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Special Issue - Mining Ergonomics

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Editor

Welcome to what I hope will be the first in a series of special issues of *Ergonomics Australia.* To set the scene, I've presented in the tables below compensation claims figures for Queensland Coal and Metal mines for five years (92/93 - 96/97). TLC >5 < 60 days includes claims for lost time of greater than 5 days, but less than 60 days. TLC >60 days/PPD/LSM includes claims for lost time of greater than 60 days, permanent disability, or lump sum payment. Hit object includes stationary, moving, falling objects, and between objects. While the limitations of compensation statistics are apparent, the tables also direct attention to manual handling; and the exchanges of energy which occur during falls, contact with objects, and vehicles.

Injury Mechanism x Claim Severity for 5 years (92/93 - 96/97)
Queensland Claims from Coal Mining Industry (ANZSIC 110)

Mechanism	TLC >5 < 60 days	TLC >60 days/PPD/LSM	Fatalities
Falls from height	111	14	0
Falls same level	260	22	0
Hit object	372	36	2
Noise	0	791	0
Manual Handling	644	91	0
Cave In	20	7	11
Vehicle	140	32	3
Other	307	66	0

Injury Mechanism x Claim Severity for 5 years (92/93 - 96/97)
Queensland Claims from Metal Ore Mining Industry (ANZSIC 131)

Mechanism	TLC >5 < 60 days	TLC >60 days/PPD/LSM	Fatalities
Falls from height	31	14	1
Falls same level	101	20	0
Hit object	31	0	0
Noise	0	336	0
Manual Handling	104	15	0
Vehicle	35	8	1
Other	38	9	1

One of the injury mechanisms which is not well captured by compensation statistics because of the cumulative nature of the resulting injuries is whole body vibration. The first paper in this special issue concerns current status of standards for assessing exposure to whole body vibration. Other papers in the series address the effects of heat stress in mining, access and egress, and a series of case studies regarding describing specific problems. Enjoy!

Robin Burgess-Limerick

Whole-Body Vibration Standards

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Whole-body vibration standards are presently in a state of change. It has been recognised that the current Australian Standard does not properly assess the risks of whole-body vibration especially if exposures include shocks or jolts and jars.

There is limited relevant scientific information on the effects of whole-body vibration on the human body. Most exposure studies relate to the z-axis and were conducted in laboratories. The contribution of vibration in the x- and y-axes to back pain and other symptoms is not known. Also, it is not possible at the moment to specify, with any precision, the type or probability of injury caused by vibration exposure. Some anecdotal and statistical evidence or biomechanical research indicates that jarring in vehicles is the direct precipitator of some vibration related back problems. However, none of the current standards addresses the effects of intermittent exposures to vibration or the influence of work breaks.

Australian Standard

The Australian Standard *AS 2670-1990, Evaluation of human exposure to whole-body vibration* duplicates the previous International Standard (ISO 2631-1985). It provides exposure limits for three criteria boundaries:

- *Reduced comfort boundary* - (comfort) applies mainly to vibration in transport and nearby machinery. The standard states...“In the transport industry, the reduced comfort boundary is related to difficulties of carrying out such operations as eating reading and writing”. This boundary may not be relevant to the mining industry.

- *Fatigue decreased proficiency boundary* - (fatigue) “The boundary specifies a limit beyond which exposure to vibration can be regarded as carrying a significant risk of impaired working efficiency in many kinds of tasks, particularly those in which time-dependent effects (“fatigue”) are known to worsen performance as, for example, in vehicle driving.”

- *Exposure boundary* - (health) - preservation of health and safety. “The exposure limit is set at approximately half the level considered to be the threshold of pain (or limit of voluntary tolerance) for healthy human subjects restrained to a vibrating seat”. These limits are based on laboratory studies on male subjects.

In practice, it is common to use the Fatigue Decreased Proficiency boundary as well as the Exposure boundary for guidance on worker exposure.

