The maintainers identified a number of tools and platforms purpose built to assist with equipment maintenance. Time was spent with equipment operators who identified similar issues to those identified during the previous BHP site visits.

Two Peabody central Queensland surface coal mines were visited from 21-22 January and 3-4 March 2020. Time was spent with maintainers in the workshop who provided examples of identified difficult maintenance tasks as well as demonstration of tools developed to assist with maintenance tasks.

Focus groups comprised of between 6 and 17 operators and maintainers representing a diverse cross section of the current site workforce were conducted across the participating sites, with the aim of identifying equipment, tasks and situations in which the range of potential operator or maintainer characteristics were not accommodated, including both situations which had been resolved by design changes made onsite, situations which were currently managed through administrative controls, as well as any situations for which no solution had been identified. Working within individual site requirements, video footage and still images were captured to illustrate the design issues identified during the focus groups.

Detailed information obtained during the visits is provided in Appendix A. Additional information describing manual tasks risks associated with earth-moving equipment maintenance, and suggested control measures, derived during participatory ergonomics processes in place across a range of mining companies is provided in Appendix B.

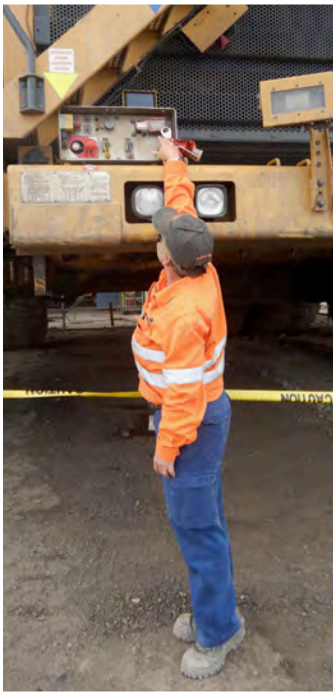
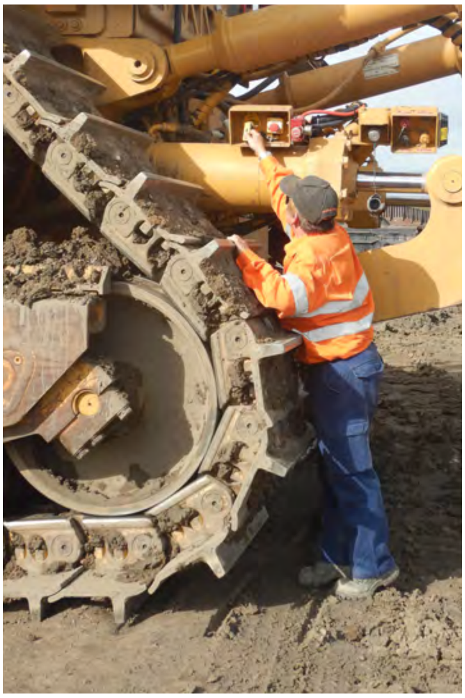
Figure 7: An illustration of the diversity from within the research team

The information gained during the project was used to populate an EMERST control framework for equipment design for diversity. Two required operating states were defined:

(1) Earth-moving equipment can be safely and comfortable operated by people of a maximum range of anthropometric diversity

(2) Earth-moving equipment can be safely and comfortable maintained by people of a maximum range of anthropometric diversity

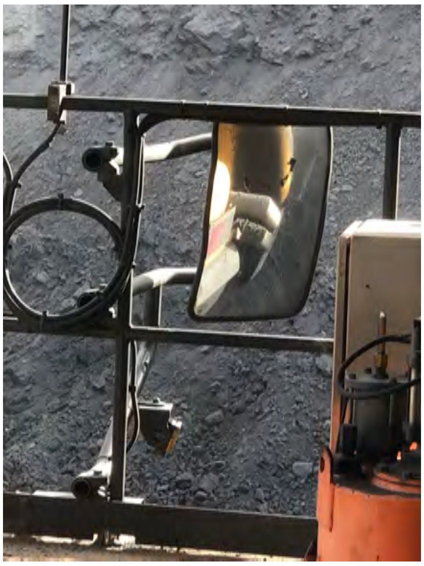
A range of credible failure modes were identified including:

Credible Failure Modes	
1.1 Small operators have difficulty reaching isolation points, fire suppression and emergency stop.	 
1.2 Small operators find access systems initial step height uncomfortable	

Credible Failure Modes	
1.3 Height and weight of refuelling hose and attachments makes refuelling difficult	
1.4 Location of displays requires excessive neck extension and/or shoulder extension	

Credible Failure Modes	
1.5 Controls difficult or uncomfortable to operate for smaller operators	 
1.6 Equipment operation requires extended periods of neck rotation	

Credible Failure Modes	
1.7 Seat suspension cannot be adjusted sufficiently to suit the mass of small operators	
1.8 Seat height cannot be adjusted to suit leg length of small operators	
1.9 Routine maintenance or inspection tasks performed by operators require excessive reach	

Credible Failure Modes	
1.10 Seat belt height cannot be adjusted to be comfortable for small operators	
1.11 Mirrors do not provide the field of view required by small operators	
1.12 Truck handrail impedes vision for smaller truck drivers	

Credible Failure Modes	
2.1 Maintenance tasks require manual manipulation of heavy masses, or exertion of high forces	
2.2 Maintenance tasks require awkward postures	 

Discussion

The considerable consistency observed across focus groups and workshop observations undertaken during this project confirms that the concerns regarding the current design of mining equipment which prompted the project were justified in that aspects of earth-moving equipment designs may unnecessarily restrict the range of potential employees who can operate and maintain the equipment, and in turn create elevated risks of injury for those who currently undertake tasks associated with operating and maintaining the equipment. The observations also confirm the concerns are not limited to one particular mine operator, mine site or original equipment manufacturer.

During the focus group discussions most operational concerns were raised by female members of the workforce, with concerns related to anthropometric issues associated with seating; visibility whilst operating haul trucks; inability to reach isolation points, and procedures regarding in-pit refuelling. Female operators indicated they felt most mining equipment was “designed for a 6 foot male”, however shorter stature male operators reported somewhat similar operating concerns. Of note, female operators indicated a reluctance to report concerns fearing their actions may be considered as ”whinging”, and that reporting may subsequently jeopardise job security. A number of female operators reported instances of swapping allocated shift equipment with fellow male crew members, in particular haul trucks that were known to present difficulty with in-pit refuelling. A number of smaller stature female operators reported difficulty with in-cab adjustments to seating to suit their weight, their ability to comfortably reach foot pedals, and reaching dashboard controls and switches whilst maintaining adequate visibility of the circuit and their surrounds. Additionally, a number of female operators reported shoulder, neck and chest discomfort with the placement of the sash component of the seatbelt. A female operator (55 kg / 157 cm) reported that she habitually operated a wheel dozer with the seat air cushion mechanism completely deflated. In this position she reported her foot often slipped off the pedals, however this set up was her preferred operating position. She believed removing as much air as possible from the seat provided a less jarring ride. To the contrary, removing the air completely negated seat attenuation to reduce exposure to excessive whole-body vibration levels, placing her at significant risk of musculoskeletal injury and other associated tissue damage associated with excessive exposures.

Maintenance tasks associated with heavy earth-moving equipment are a frequent and significant source of exposure to musculoskeletal injury risks. In general across mine sites, the majority of the maintainer workforce is male dominated, however, an increasing number of female maintainers both as apprentices and fully qualified maintenance personnel are joining the workforce. In general, design inadequacies associated with these tasks typically relate to poor access, inadequate provision of lifting points, inappropriate tooling, and the need for excessive manual forces to undertaken and complete maintenance tasks. Female maintainers face additional challenges in undertaking routine maintenance tasks both in the workshop and when providing in-pit repairs. As an example, a female apprentice maintainer approximately 3-4 months into her apprenticeship commented “she wasn’t yet strong enough but would get stronger”. She provided examples of tasks she experienced difficulty with such as bolting, oil refuelling, and truck servicing. In particular, comment was made that the torque of many bolts required excessive exertion to undo them, and that it was often not possible to get a rattle gun into the confined working space to assist with the task. The apprentice commented that she was often in awkward postures such as up ladder and holding a hose at the same time, particularly to access oil service points which are usually located higher up on the equipment. Most male maintainers interviewed listed routine maintenance procedures which provided challenges - ranging from flame rails on 709C trucks so narrow they couldn’t wear tool belts when working, to absence of lifting points to enable hose change outs on haul trucks. Maintainers frequently commented the “everything is big and heavy, we need proper lifting gear and tools which we don’t have”. Haul truck hose change out was a task that presenting particular difficulty and maintainers considered it would be better to change out hoses on a regular maintenance schedule rather than waiting until damaged and needed replacement. Changing worn or damaged hoses involved difficulty gaining access to the top link and hoist pins, working in confined spaces where trolleys were not able to be uses and therefore everything needed to be held manually. By example, to change out the top pin (65 kg), pulling gear was needed, which weighed about 200 kg (puller, spacer and rod). Additionally, the work is undertaken from a short narrow platform which restricts trolley access. The task therefore becomes a two person manual task. The suggested solution was provision of lifting lugs allowing the pins to be pulled out and replacement to be undertaken using slings attached to the chassis rail.

Many of these challenges may have been overlooked by original equipment designers and manufacturers who do not see or understand the conditions under which maintenance tasks in particular are performed. More importantly the standards and guidance material available to designers does not adequately equip them to understand address these challenges. While the general business case for increasing workforce diversity in mining is well established, and improving earth-moving equipment design can remove significant anthropometric and other work demand impediments to establishing a more diverse mining workforce, it is clear practical on-the-ground improvement of current operational practice and improvements in equipment design is required, particularly for maintenance tasks.

Conclusion

The current design of earth-moving equipment places restrictions of the diversity of employees who may comfortably perform the tasks required to operate and maintain the equipment. The information obtained during focus group workshops and task observations undertaken at seven surface coal mines was used to develop an EMERST control framework approach to equipment deign for diversity. Two required operating states were defined:

(1) Earth-moving equipment can be safely and comfortable operated by people of a maximum range of anthropometric diversity

(2) Earth-moving equipment can be safely and comfortable maintained by people of a maximum range of anthropometric diversity

Fourteen generic credible failure modes were defined to provide assistance to equipment designers viz.,

1.1 Small operators have difficulty reaching isolation points, fire suppression and emergency stop
1.2 Small operators find access systems initial step height uncomfortable
1.3 Height and weight of refuelling hose and attachments makes refuelling difficult
1.4 Location of displays requires excessive neck extension and/or shoulder extension
1.5 Controls difficult or uncomfortable to operate for smaller operators
1.6 Equipment operation requires extended periods of neck rotation
1.7 Seat suspension cannot be adjusted sufficiently to suit the mass of small operators
1.8 Seat height cannot be adjusted to suit leg length of small operators
1.9 Routine maintenance or inspection tasks performed by operators require excessive reach
1.10 Seat belt height cannot be adjusted to be comfortable for small operators
1.11 Mirrors do not provide the field of view required by small operators
1.12 Truck handrail impedes vision for smaller truck drivers
2.1 Maintenance tasks require manual manipulation of heavy masses, or exertion of high forces
2.2 Maintenance tasks require awkward postures

Presentations regarding the preliminary findings of the project were presented to the EMESRT advisory committee, the ACARP Research Committee, and to the Standards Australia mirror committee responsible for earth-moving equipment (ME-063). The information has subsequently been circulated within a major manufacturer of earth-moving equipment.

Recommendations

This research was an initiative of the Earth Moving Equipment Safety Round Table, a collaboration of mining companies with a long history of influencing the design of mining equipment through providing Original Equipment Manufacturers with a consolidated view of the experiences of mining companies. Links have also been established to the ISO committee responsible for the relevant standards. It is recommended that:

(i) EMESRT promotes earth-moving equipment design improvements to reduce barriers to workplace diversity through communication of these results to Original Equipment Manufacturers, and standards committees (ME-063 and ISO TC127 / SC 2).

The equipment design limitations identified in this research frequently led to the performance of manual tasks associated with equipment operation, and especially maintenance, that involve high exertion and/or awkward postures. Frequent or prolonged performance of such tasks increases the risk of musculoskeletal disorders. A combination of task redesign and administrative controls should be employed to reduce these risks. Harnessing the expertise of the workers who undertake the tasks through a participatory ergonomics process has potential to both ensure that the solutions proposed are optimal, and will be accepted by workers. (Appendix B provides examples of the outcomes of such a process). Training in ergonomics principles, team work and problem solving is likely to be required; as well as the provision of tools for the efficient analysis of manual tasks risks and for the development and documentation of proposed and implemented changes. However if this can be achieved, the evidence is that such a program will reduce injury risks (Burgess-Limerick, 2018) and such approaches are recommended by resource industry regulators[1]. It is recommended that:

(ii) mine operators put participatory ergonomics programs in place that: assess hazardous manual tasks associated with equipment operation and maintenance; and implement a combination of design and administrative controls to reduce risks as far as reasonably practical.

[1] e.g., https://www.resourcesandgeoscience.nsw.gov.au/__data/assets/pdf_file/0004/291784/Guide-to-the-prevention-of-musculoskeletal-disorders-in-the-mining-and-extractives-industry-in-NSW.pdf

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Appendix A: Detailed information obtained during workshops and observations

Required operating state 1: *Earth-moving equipment can be safely and comfortable operated by people of a maximum range of anthropometric diversity*

1. Location of haul truck isolation point: operators reported issues with positioning the truck to allow the isolator switch to be reached, and to facilitate easier refuelling. The isolator is located on front of truck (operators indicated the switch on one truck operates upwards making it more difficult to operate), requiring operators to get down from cab to isolate, return to the cab to "check for dead" and return to ground to refuel - the question asked in focus groups was "could the isolation points be located on the deck of the truck?". Comment was made that excavators have a similar design, and it was suggested that fitters should be able to isolate from the ground also.

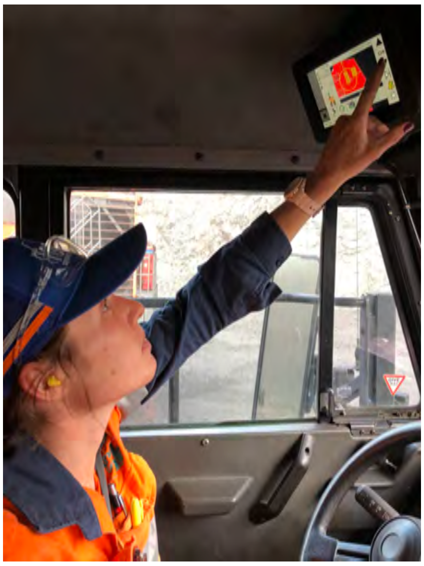
2. Positioning of the truck to allow refuelling on site: operators reported bunds built to allow the haul truck wheels to straddle like a speed bump/V drain - this configuration lowers the nose of truck to make it easier to reach the isolator. Operators also reported difficulty removing the fuel hose nozzle, as the coupling was often clogged with dirt. Both male and female operators reported struggling with the task, in particular locking-in the coupling mechanism, indicating the hose needed to be held up to ensure flow, and the group questioned if a smaller diameter hose could be used. The focus group also discussed a hinged hose arm mechanism which required significant operator strength pull it across to the truck. Operators questioned if design improvements could not be made to reduce the stress associated with pulling the hose into position, and also raised the issue of the height of the coupling at the diesel bay, indicating it was designed "for a 6ft male" (operators reported having seen rags etc. used to tie the hose into place). Operators reported stress to their upper body, back and shoulders when undertaking this task, and questioned if some kind of auto-refuelling system could be designed (similar to aircraft mid-air refuelling). At one site, a number of operators reported they could not reach the isolator on some "F series" trucks, and so needed to hand the truck over to operator on the next shift for refuelling. Some of the participating sites utilised service trucks to refuel trucks in pit, which while relieving the operators of the task, transferred the risk of injury to the service truck operators. The task then became more constant for the service truck operator, in turn creating a greater risk of injury due to repetitiveness of the task.



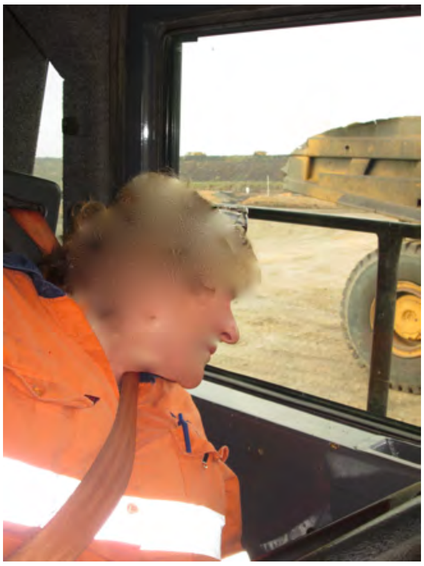
3. Straight safety rails on "F" series trucks: female operators reported that their view was obstructed, but that "97 series" trucks had a rail more "V" shaped which provided better visual access at crossroads and for approaching vehicles. Operators indicated that although they adjusted for height, shorter statured operators experienced more difficulty than those with a longer torso.

4. Seat adjustment: smaller operators indicated "F series" trucks were uncomfortable to operate due to the floor pedal/seat position, indicating to achieve a comfortable seat position an excessive amount of strain was placed on their ankles to operate the pedals. Other operators reported seat adjustability problems as the dampener mechanism interfered with seat movement when driving over rough surfaces. Smaller operators (50-60 kg) reported seats were rated from 80 kg upwards and with adjustment as low as possible the ride was still "bouncy". They also reported that they were unable to reach the pedals comfortably. Female operators reported they usually didn't complain as didn't want to be seen as "whinging". Other operators reported swapping assigned trucks with other operators to enable them to operate a vehicle they were more comfortable in. Dicky seats were reported as being very uncomfortable.
5. Seat belts: female "F series" truck operators reported seat belts cutting into their shoulder and neck. Operators reported tucking the seat belt under their arm rather than having it placed across their shoulder.
6. Sunshades on haul trucks: operators reported perforated mesh sunshades were difficult to pull down, and ineffective in blocking afternoon sun. They reported the mechanism clogged with coal dust making it difficult to operate the screens unless two hands were used to pull the screen down into place. Most operators reported they did not use them, and instead used duct tape to block out glare.

7. Retrofitted cab equipment: smaller operators reported excessive reach required to operate the dispatch screen and radios.

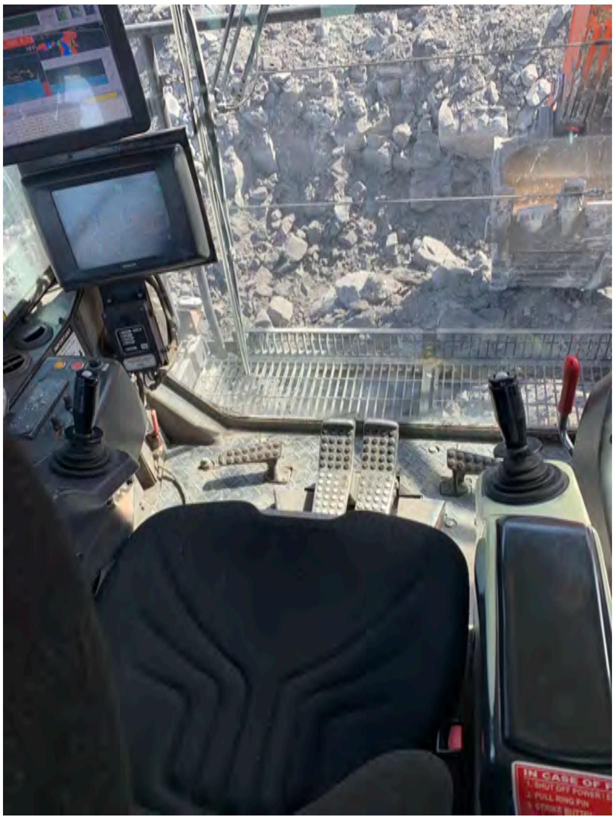


8. Side and rear mirrors: a number of operators reported problems with side and rear mirrors, with female operators reporting excessive rotation of their upper body and neck was required to see when reversing (mainly with D789/785 trucks). Rear cameras were considered problematic as they didn't not provide an adequate viewing angle, resolution was poor, and consistently clogged with dust and dirt. Operators indicated rear mirrors were difficult to clean. In particular rear grader windows were highlighted as being particularly difficult to clean.



9. Dozer seats were considered particularly problematic as they require the operator to sit awkwardly during operation. Suggestions were made to have the seat and console move as one unit as is the arrangement in scrapers. Dozer operators estimated more than 50% of their shift was spent with their body/neck rotated to enable them to look over their shoulder to see where they were operating.

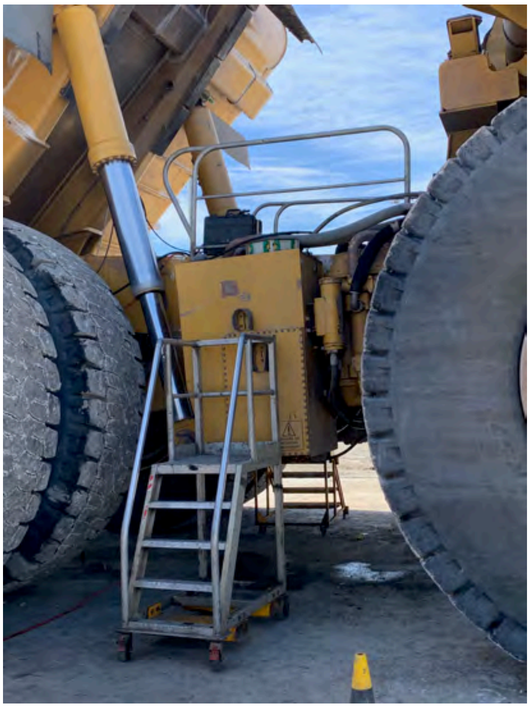
10. Digger seating/cab design was considered problematic because it is difficult to see the tracks when moving digger across overburden.

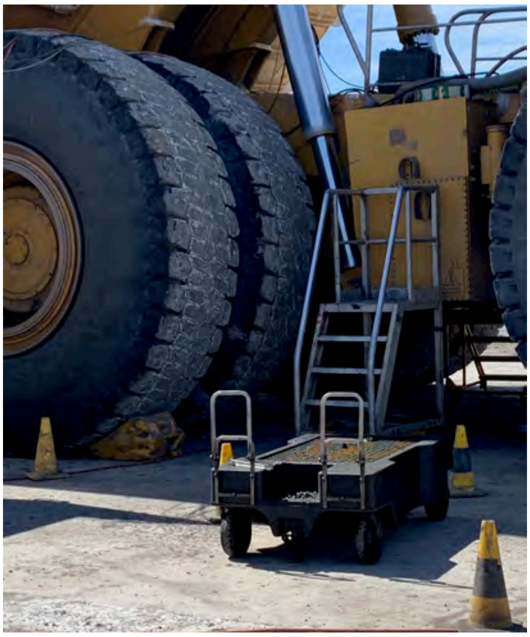


11.Height of access varies across equipment and is sometimes high

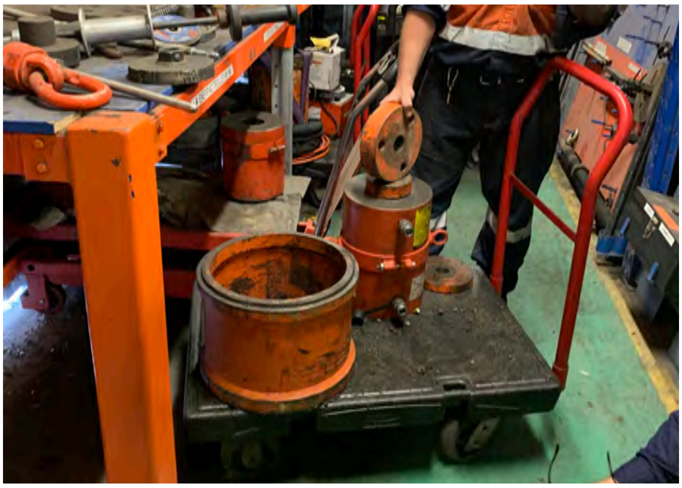
Required Operating State: *Earth-moving equipment can be safely and comfortable maintained by people of a maximum range of anthropometric diversity*

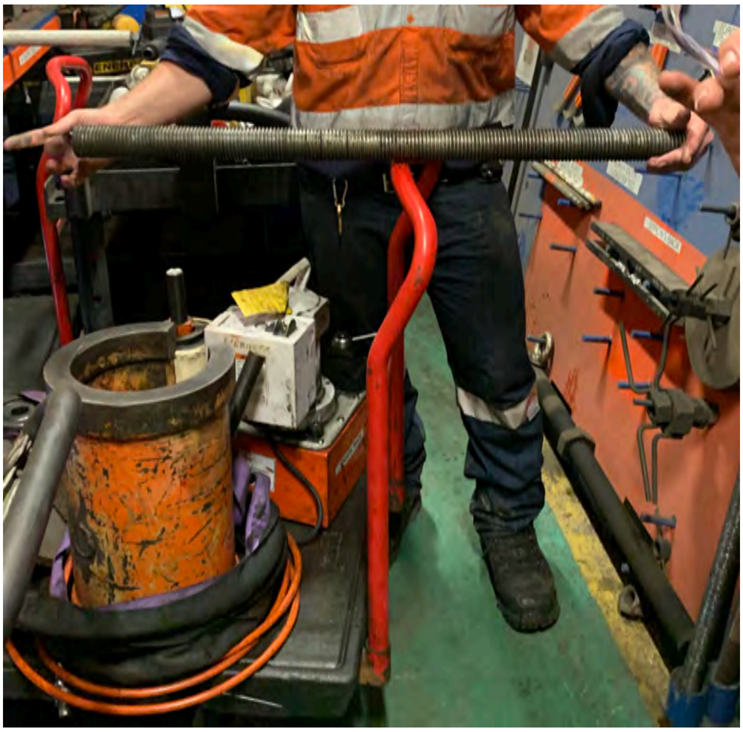
12. Maintainers reported the workshops on site would custom make stands/equipment needed for jobs if asked, as these were not usually supplied with the equipment. Maintainers expressed frustration in obtaining the correct tool for the task at hand, and group discussions highlighted the need for and benefits of standardising equipment and tooling that was “fit for purpose” across the equipment fleet. Additional comments included the need for more crane operators on site, and maintenance services provided with priority access to cranes when needed.



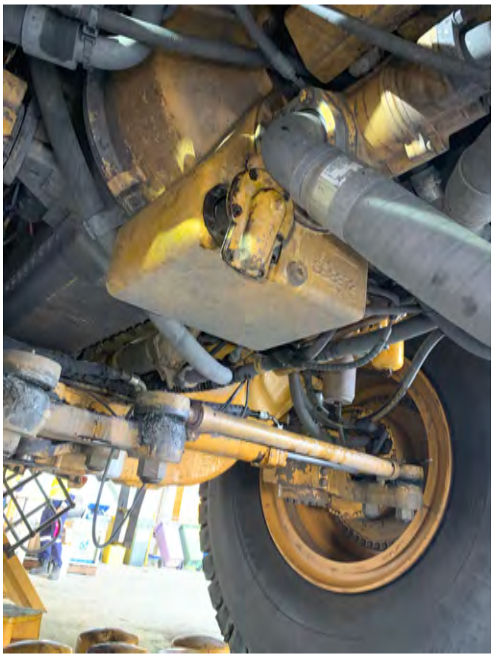


13. Maintainers commented that “everything is big and heavy and we need the right tools for the job, but often we don’t have them”.