The Australian Standard describes two different ways to evaluate vibration exposure:

Third-octave method

This is the recommended method for assessing exposure limits for this Standard and the most commonly used. These limits are evaluated by comparing the unweighted third-octave spectrum levels with a set of criteria curves for each axis. The permissible exposure time is established from the highest third-octave band with respect to the various criteria curves. The criteria curves are drawn to give emphasis to those frequencies which are more damaging to the human body, ie z-axis (4-8 Hz), x and y axes (1-2 Hz). (Figure 1)

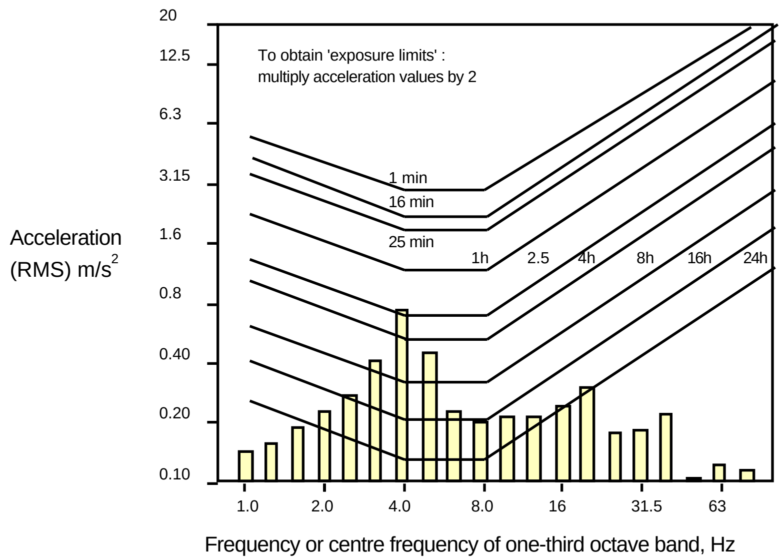
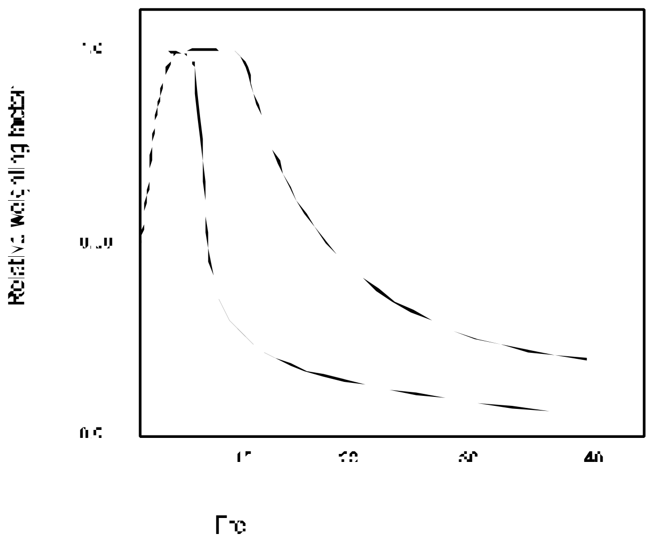


Figure 1. Australian Standard Vibration Time Limits for Z Axis: Fatigue-decreased deficiency boundary

Overall RMS method

The standard also prescribes another method of assessment when it is not possible to use the third octave method. The weighted, overall root mean square (RMS) may be used to assess comfort and performance but is not recommended for health and safety exposure criteria. The Australian Standard weighting curves are shown in Figure 2. However, the one-third-octave method is recommended as the method of choice.


Relative weighting factor
40

ISO standard. It has abandoned the third-octave band method and uses the *overall, weighted RMS* value to evaluate exposure. The frequency weighting emphasises the more damaging frequencies in a similar way to the Australian and British Standards. The standard is also similar to the British Standard in its use of the VDV for exposures that include shocks.

Often, it is only the z-axis (up and down) which dominates the vibration exposure. However, in cases where all axes contribute substantially, provision is made to combine these values to give the total vibration exposure value. This is necessary with bulldozer and loader rides resulting in higher exposures in these vehicles. This consistent with the vehicles' activity, particularly the loading (x-axis) and turning (y-axis) phases.