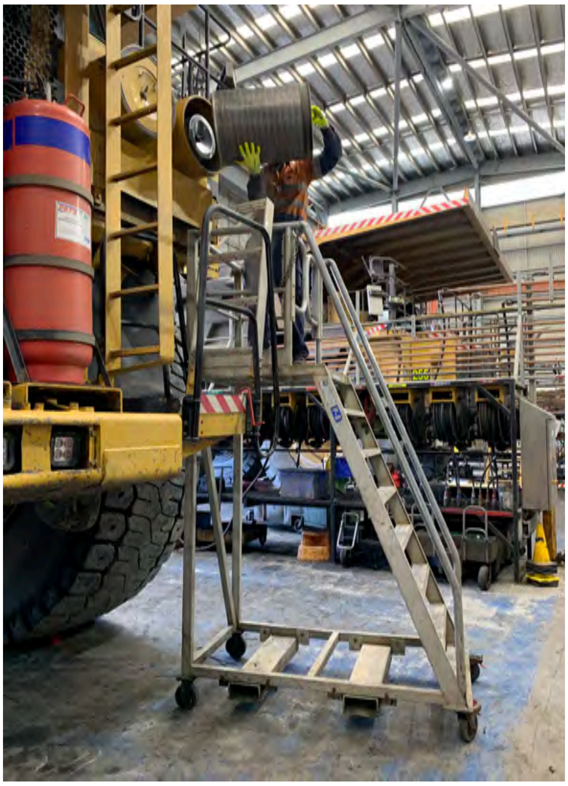
14. A female diesel fitter approximately 3-4 months into her apprenticeship reported that “she was not yet strong enough but would get stronger”. She provided examples of difficult situations such as the awkward positions required for bolting, oil refuelling, truck servicing/ bolting. Comment was made that the torque of many bolts required high exertion to undo them, and it was often not possible to get a rattle gun into the confined working space. The apprentice commented that she was often in awkward postures such as up a ladder and holding a hose at same time, particularly as oil service points were usually located higher on the equipment. She commented that a boom hose support would help reduce the manual handling involved in the task.



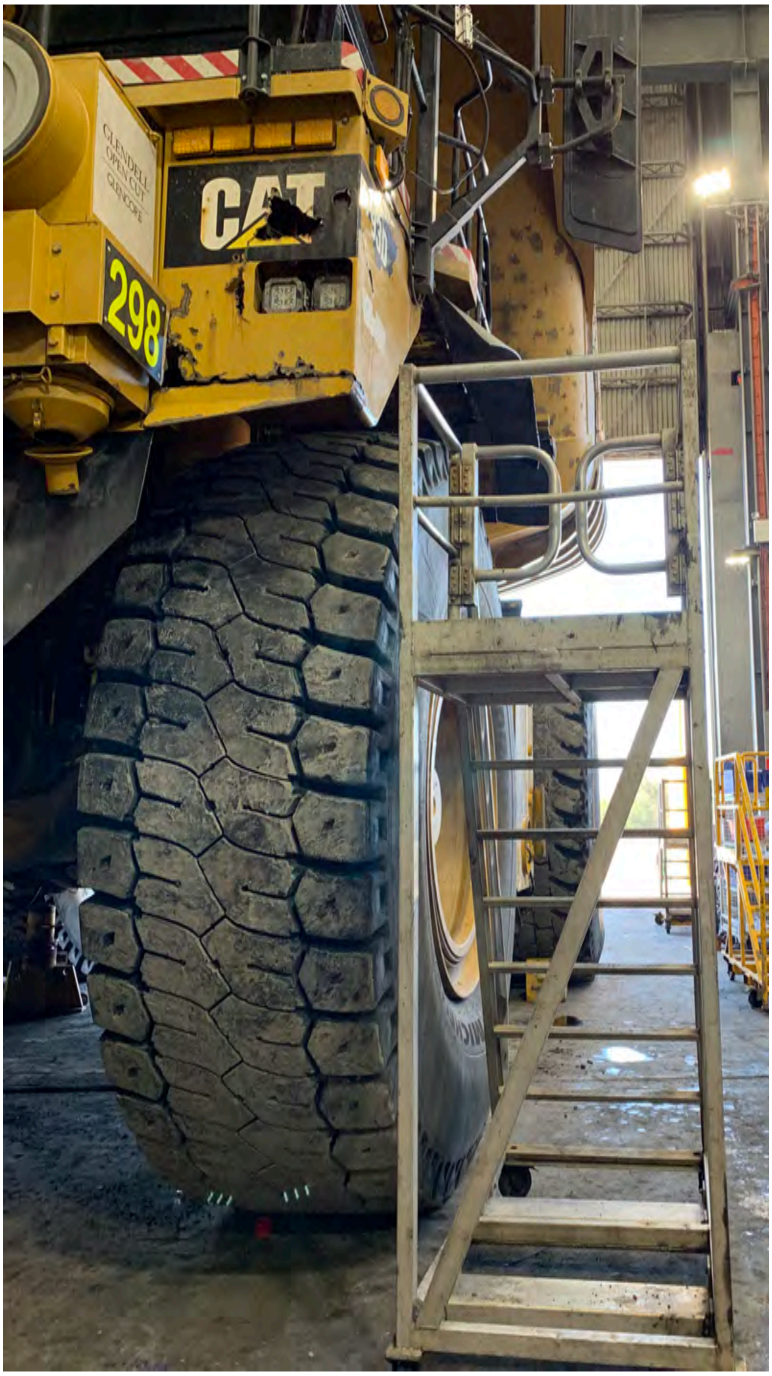
15. When performing maintenance on 709C’s, maintainers reported that the flame rails were so narrow that they couldn’t wear their tool belts because they caught on the rails. Difficulty in getting a good footing to climb down was reported, which was problem if a tool was dropped.
16. Hydraulic pump change out: maintainers reported the task required operation of a hydraulic jack with a metal plate attached, and that while chains were available the crane could not get in close enough. Undoing bolts from cylinder heads to block became difficult as the head stretches and moulds into the block. A breaker bar/rattle gun was needed, however, as the task is performed inside the engine bay there is not enough room. Additional comment was made that maintainers were not provided with enough information regarding the weight of components and often jobs were too heavy for one person alone to complete.
17. Changing haul truck starter motors: there are two, one located above other, weighing approximately 30 kg each. Replacement requires reaching above head, and awkward positioning. Maintainers reported that when standing on the step, there is often grease on it which makes working difficult. The task often requires standing on the air pipe to get access for the top motor and it is a two person job. It is difficult to get tools in to loosen bolts as working in a confined and awkward space, and a sling can’t be used. Additionally there is a thick washer that stops getting the socket in easily. Problems occur particularly with old water trucks/Cat trucks/930 E’s because all have thick washers.

18. Changing condensers: the task requires the grill to be taken off. This is difficult because the stairs making positioning difficult. Ideally the task needs to be undertaken from the front of the machine. Different sites had developed different solutions to this problem.

19. Changing haul truck air filters: maintainers are required to adopt awkward postures to access the filters. The internal pressure makes taking old filters out difficult, and they are heavy and dirty. The task is undertaken by standing on the stair plate and leaning out. Different solutions have been developed at different sites.



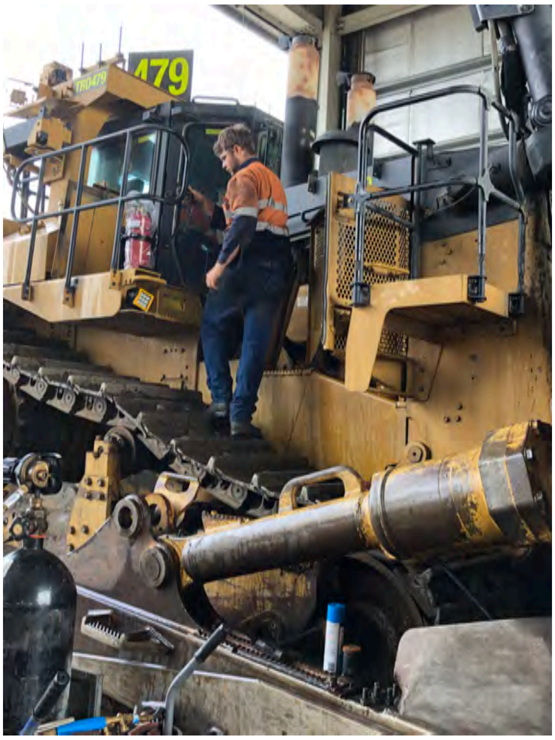
20. Removing /replacing haul truck front struts: this is a 2 person job. One of the sites had a purpose built stand that went over wheels and allowed maintainers to work from in front rather than from the side.



21. CAT dozer "hell hole": dozer maintenance requires maintainers to go into it head first to perform work. The new D10T model was highlighted as particularly problematic. Maintainers reported that it was difficult to get the covers off and and difficult to fit into "hell hole" (especially for larger people), and the general comment was "shorter is better, thinner the better". Maintainers reported that in the confined space any damaged hoses meant oil/fire suppression liquid spilling out and onto them. Burns from contacting hot components are also a potential hazard. Better access could be obtained if the seat and other access plates were removed, but was rarely done due to the additional time required for removal.

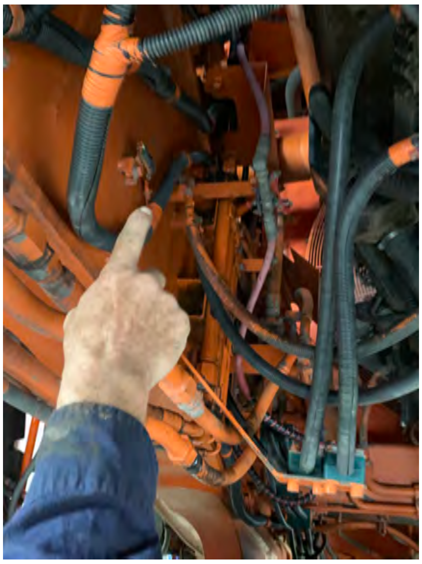
22. Removing and replacing dozer “belly guard”: weight is approximately 300kg but up to 700kg when loaded with stones and dirt. A jack (TED) has been designed to assist with task. The maintainers suggested a control where a tractor fitted with a hydraulic arm and remote control could walk it out. CAT provide a tool but maintainers indicated it was not adequate. Maintainers reported potential for crush injuries to arms/hands/legs and fatalities associated with this task.

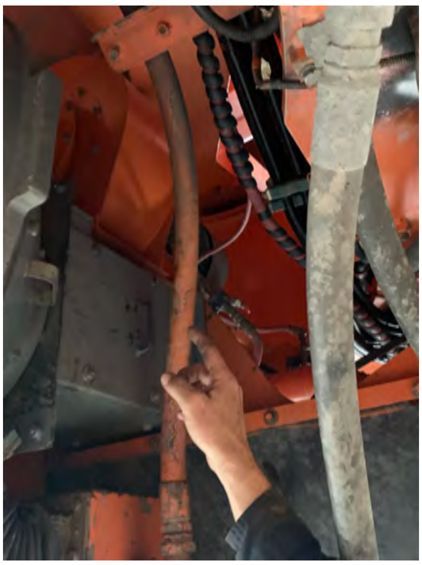
23. Access to dozer D11T - the way the door opens means maintainers are required to work from on the tracks to access maintenance points. There is no handrail at front of the cab, and the placement of lights makes cleaning or repair difficult. Maintainers reported difficulty getting to access turbos, coolant, and belts, and that the fire suppression pipe was in the way much of the time.

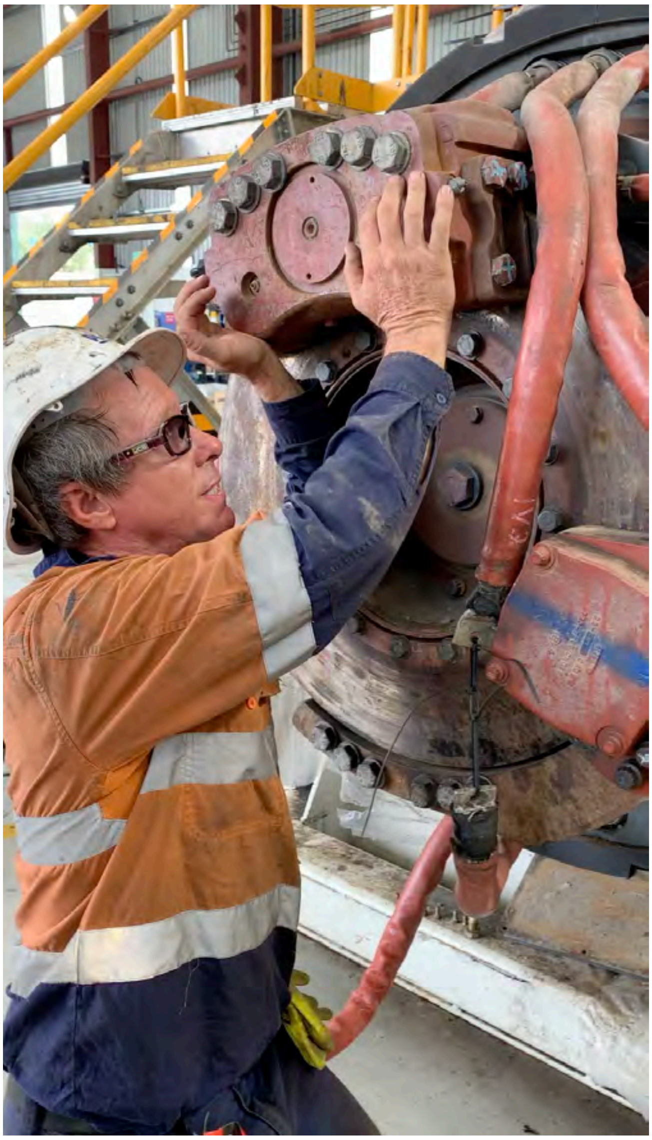


24. A number of sites had fabricated plates to make access easier for dozer maintenance, either to fit between tracks, or on front of the dozer.

25. Hose change out on Cat and Liebherr trucks (282C): “everything is big and heavy, need proper lifting gear and tools”. Maintainers reported difficulty changing hoses when they blew and considered it would be better to change out on a maintenance schedule rather than waiting until damaged and needed replacement. Working down low was considered to be manageable, but getting up top to drag the link and hoist pins was hard work, they needed to be held manually as it was difficult to get a trolley in.To change out top pin (65 kg), need pulling gear which is about 200 kg (puller, spacer and rod - need to get into place) and because have short narrow platform too small for a for trolley - need two strong people to undertake the lift. Solution suggested would be lifting lugs and slings attached to chassis rails. This would allow the pins to be pulled out and replacement to be undertaken. The task is difficult as can’t fit two people into the space to complete the task, and can’t fit extra equipment into confined space. Maintainers consider this requires an OEM solutions is standard Liebherr problem rather that trying to design equipment on site to assist maintenance/use slings etc. to try to reduce manual handling issues. Maintainers reported this to be a significant problem when replacement was required to be undertaken in pit.

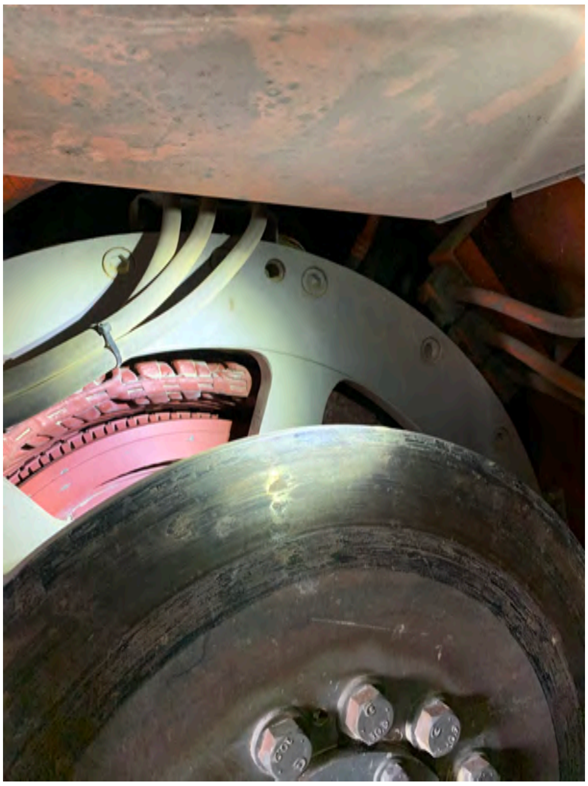






26. Replacing the rear suspension struts on haul trucks was identified as an issue: across the top is a pin with a bolt plate with 3 bolts holding it in place. The tyre needs to come off and then a threaded bolt goes into pin and collar overtop. A ram goes on the end to pull the pin out into the collar (300 kg total weight - pin 150 T ram and collar), and there is nothing to support it. Maintainers reported lifting lugs and a sling to support the 90 kg hoist pins and a better method of lifting would significantly reduce the difficulty of the task. Comment was made that usually maintenance bays did not have adequate access forklifts or small cranes, such as a Franna.

27. Replacing Liebherr final drive: need to replace gear set and electric motor and brake pack up front. There are 2 park brakes on each disk (45 kg each), which need to be lifted into place as a whole unit. Work is undertaken in a confined, hot space in the axel hole of the truck. Maintainers are adopting awkward postures and reaching overhead to get the unit into place. There are 65 kg brake pads on each side which need to be lifted up above head height so a second person can get the pins in and secure the brake pad in place. There is one on the inside of the drum as well which has even more difficult access. Maintainers need to get around the axel bolt and bolt to access the holes. There is 100 kg weight in front and back pads - bolts need to go through both to hold brake pads together. Maintainers indicated they needed lifting gear so that they were working from above rather than below, as well as a second person to assist.



In addition to the workshop tasks above, the following in-pit maintenance tasks were highlighted by both operators and maintainers as potential musculoskeletal injury tasks. Maintainers reported most in pit repairs were subject to significant time constraints to enable production to continue as quickly as possible. The equipment was generally hot, dirty and greasy which made the task more difficult in terms of access, with the lifting equipment/cranes etc often unavailable for the task.

28. Dragline cable handling: the dragline cables weigh approximately 12 kg/metre, with 350 metres attached cable. The tractor can't get in close enough to the base of the dragline feet to hook up the cable. Hooks are provided to lock the cable into, and need an electrician to undertake this part of the task. It was reported that 3 winches on front and back of dragline were needed to undertake the task (currently using 1 front and 1 back), and better designed cable boats were required. Drag line cable requires moving daily.

29. Shovel cable handling: smaller cable than dragline cable and approximately 10 kg/metre. The same issues were reported with shovel cable handling as dragline cable changing. Stands are used for moving the plugs. The shovel relocates approximately 1-2 times a month. Attachments have slings, but this is a very physical task as the cable needs to be pulled, often the foot is used to hold the cable up for leverage, before placing the slings. Focus group members indicated shovels needed cable stands/winching system. A female operator reported she worked with 2 males who lifted the heavy cable because she could not.

30. Checking fluid gauges on haul trucks: shorter stature operators reported they could not easily access the dipsticks. Awkward postures were required to complete the task as operators need to access and crawl along a narrow ledge under the truck, to access the dipstick. Maintainers suggested a sight glass which would enable visual inspection from ground level as a possible solution to remove the awkward postures required to complete this task.

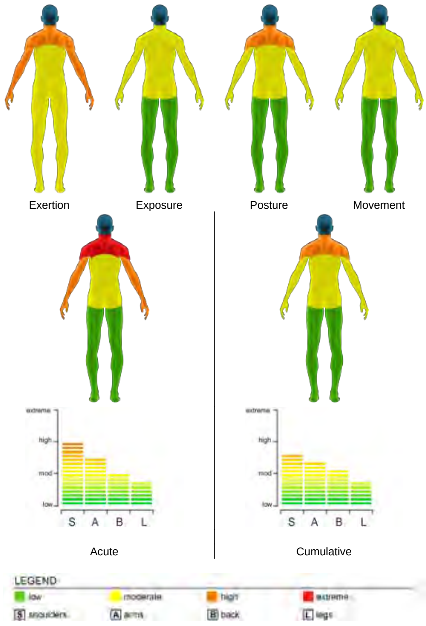
Appendix B: Controls identified by mining companies to reduce manual tasks injury risks associated with earth-moving equipment maintenance tasks.

Changing the Lock Ring on a Haul Truck Tyre

Before - Two people handling the heavy lock ring

- When changing a haul truck tyre, a 44 kg lock ring has to be removed or installed. This process in the past has pose a high injury risk. In addition to heavy lifting and awkward postures above shoulder height, there is also the potential of the lock ring springing out of the hub causing impact injuries. Two people were required to perform this task that also involved in setting up a restricted area.

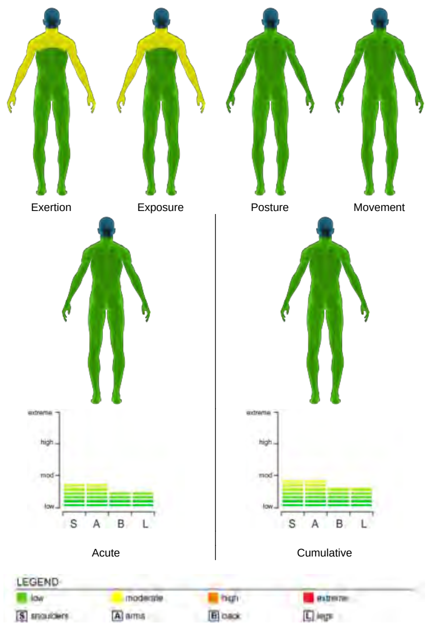
Pinch Point



After - Custom brake winch handles the lock ring - now a one person job

- The injury risks have significantly been reduced with the introduction of a purpose wind up/wind down brake winch tool. The tool captures the lock ring at the top section without the tyre fitter being in the line of fire, it also eliminated the need to work above shoulder height. The tool is also portable, which allows the fitter to move it out of the way maintaining housekeeping. The wheels are lockable, therefore controlling unplanned movement.
- ***Note: The task is now a one person job, doubling productivity.***

Pinch Point



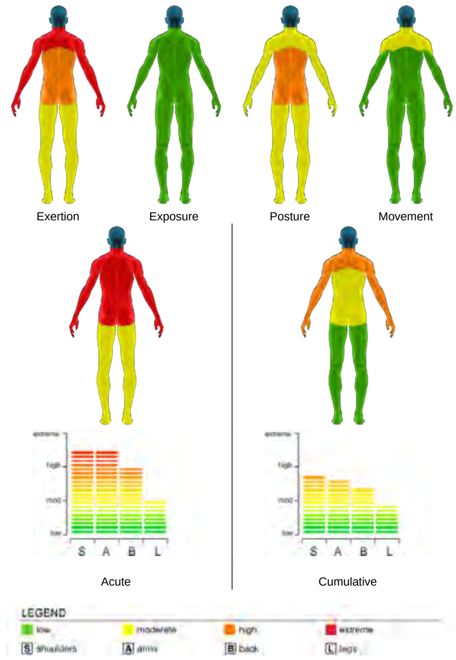
Risk Reductions

	Acute	Cumulative
Shoulders :	63%	46%
Arms :	50%	36%
Back :	50%	44%
Legs :	33%	17%

Attaching Sling to Bogged Haul Truck

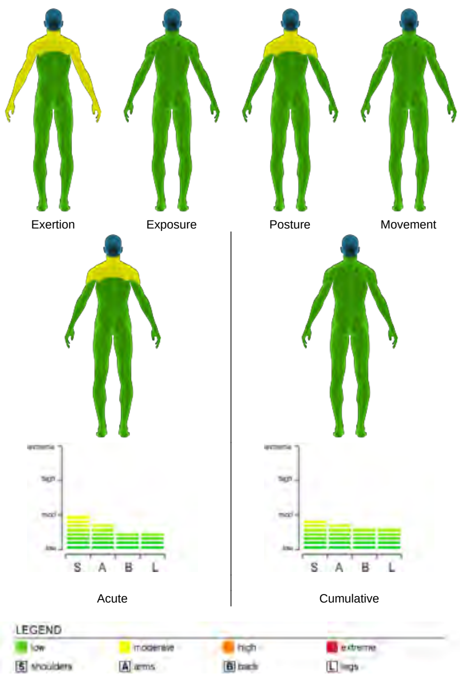
Before - Using heavy D-Shackles

- During normal operations trucks can often get bogged, particularly in wet weather and when stockpiling ore. If a dozer is not available then the bogged truck must be pulled free with another truck.
- A 34kg 44 Ton D-shackle attached to a snatch sling is used to un-bog the truck. Positioning the D-shackle involves heavy lifting and awkward postures, particularly if the hook is obstructed by the truck's bumper. The pin threads are also often dry and dusty and difficult to screw.
- Personnel have previously tried to use just the sling, however they have found the hook cuts and damages the sling.



After - Modified tow hook only needs a light sling

- The solution was to fabricate a hook to the front and rear of each haul truck. This allows for the slings to be attached directly to the trucks, eliminating the need for the D-shackles to be used.
- These hooks eliminate the use of a heavy shackle and the requirement for personnel to get into awkward positions. It has also prevent the tow slings from cutting.
- New ropes have also been introduced which are water resistant, which are lighter in muddy or wet conditions.



Risk Reductions

	Acute	Cumulative
Shoulders :	60%	50%
Arms :	70%	54%
Back :	75%	55%
Legs :	50%	29%

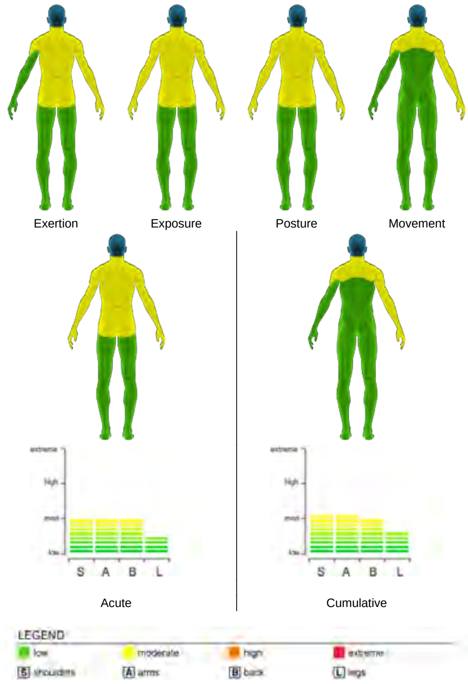
Inflating Truck Tyres

Before - Manually inflating tyres

- Personnel routinely carry out tyre pressure testing and inflation on a daily basis. This task involved personnel attaching a connection to the tyre valve, then with one hand applying downward pressure (pictured), while the other hand held onto the gauge. A number of issues were identified by the tyre fitters:

1. Repetitively depressing gauge valves places strain through the wrist.
2. Instability of pressure gauge therefore elevated risk of pinch points.
3. Awkward postures when checking gauge readings.
4. Close proximity of the tyre due to short hose with 'line of fire' issues.

Pinch Point



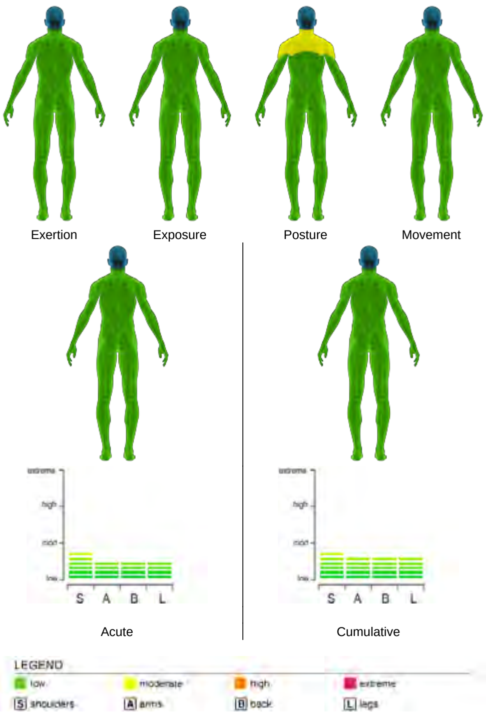
After - Remote tyre inflation unit

- This manual handling task has been improved by the introduction of a purpose built remote mobile inflation station (pictured). Improvements are as follows:

1. Easier portability of pressure gauge as it is on four wheels.
2. No more awkward postures on wrists or pinch points to obtain a reading, as the pressure gauge is operated via a blue lever handle.
3. No more awkward bending over to take a reading.
4. Mobile station can now be located at a safe distance from the tyre (10 m hose) eliminating 'line of fire' concerns.