The new International Standard introduces a vibration dose value (VDV) for vibration exposures with crest factors above 9. Unfortunately, it does not clearly define recommended limits for VDV but suggests that they be used to compare rough rides.

The Standard uses a 'caution zone' for classifying vibration exposures that lie between specified limits depending on the exposure duration (Figure 3). Exposures above this caution zone are 'likely to cause injury'

Recommendations are based mainly on exposures in the range 4-8 hours. There is limited research evidence outside this range. The frequency weightings applied in the new International Standard to the vibration measurements in the z-axis differ slightly to those in the Australian and British Standards.

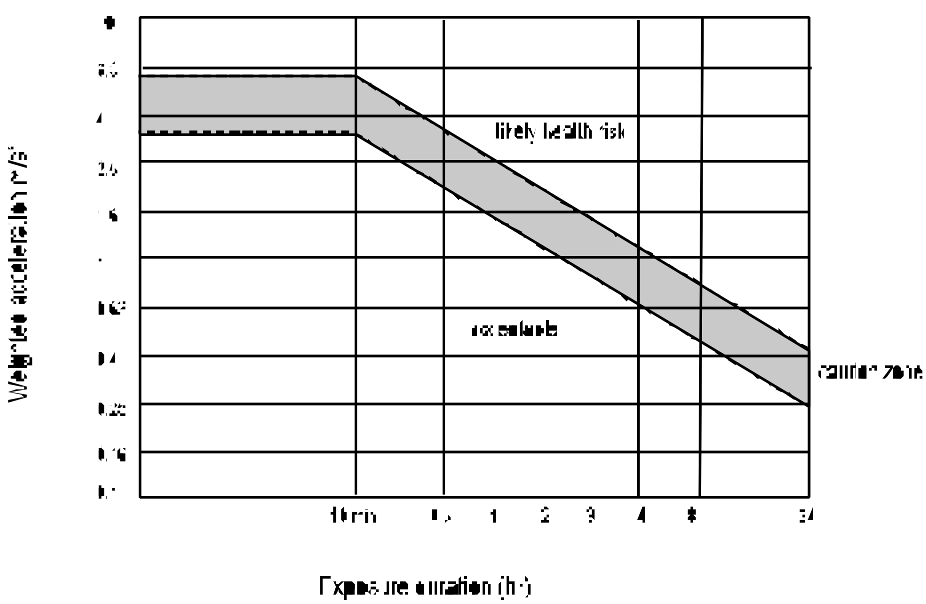


Figure 3. New International Standard (ISO 2631-1, 1997): Health guidance caution zones

The Ups and Downs of access to Heavy Vehicles in the Mining Industry

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Introduction

This article is based on my experience in a variety of open-cut mines in WA (coal, iron-ore, gold and bauxite) and deals with problems of access to pieces of heavy earth-moving machinery, such as haul trucks and dozers. I have only limited experience in underground mines but I suspect the problems are the same there. In general, manufacturers follow the traditional approach in which a vehicle or piece of machinery is designed to perform a particular range of functions and the operator is added on afterwards. This approach invariably compromises the operator's efficiency, comfort, health and safety, and is in contrast to the ergonomic approach where the vehicle is created around the capabilities and limitations of the operator. In recent years there have been some signs of progress in this respect, but much remains to be done. In particular, the trend towards 12 hour shifts in inappropriate industries, such as mining, makes attention to vehicle ergonomics even more essential.

To date, most attention in this area has been devoted to cab layout and instrumentation, and ride quality, but one feature that has been largely ignored is that of vehicle access. The basic problem is that many access systems demand of the driver a surprising degree of gymnastic ability and expose him (and sometimes her, because women do drive haul trucks) to the risk of slipping and falling from a height. That forgotten person, the maintenance worker, is often worse off than the driver as far as access goes, but space dictates that we leave him to his fate for the present.

Access system requirements
When boarding or descending from a vehicle the operator should be able to have three functional points of support on the system at all times, ie two feet and one hand, or two hands and one foot. This is basic ergonomics and it is good to see it included in AS3868 (*Earth-moving machinery - design guide for access systems*).