Risk Reductions

	Acute	Cumulative
Shoulders :	25%	33%
Arms :	50%	44%
Back :	50%	38%
Legs :	0%	0%

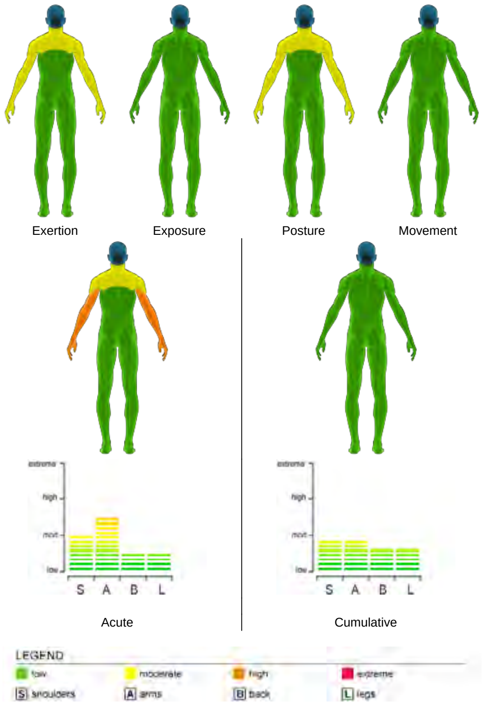


Removing Magnetic Oil Drain Plugs on Heavy Mobile Plant

Before - Using a socket and breaker bar

- Diesel fitters are routinely required to remove magnetic drain plugs when checking and replacing oils in heavy mobile equipment. To complete this task the fitter would use a socket and breaker bar to undo the drain plug. The injury concerns identified with this procedure include; the potential for slips, trips and falls with oil leaking onto the ground, and burns from hot oil splashing onto hands, face and body. Additionally, there is the risk of potential environmental contamination.

Pinch Point



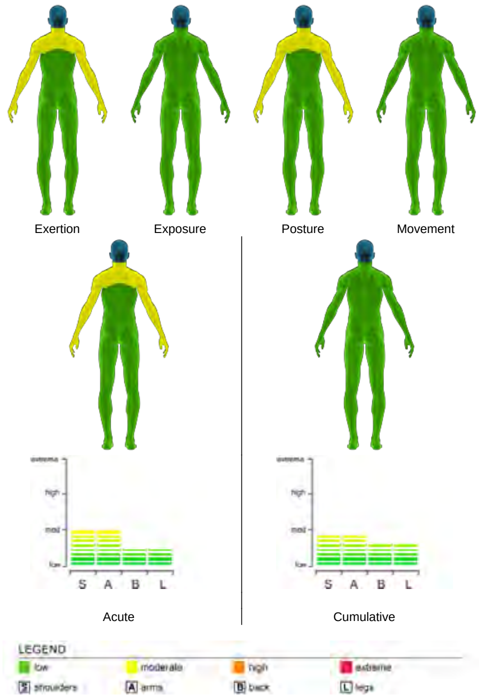
After - New magnetic tool to contain hot oil

- A purpose built magnetic tool has been fabricated (pictured) that is placed over a half inch drive bar before fitting it to the magnetic drain plug. When the plug is removed oil then flows into this tool. This innovation has eliminated both the potential for slips, trips and falls and the potential of burns to hands and other areas of the body because the hot oil is now safely contained within this tool.

Pinch Point

Risk Reductions

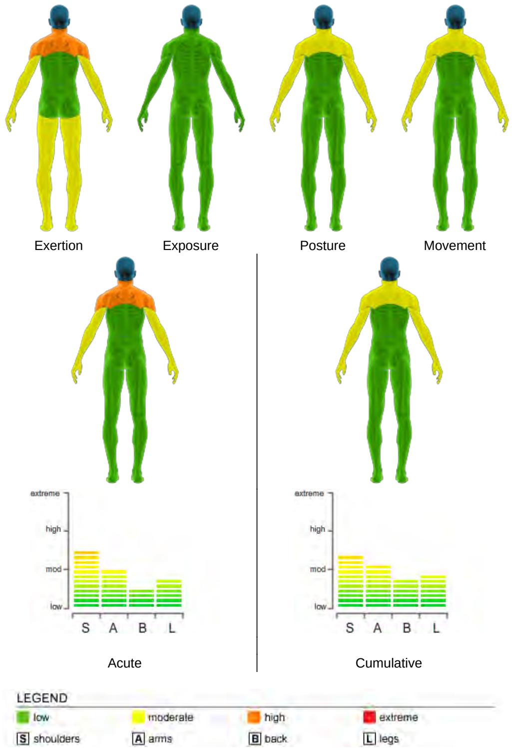
	Acute	Cumulative
Shoulders :	0%	0%
Arms :	33%	0%
Back :	0%	0%
Legs :	0%	0%



Accessing Truck Flatbed

Before - Climbing up the tyres

- Contractors need to frequently access the flatbed of the truck to restrain and tie down equipment. As no proper access point was available, contractors had to climb up the outside of the vehicle (e.g. tyres) and hold on with unnecessary shoulder and arm force to perform the task. Personnel also identified that this process posed a high risk of slips and falls.

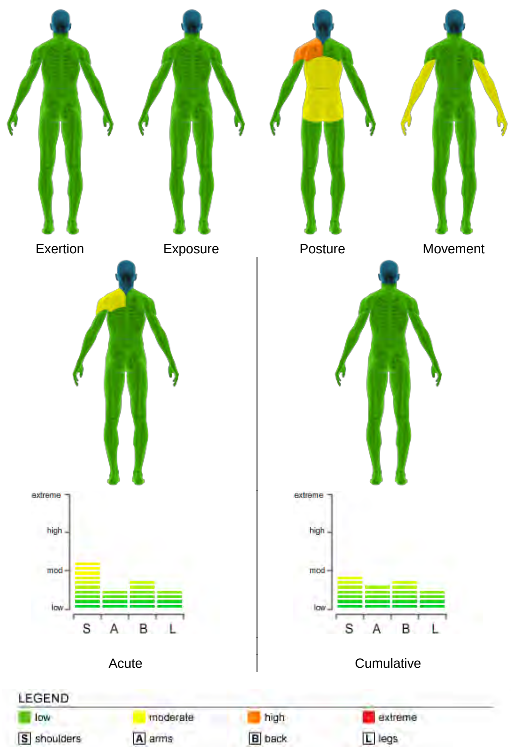


After - New ladder access installed

- A custom made step ladder has now been fitted to the side of the flatbed truck. This control has significantly eliminated the risk of slips, trips and falls, as personnel can now safely ascend and descend whilst maintaining three points of contact. The strain on the arms and shoulders have also been significantly reduced.

Risk Reductions

	Acute	Cumulative
Shoulders :	17%	27%
Arms :	50%	33%
Back :	0%	0%
Legs :	33%	14%

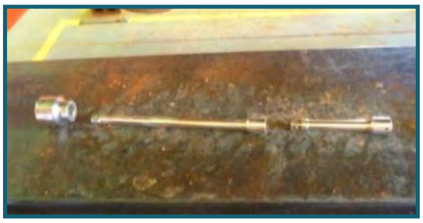


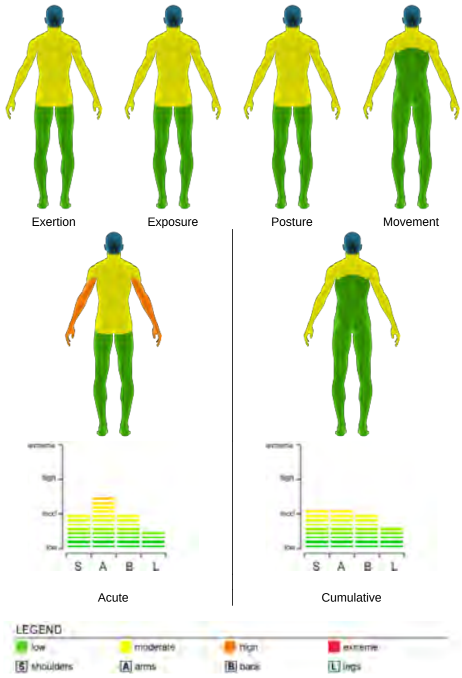
Installing Inner Axle Oil Seal

Before - Heavy tools not 'fit for purpose'

- Light vehicle mechanics routinely need to replace worn inner seals on the front axles of light vehicles, which was done using a socket set (pictured). The injury concerns included:

1. Poor fitting of socket over seal, with cumbersome performance.
2. Awkward reach under vehicles with short and heavy tooling (3 kg) that is not designed for the task, creating potential for shoulder injuries.
3. Loss of control of heavy incorrect tooling resulting in inefficient work practises and potential hand and finger lacerations.





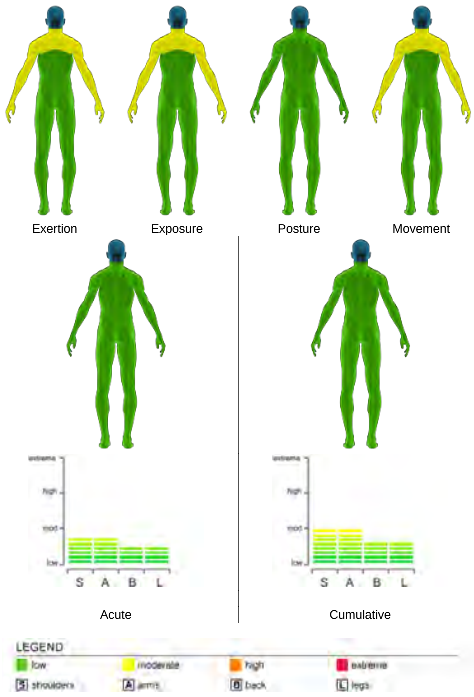
Pinch Point

After - Lighter customised task specific tools

- Purpose built inner axle seal installers have now been fabricated in aluminium, therefore:

1. Shafts made to required length eliminates the need to reach under vehicles, resulting in better postures.
2. Lighter tool weight (1.5 kg), has less strain on the upper limbs.
3. Compounding of inappropriate tooling no longer necessary. This has eliminated any slippage and risk of components separating during the task, minimising the risk of hand injuries.

Pinch Point



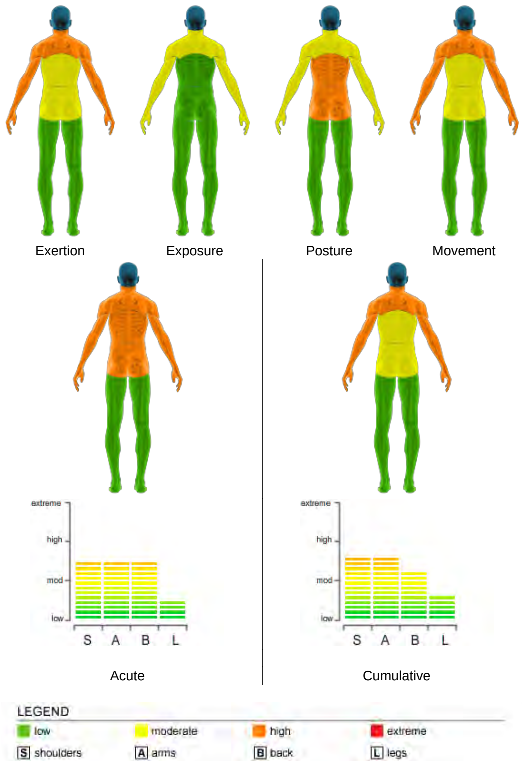
Risk Reductions

	Acute	Cumulative
Shoulders :	25%	11%
Arms :	50%	11%
Back :	50%	38%
Legs :	0%	0%

Jacking up heavy machinery to change tyres

Before - Heavy manual jack to lift the machinery

- Maintenance personnel used a very heavy and cumbersome trolley jack to raise heavy machinery to change tyres. This jack required a lot of effort to manoeuvre into place and considerable repetitive exertion through the upper limbs to jack it up. In addition, there was a 'line of fire' safety risk, because there was the potential for sudden recoil of the jack handle due to the significant stored kinetic energy.



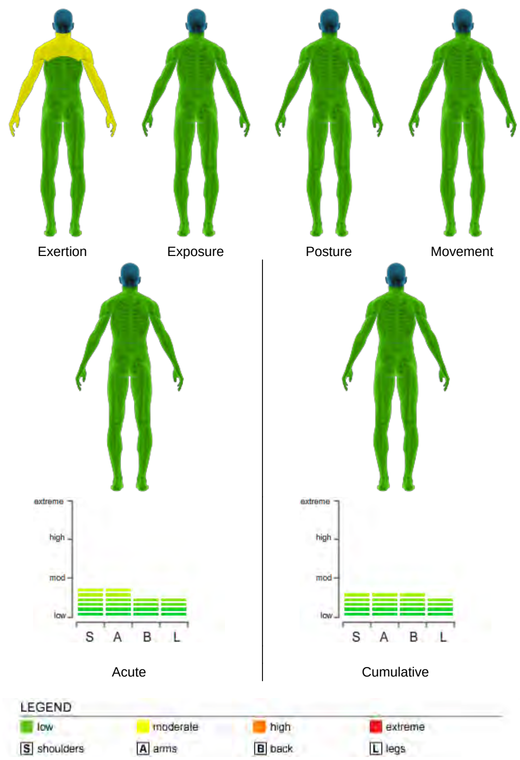
After - New hydraulic air power jack

- The injury risks have been significantly reduced by replacing the heavy trolley jack with a high torque hydraulic air powered jack. This new jack is much easier to manoeuvre, and lifts via an airline that is controlled via a turn dial (pictured). This improvement has minimised musculoskeletal injury risks and eliminated 'line of fire' safety concerns.

Dial to raise or lower

Risk Reductions

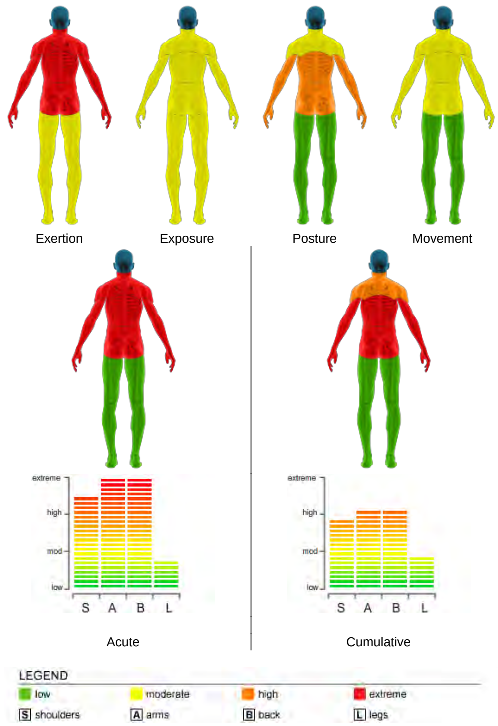
	Acute	Cumulative
Shoulders :	50%	54%
Arms :	50%	54%
Back :	67%	50%
Legs :	0%	0%



Replacing a Cat 785 Dump Truck Drive Shaft

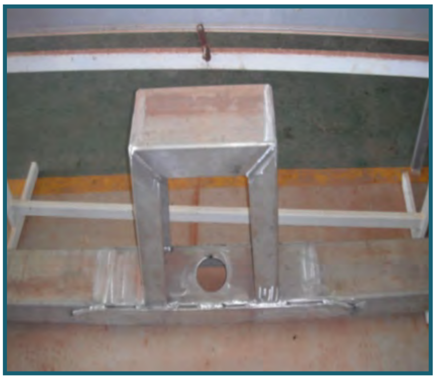
Before - Heavy manual effort to manoeuvre the heavy drive shaft

- Replacing a Cat 785 drive shaft was an extremely labour intensive process involving; a Franna crane, chain blocks, slings, pinch bars and considerable manual labour. The drive shaft itself weighs approximately 180kg. In order to complete the above task personnel are required to apply almost maximal exertion through the upper body often whilst in awkward postures (pictured).



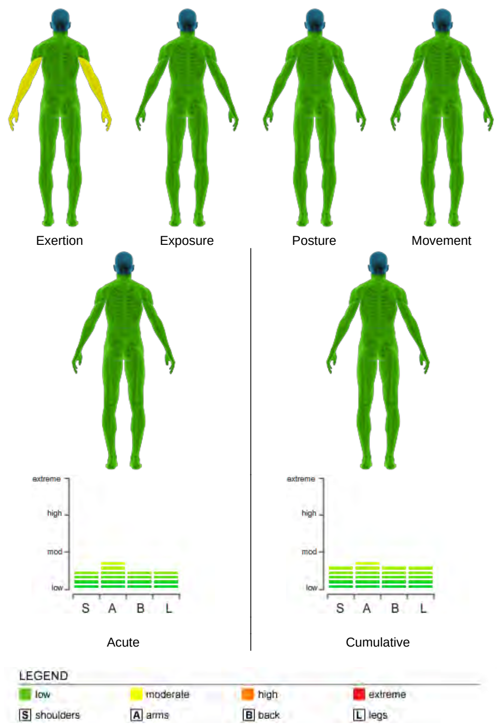
After - Customised support for the drive shaft

- A new innovation has been engineered that provides support to the drive shaft when replacing the universal joints (pictured). This in turn eliminates the need to suspend and support the drive shaft, therefore, only minimal muscular exertion from the upper body is now required to perform the task.
- Note: This innovation also saves approximately two hours from the job duration.



Risk Reductions

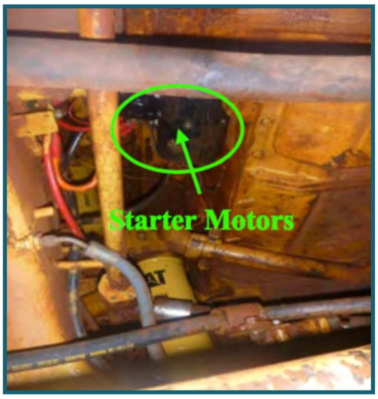
	Acute	Cumulative
Shoulders :	80%	67%
Arms :	75%	65%
Back :	83%	71%
Legs :	33%	29%



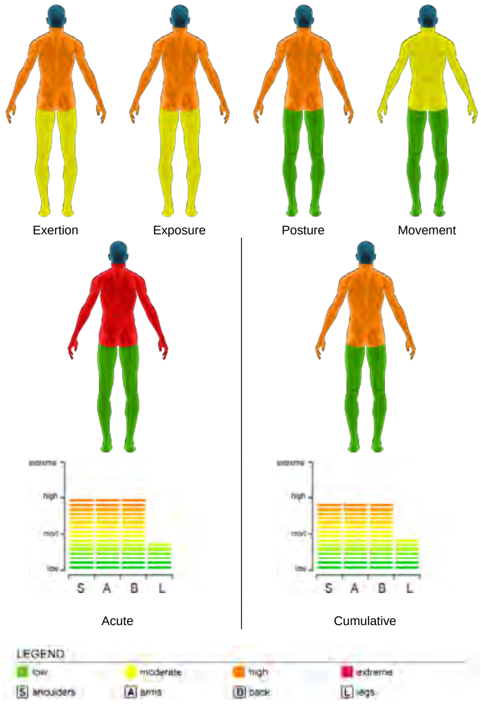
Replacing a Haul Truck Starter Motor

Before - Manual handling, ropes and cumalongs used

- The task of removing and replacing a starter motor was very labour intensive. It required personnel to get under a haul truck and reach up to a height of approximately 2 m to access the starter motor weighing over 20 kg. To help remove/replace this component personnel often used ropes and cumalongs. The task of removing starter motors (often two at a time) typically took 4 - 6 hours to complete. Heavy exertion combined with prolonged awkward postures resulted in an extreme injury risk to the upper body, and in addition there was also high risk of pinch point injuries.



Pinch Point



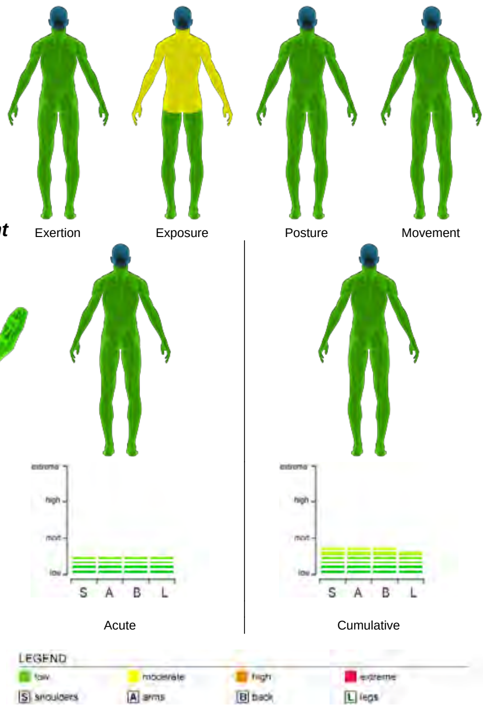
After - New custom-made starter motor cradle

- A purpose built starter motor cradle with an extendable pole has been built. The pole can be lowered and elevated by remote control using a 12 V power source. Once elevated into position the cradle sits directly under the starter motor. Personnel then attach the motor to the cradle and lower it down to the ground; and visa versa. The task now only takes about 2 hours to complete. The risk of pinch point injuries has also been significantly reduced.

Pinch Point

Risk Reductions

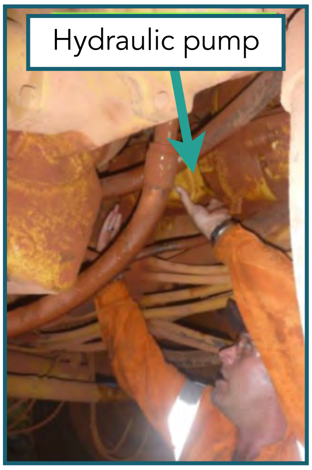
	Acute	Cumulative
Shoulders :	75%	60%
Arms :	75%	60%
Back :	75%	60%
Legs :	33%	29%



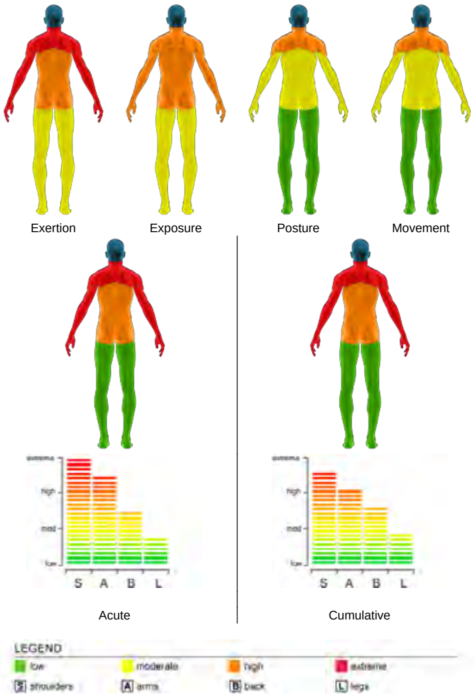
Replacing Hydraulic Steering Pumps on 776D Haul Trucks

Before - Overhead manual handling the heavy pump

- Diesel fitters are regularly required to replace hydraulic steering pumps weighing 50 kg on 776D haul trucks. To perform this task, personnel were required to crouch under the truck, reach above shoulder level, then use various tools to unbolt and dismantle the pump, which required excessive upper limb exertion. To make this job even more difficult personnel often had to manoeuvre various hydraulic hoses with one hand, and use the other hand to access the pump. A high risk of pinch points injuries was also present.



Pinch Point



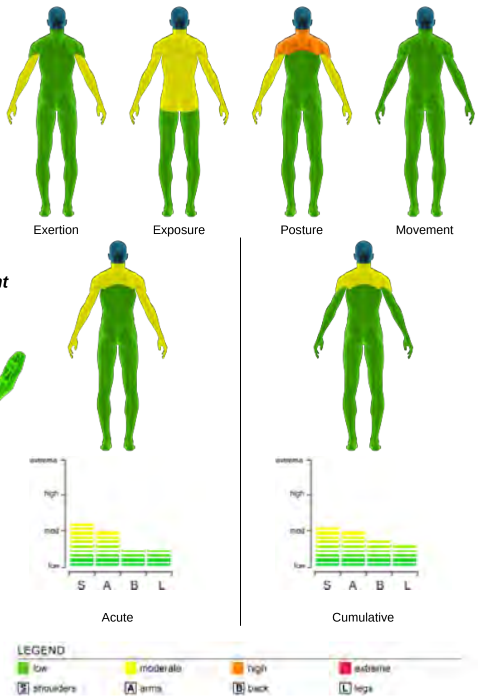
After - Pump support jack with mounting bracket

- A mounting base plate was fabricated that fitted to a jack (pictured). When a steering pump needs to be replaced, personnel position the jack under the truck, then use their foot to increase the desired height. Once the base plate is directly under the steering pump, it is bolted to the plate. The pump then is disconnected and the pump gently lowered to the ground via the jack (and visa versa when installing the new pump). This has significantly reduced the static exertion that was originally required by the shoulders and arms and also decreased the time required to changing the pump.

Risk Reductions

	Acute	Cumulative
Shoulders :	58%	57%
Arms :	60%	53%
Back :	67%	54%
Legs :	33%	29%

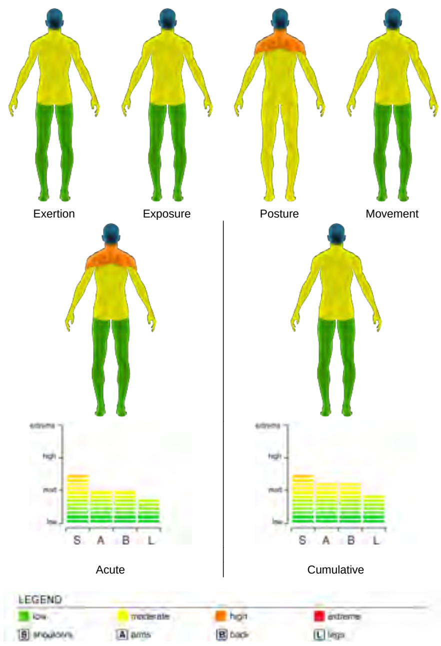
Pinch Point



Checking Truck Tyre Pressures

Before - Manually checking pressures

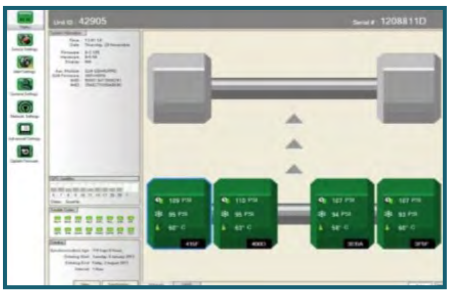
- Mine operators were routinely required to check tyre pressures on their trucks. This task was done during vehicle inspections and servicing. The task involved personnel attaching a tyre gauge to a valve located within the rim. Often this valve was located up high (dependent on wheel rotation), some operators would have to strain to reach up high. Other operators even reported climbing within the rim to take tyre pressures. Significant safety risk was also related to the possibility of tyre failure due to the enormous pressures in mine truck tyres.