Common problems
The main problems relate to deficiencies in boarding ladders, namely:
1. Having the bottom step too high above the ground. AS3868 recommends 400mm, the record height I have come across is 1000mm, but I am sure others can beat this!
2. The lowest or two lowermost steps are flexibly mounted on steel cable (in order to reduce the risk of damage under rough use conditions). As soon as the operator puts his foot on the bottom step it swings away from him, thus placing extra strain on the arms and shoulders. This is particularly hard on the intrepid middle-aged ergonome burdened with a load of expensive vibration measuring equipment.
3. Boarding ladders are sometimes vertical (or almost so) and handrails are often too far apart, or in the wrong place.
4. The access path is sometimes skewed (due to vehicle construction constraints) and the positioning of steps and grab rails often puts the climber off balance - where there is only a single handhold it is easy for the operator's body to swing around the grip point, with the chance that he will lose his grip or footing.
5. Some of the steps or handrails may be covered in thick red mud, which compounds the above problems.

Other common problems relate to the lack of purpose built steps and handles, so that operators have to make use of tyres, tracks or other parts of the framework within reach. This is, of course, an ergonomic no-no but it's still awfully common. For example, to access the driver's cab on a large tracked bulldozer, the operator has to climb onto the draught arm near the blade, then up onto the track, make his way along the track and step

Operational constraints
Open-cut mines are harsh environments for plant and machinery, and place great demands on their structural integrity. For example, a shovel operator at a mine in the Pilbara tried to clear a rock jammed in the jaws of his shovel by bashing it against the tray of the waiting haul truck. This excited the driver greatly, alarmed his passenger (me), and didn't do the tray much good. It was also ineffective and a dozer had to be used to prise the rock free. The point is that what may appear to be a strong boarding ladder is, in fact, relatively flimsy and it won't be long before it is bent, b------d, or even knocked off (and I don't mean stolen). Thus, the flexible bottom step, even though it is difficult to climb, lasts a lot longer than a rigid one. Access systems thus require a degree of compromise between what is desirable and what is practicable in the mining environment, but at present the balance seems to lie too far in the direction of what is rugged and easy to install.

Some solutions
1. A simple improvement to a haul truck boarding ladder is to replace the steel cable holding the bottom steps with strips of old conveyor belt rubber - this makes the step firmer when the driver starts to climb but still provides side to side flexibility if hit by rocks etc. Even better is to......
2. Replace the bottom six or so steps of a rigid boarding ladder with a hydraulically operated section that can be swung up out of harms way when the vehicle is in motion. This needs to be linked to the vehicle's engine so that the driver cannot drive away with the ladder in the down position. It is an expensive solution (compared with an ordinary ladder) but is only a fraction of the cost of a haul truck. (see below)

3. Bulldozers present greater problems than haul trucks because they are generally used for ripping as well as pushing so that it is not practicable to construct a boarding system at the rear. However, improvements can be made by careful positioning of handles near the blade and along the engine cowling, and steps leading up to the cab. Hydraulic lifts have been fitted to some bulldozers, which swing the driver up from the ground and deposit him near the cab, but whether these devices are sufficiently rugged to withstand the stresses of normal use conditions is not yet clear. Good ergonomic (and engineering) advice is to keep things as simple as possible.

Conclusions

I have not attempted to deal with other items of plant common in many mining environments, such as scrapers and wheeled loaders, or specialised underground mining vehicles. Medium sized vehicles are often more difficult to rectify than large ones, because space considerations mean that alternative solutions are more difficult to implement. Much can be done by giving a bit more thought to the size, shape and strength of the users of the equipment, before the vehicle gets into the field and not afterwards. Obviously the very important areas of vibration, seating and posture, and instrumentation need continuing attention, but access does seem to be a neglected field. Perhaps there are some useful student projects here.

Ergonomics and Mining: Case Studies

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These case studies were originally compiled for a presentation given to the Mining Health and Safety Association of Ontario. The studies involved the Ontario Ministry of Labour (MOL) ergonomist in the Northern region. These studies were done at 3 different mining companies in Northern Ontario. In each case the rationale for the study, the assessment methods and recommendations and outcomes will be outlined.