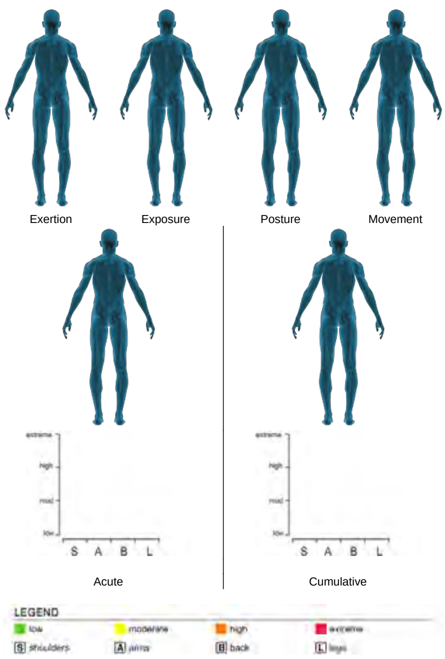
Pinch Point

After - Elimination: Remote tyre pressure sensor system

- This cumbersome manual handling task has now been completely eliminated. 'Tyre Sense' is a computerised system that transmits information (i.e. tyre pressure and temperature) wirelessly from the tyre to a Wenco box and can be viewed remotely on a computer screen (pictured). It is anticipated the whole fleet will be fitted out by March 2014. This innovation has eliminated both the musculoskeletal injury risk as well as the potential of serious injuries occurring as a result of tyre failure.



Pinch Point



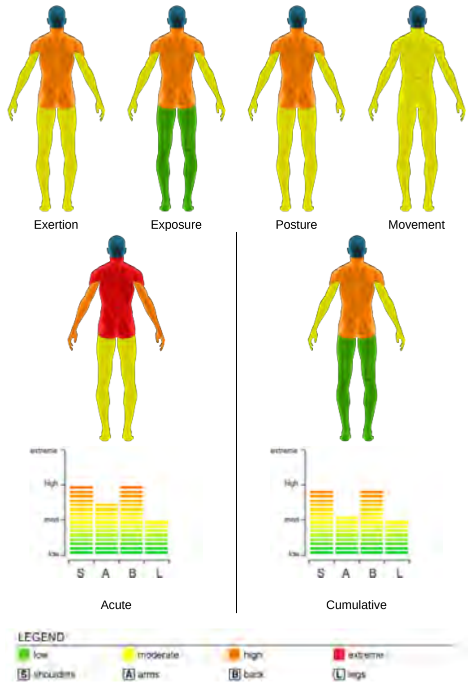
Risk Reductions

	Acute	Cumulative
Shoulders :	100%	100%
Arms :	100%	100%
Back :	100%	100%
Legs :	100%	100%

Removing Heavy Railway Undercarriage Packages

Before - Hydraulic jack with awkward access

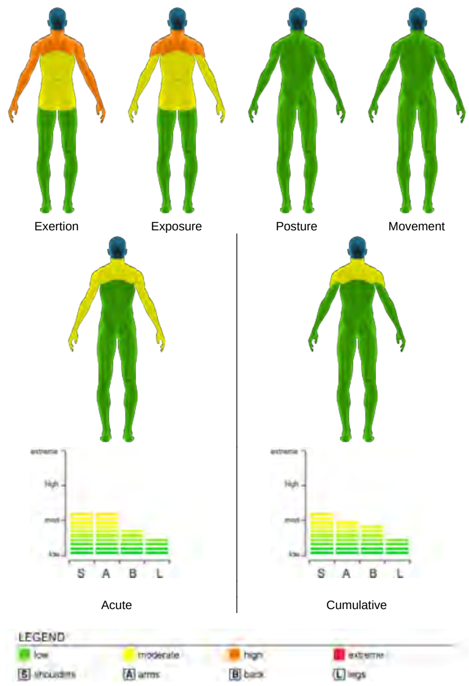
- Railway packages act as shock absorbers between wagons. Over time these packages get worn and need to be replaced, on average every 2 - 4 weeks. The task involved using a trolley that was wheeled along tracks with a hydraulic pump and a cradle centred in the middle. The pump was then lifted into position. Typically two people then proceeded to lever the package using long bars and sledge hammers. Each package weighed approximately 120 kg. As well as the awkward postures and heavy exertion to lean over the trolley and access the package, the trolley itself also posed a trip hazard and safety risk regarding the stability of the jack.



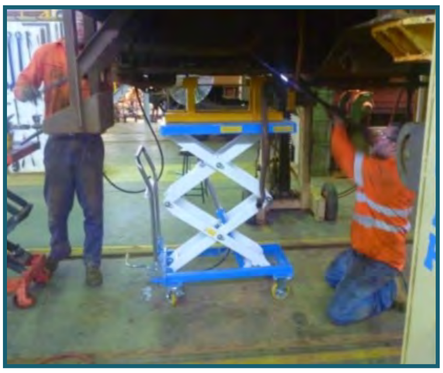
Pinch Point

After - New scissor lift and package frame

- A purpose built wheeled scissor lift has been sourced. This allows for precise positioning under the package so that personnel now have much better access to lever the package out, thereby avoiding awkward postures.
- A purpose built stand for greater package stability has also been fabricated with removable cross bars that allow better access to the package.



Pinch Point



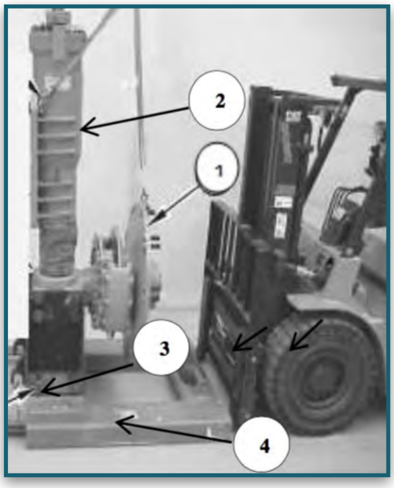
Risk Reductions

	Acute	Cumulative
Shoulders :	38%	33%
Arms :	17%	11%
Back :	63%	53%
Legs :	50%	50%

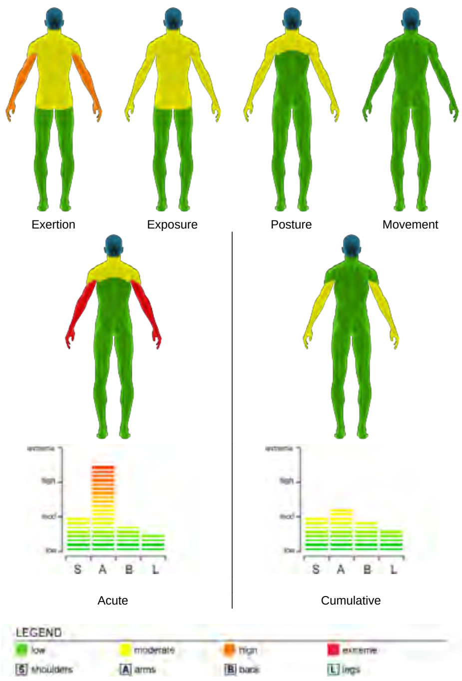
Adjusting Front Strut Jib for 776D & 777F Haul Trucks

Before - Manual pack of the front strut jib required

- Replacing front struts on 776D & 777F haul trucks is a time consuming and labour intensive process. On average this task occurs approximately 42 times per year. The spindle (1) & front strut (2) are mounted slightly off vertical, so when using the forklift jig (4) to remove this assembly it has been quite difficult. To compensate personnel were required to pack plates under one of the brackets (3) to compensate for the strut assembly angle. Despite the adjustment this still posed risks of hand crush injuries and line of fire issues if the packing was to dislodge due to unplanned movements as the assembly weighs almost 2 Tonne.



Pinch Point



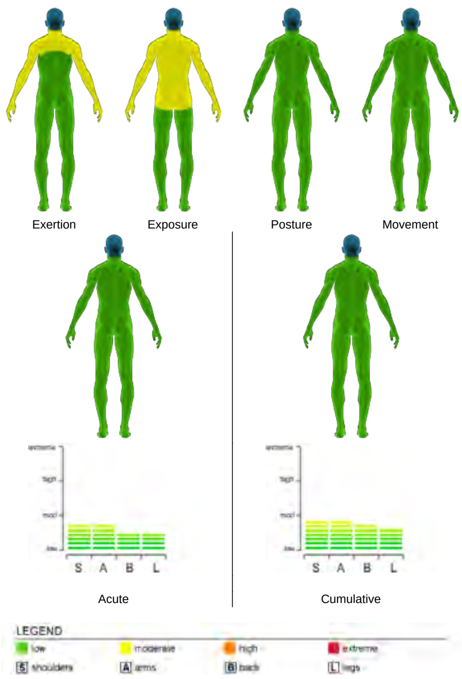
After - New adjustable front strut jib

- The front strut jib has now been modified so that it can precisely adjust to the desired assembly angle. Threaded adjustable rods have been fabricated into the front strut jib as circled. Therefore, when the forklift inserts it's tines into the jib, personnel simply use a rattle gun to screw the bolts down against the fork tines creating the desired angle that matches the front strut assembly. This improvement has eliminated the potential of hand crush injuries and line of fire injuries as no more packing is required.

Pinch Point

Risk Reductions

	Acute	Cumulative
Shoulders :	25%	13%
Arms :	70%	30%
Back :	33%	14%
Legs :	0%	0%

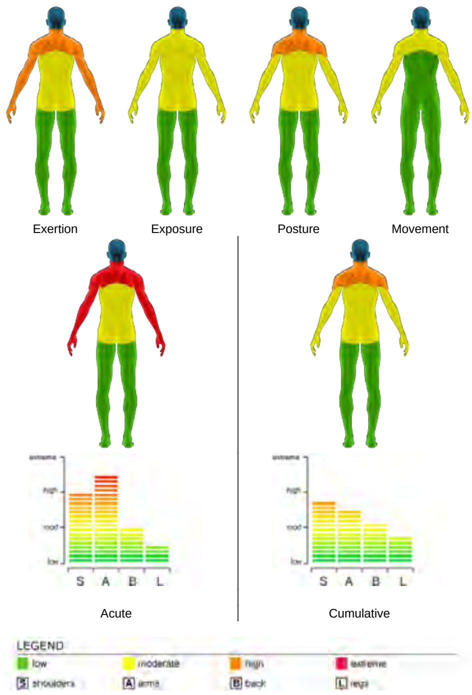


Removing a Tyre Locking Ring on Heavy Trucks

Before - Manually removing the ring with tyre levers

- Tyre fitters are routinely required to remove and fit tyre assemblies on heavy mobile equipment. One injury risk associated with this task was when removing a single piece locking ring that joins the tyre to the wheel. To remove this ring a single fitter manually used two levers (pictured) to remove the ring that on average weighs 43 kg. In addition to the musculoskeletal injury risks, there were also significant safety risks of a falling locking ring striking the fitter.

Pinch Point

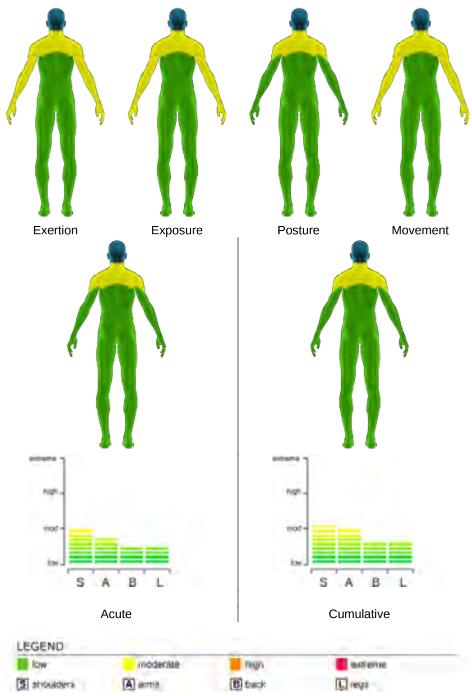


After - New adjustable ring locking tool

- A number of improvements have been made to this task, including:
  1. The implementation of a locking ring tool. Personnel now use an adjustable tool to lock onto the wheel assembly. The fitter then uses flat bar levers to remove the locking ring. Once the locking ring is dislodged it rests on the cradle (pictured).
  2. Two people are now required to use the locking ring tool to carefully lower the locking ring down.
  3. Mandatory bump or hard hats are to be worn.

Pinch Point

Ring locking tool



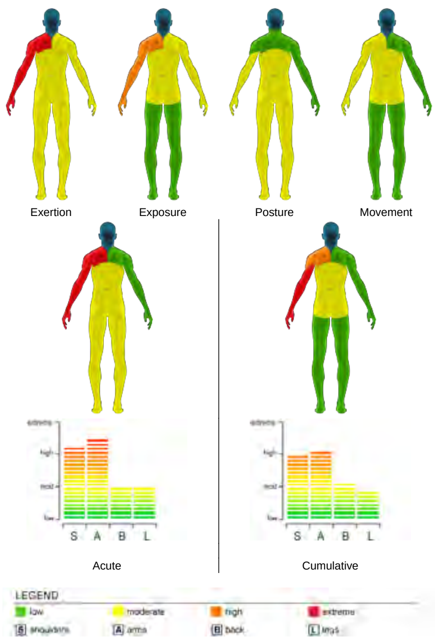
Risk Reductions

	Acute	Cumulative
Shoulders :	50%	36%
Arms :	70%	33%
Back :	50%	44%
Legs :	0%	17%

Cleaning Haul Truck Air Filters

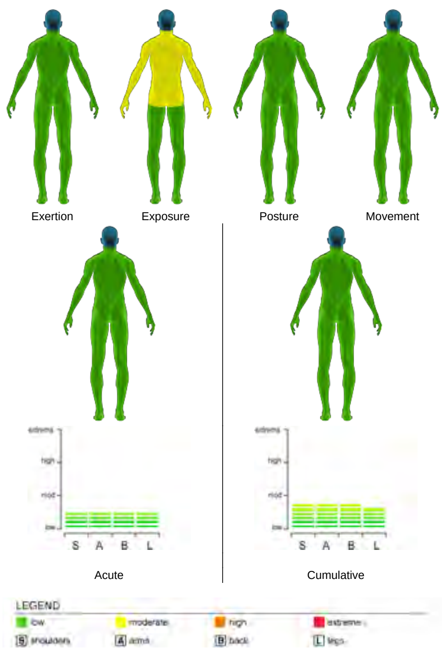
Before - Carrying filters up and down stairs to the high pressure air wand on the ground

- Truck air filters are typically cleaned every two days. The task involves climbing up the truck stairs and bending down to remove the air filter. Personnel then carry the filter weighing up to 30 kg down a flight of stairs with one arm. Once on the ground the serviceman uses a standard high pressure air wand to clean out the air filter. The person then carries the filter back up the stairs and repeats the process again. The filter needs to be cleaned on the ground because of the excess dust produced when using the standard air wand. Not only is there significant musculoskeletal injury risk, bust there is also significant risk of falling down the stairs.



After - New modified light weight air blower

- A modified light weight air filter blower (1 kg) with various nozzles has been introduced. The task now involves carrying the blower and air line up the stairs to blow out the dust from the air filters. The serviceman simply inserts the blower into the air filter and the dust falls out the bottom of the filter and through a grate (pictured), instead of spraying dust everywhere like the previous standard air wand. This blowdown activity is undertaken outside of the workshop.



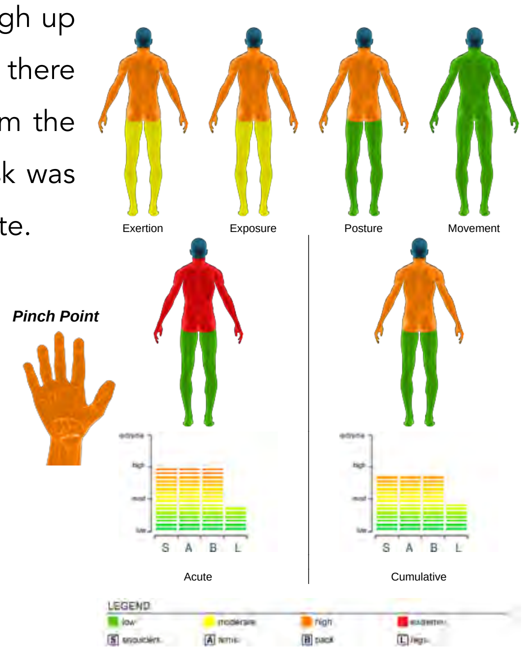
Risk Reductions

	Acute	Cumulative
Shoulders :	78%	63%
Arms :	80%	65%
Back :	50%	33%
Legs :	50%	29%

Changing Hydraulic Hoses on Haul Trucks

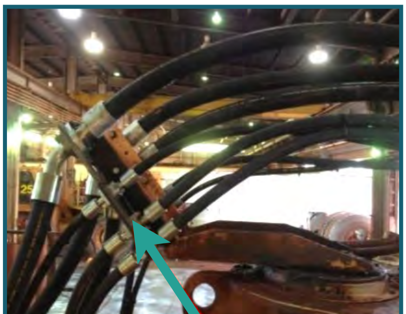
Before - Changing out awkward hydraulic hoses

- Bullhorn hydraulic hoses that supply grease, brake fluid, cooling and hydraulic fluids are present on all haul trucks. Each of these hoses (approx. 10 per truck) can weigh up to 27 kg and are about 5 metres in length. Not only where there significant injury risks when changing out a defective hose from the high exertion, awkward postures and pinch points, but the task was particularly time consuming and usually took 4 hours to complete.



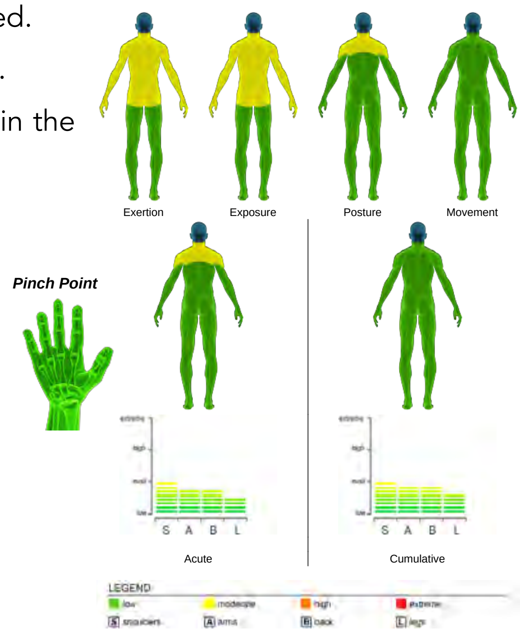
After - New bulkhead manifold reduced injury and improved productivity

- The installation of a bulkhead manifold has eliminated the rubbing of hoses around the clamp, leading to significantly less hose failures. Additionally, this manifold has also resulted in smaller components that need to be replaced rather than the whole hose, with both cost and injury reduction benefits. The length and weight of each hose section has also been halved.
- Clamps have been eliminated, removing pinch point injury risks.
- There has also been a productivity gain with a huge reduction in the the time to change a hose to only


New Bulkhead Manifold

Risk Reductions

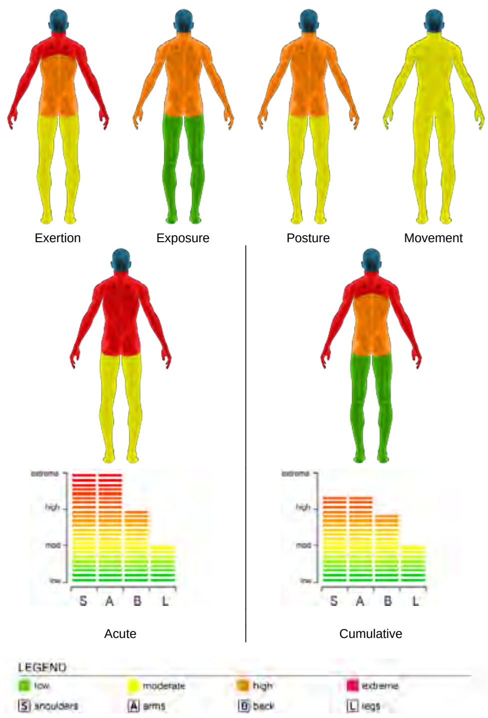
	Acute	Cumulative
Shoulders :	50%	43%
Arms :	63%	50%
Back :	63%	50%
Legs :	33%	29%



Changing Hydraulic Pumps on 777 Haul Trucks

Before - Manually handling heavy and awkward pump

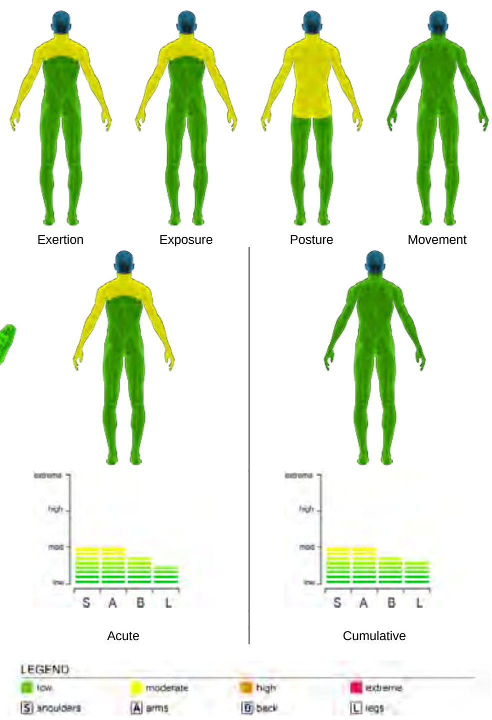
- Fitters are routinely required to access and replace main hydraulic pumps on haul trucks. This task was extremely labour intensive with awkward postures (pictured) often adopted for up to 3 hours and the pump weighing in excess of 180 kg. There was also a very high risk of pinch point crushing injuries to the hands and fingers.




Main hydraulic pump

After - New mounting bracket is used to manoeuvre the heavy pump

- A purpose built mounting bracket and linear guide has been fabricated (pictured). The task now involves a fitter chaining the pump to a linear bearing arrangement and then sliding the pump along a linear rail. The pump is removed via an overhead crane. This innovation has significantly reduced the exertion, awkward postures and pinch point injury risks.




New mounting bracket

Risk Reductions

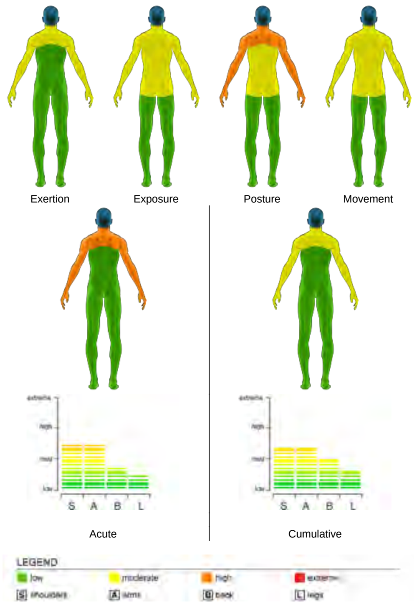
	Acute	Cumulative
Shoulders :	67%	58%
Arms :	67%	58%
Back :	63%	60%
Legs :	50%	38%

MAINTAINING 777 & 785 RADIATORS

Before - Radiator stand with trip hazards and awkward postures

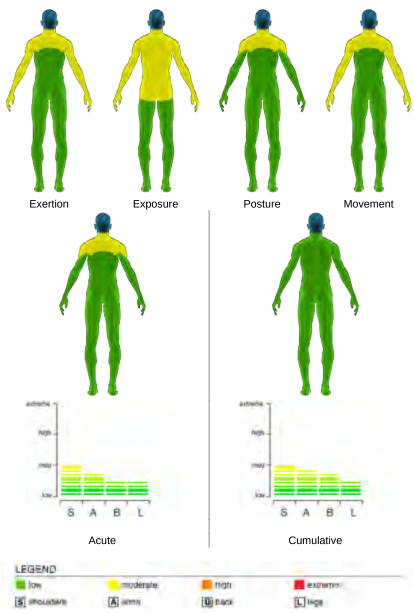
- Fitters are routinely required to repair and maintain HME radiators. The task involved having the radiators positioned on a secure stand (pictured). However a number of issues were identified:
- Trip hazards from protruding fork tine channels.
- Falls risk from safety step as limited and inadequate places to position steps.

- 3Radiators mounted in high stands caused instability when moving.
- Awkward neck and shoulder postures when reaching the top of the radiator.



After - Custom made radiator stand with better ergonomic design

- The above MHE concerns have been addressed by the fabrication of a purpose built radiator platform and frame. The improvements include:
  1. Removing trip hazards by taking away exposed steel sections and replacing with a non-slip checker plate deck.
  2. Removing falls risk due to inadequate safety step placement and over reaching.
  3. Radiators are mounted lower reducing strain on upper limbs.
  4. New stands are also multi-fit for both 777 & 785 radiators.



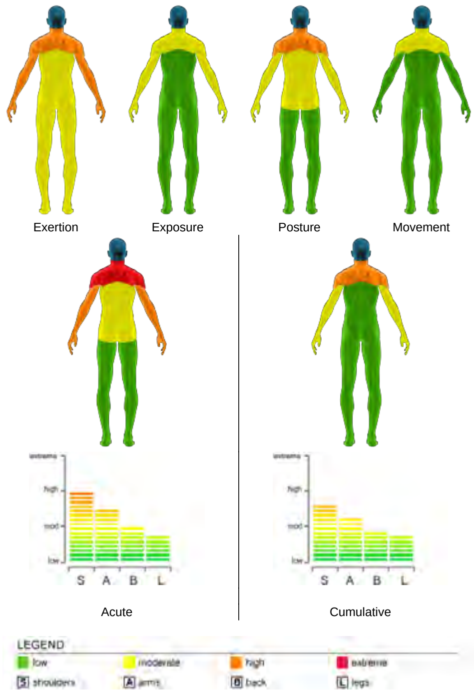
Risk Reductions

	Acute	Cumulative
Shoulders :	33%	27%
Arms :	50%	36%
Back :	33%	25%
Legs :	0%	20%

Removing Light Vehicle Undercarriage Bash Plates

Before - Two people required to handle the removable bash plate

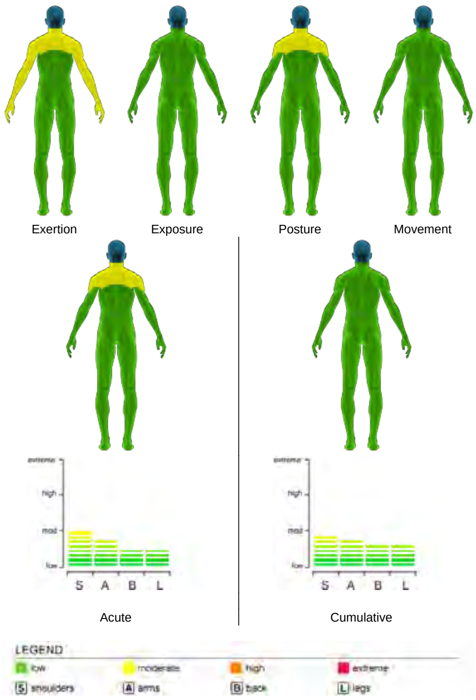
- Light vehicle (e.g. Hilux) undercarriage bash plates are routinely required to be removed by mechanics in order to complete a standard vehicle service. The bash plate itself weighs 10 kg, however, during the wet season this plate often gets filled with mud, often increasing the weight to over 20 kg. Removing the plate was very awkward requiring six bolts and two spacers to be removed by two people.
- Note : There was also a risk of pinch points injuries if bash plate suddenly dislodged.



Pinch Point

After - Hinge mounted bash plate

- Bash plates are now attached via hinges (as circled). This improvement has significantly reduced the weight when removing the plate. In addition, the bash plate can now be lowered in a controlled manner by one person, which has also significantly reduced the risk of pinch points and hand lacerations.



Pinch Point

Risk Reductions

	Acute	Cumulative
Shoulders :	50%	46%
Arms :	50%	40%
Back :	50%	29%
Legs :	33%	17%