SMELTER CRANES

Rationale and Assessment

A request was made for Ministry of Labour (MOL) ergonomics involvement by the Joint Health and Safety Committee due to a concern about the work postures and mental and visual demands for the crane operators in the converter aisle. A major contributor to this concern was the change from three to two crane operators per shift.

The re-allocation of work resulted in the operators having to spend more time in the crane cab. There was a concern about the effects of spending longer periods in the cab and having less break time.

The process of assessing the crane cabs consisted of an initial meeting with management and worker representatives, followed by two periods of cab assessment, one on day shift and one on afternoon shift. In addition to this, visits were made to other smelters to observe some of their cranes. Verbal and written information was also obtained from ergonomics staff at the DOFASCO steelmill as they have been involved with crane redesign for quite some time.

Although changes to work scheduling for the crane operators precipitated the current concern, assessment of the crane operator's task is complex. Visual and operational requirements and the lay-out of the interior of the cab, including windows, controls and seating, and work schedules all contribute to the physical and visual demands on the crane operators.

Postural Demands:
The position of the cab with respect to the bales, and the design of the window and floor required the crane operator to look over the lower edge of the window to see the work below. This requires the operator to bend forward at the waist and neck and shoulders, resulting in static loading.

The position of the hand and foot controls also affected the physical/postural demands on the operator. the controls were located 45 cm back from the window. If the operator has adjusted his chair as far forward as possible to minimize forward bending, he then must reach back slightly behind him in order to operate the controls. This again contributes to static loading. In addition, the controls required a reach up to 50 cm inches to the side of the operator. This also causes static loading and prohibits the operator from using arm rests to help support some of his body weight.

A major factor in ensuring proper working postures is the seating. The seating in this cab had been assessed a number of years earlier by a co-op kinesiology student and improvements had been made at that time. However, further possible improvements to seat suspension and ease of adjustment were identified during this visit.

Visual demands:
The crane operator's task is visually demanding due to the need for precise positioning of material, resulting in constant focusing and refocusing of the eyes, and the glare that is present due to the molten material in converters and ladles, as well as the presence of daylight through the upper roof vents at certain times of the day.

Recommendations and Outcome
A number of recommendations were provided to the workplace. These fell into two main categories:

* Modifications to the physical layout of the cab.

* Altering duration of exposure to the tasks through rest breaks or rotation.

The recommendations for physical changes to the cab ranged from major recommendations, such as re-orienting the position of the bales with respect to the cab to improve viewing positions, to less complex modifications to windows, seating and controls to improve visual and physical conditions.

The workplace initiated an engineering program to study the crane cabs. A group with management and worker representative has visited other companies to look at their cranes and gather information. Two options were considered: replacing the cab or making modifications within the existing cab. These would include changes to the window to allow more knee room and a better viewing position, alterations to control locations, and improved seating. A new cab was eventually purchased.

In addition to optimal scheduling of regular breaks when the operator leaves the cab, it was recommended that the operator take short breaks within the cab, and that exercises during these breaks be considered, to counterpart the effects of static postures. The company retained the services of a physiotherapy clinic to design such exercises. It was reported that the workers have been able to incorporate some of the exercises into their breaks that they are finding them helpful. The crane operators are also working on a flexible system for scheduling breaks to allow relief from task demands while maintaining operational effectiveness.

PERSONNEL BUSES:

Rationale and Assessment
A mining engineer requested assistance in assessing seating in personnnel. These buses were used to bring miners underground through a ramp system. The seating consisted of benches running the lengthwise along the bus. The miners found the seating highly uncomfortable due to a lack of knee clearance between the benches, and a lack of head room. Also the orientation of the seats resulted in the miners being tilted to one side when the bus is travelling up and down the ramps. This posture will result in the worker tending

to lean to the opposite side to maintain an upright head position. Static loading for the back and neck muscles will occur.

The company had a Kinesiology student on staff from the Co-operative Education program of the University of Waterloo so he was involved in the assessment as well. (The company has since hired a full time ergonomist). Seat dimensions and knee and head clearances were measured and input from the miners using the bus was also obtained. The student provided the main report. The Ministry of Labour ergonomist provided anthropometric information and seating guidelines to aid in planned modifications.

Recommendations and Outcome

Recommendations by the company kinesiology student and the Ministry of Labour ergonomist included re-orienting the seats to avoid the leaning posture due to the slope of the ramp, and allow for more knee and head room.

A follow-up visit was made by the Co-op student to evaluate modifications that were made to the buses. The seating orientation was changed to allow the passenger to face forward or backward, which eliminated the leaning posture. Positioning of the seats also allowed for sufficient knee clearance. The seat pan and back rest were angled back such that the worker was now sitting closer to the floor and about a 105o angle to the horizontal, both of which served to allow for more head clearance. Thus, the head clearance was improved without having to make more extensive modifications to the roof of the bus.

Recent informal discussions with the miners indicated that the changes were effective.

ROCKBREAKER CABS:

Rationale and Assessment

An assessment was done on the control cabs of rock breaker machines, at the request of an inspector with the MOL's Mining Health and Safety Program due to a worker complaint of back pain. The worker felt that the position of the seat with respect to the controls resulted in work postures that contributed to back pain.

The rockbreaker is operated on a 12 hour rotating shift basis by either a rockbreaker operator, or a cage tender who also operates the rockbreaker. The length of time spent on the rockbreakers were observed at the time of the visit. The assessment included measurement of the chair, controls/displays and cab, observations and body segment angle measurements of the working postures, and discussion with several operators.

It was found that the position of console with respect to the chair resulted in very little knee room for the operator. Although the seat was adjustable in a forward and back position, a lack of knee room limited how far the worker could move the seat forward. Therefore, in order to see the hammer, the worker was required to bend forward at the waist and at the neck. In this position, the muscles of the neck and back must be used to support the weight of the upper body and the head resulting in static loading.

The lack of knee room can also result in discomfort at the knee and hip due to the edge of the panel digging into the worker's knee, and the extreme angle at which the upper leg must be held, especially if the worker moves forward on the seat to try to get a better view. The leg angles were measured for one worker in his usual working position and found to be 60o from the straight forward direction for the right leg and 35o for the left leg, giving a total angle between the legs of 95o. In a normal comfortable sitting position, the total leg angle is about 10-20o.

In both cabs, the seat is off-set to one side to allow enough clearance for the operator to enter and exit the cab. In one cab, even though the console had been moved closer to the chair, it was still off-set to the left of the chair. This required that the worker reach across in front of him with his left hand as two hands are required to operate the controls. This reach in front also required static contraction by the muscles of the shoulder. Some of the muscles involved in maintaining this arm posture extend into the upper back area and, therefore, this posture could contribute to the pain and discomfort experienced in the upper back area.

During operation of one rockbreaker machine, it was observed that the worker would tend to lean to the right while operating the machine. The amount of this lean was measured at 10o. There were two reasons for this lean. The worker would tend to lean slightly to help him reach the controls which were shifted to the rights. Also, there was a monitor stand on a shelf located 115 cm above the floor. This is at about the operator's eye level. It was observed that an operator would tend to lean more to the side in order to look around the obstruction caused by the monitor shelf when watching the hammer working on the left hand side of the grizzly. This sideways or lateral bending created additional static loading of the muscles as the muscles must be contracted to hold the body in this position. This lean also would put some stress on the vertebrae of the spine.

Although the seats had been shifted in order to allow some space for entering and exiting the cab, the clearance is still limited. There was 30 cm between the back of the chair and the door. The recommended minimum clearance, based on worker anthropometry, is 33 cm. If the seat were to swivel, this would allow for additional clearance, however, a swivelmechanism might be difficult to implement on a chair of this type. The plan to make a larger cab to incorporate both workstations could have eliminated the need for any type of swivel if sufficient clearance is allowed.

Recommendations and Outcome

It was reported that there were ongoing plans for modifications to the rockbreakers. Some modifications had been made prior to the visit and additional changes, including incorporating the two rockbreaker stations into one large cab were planned. Below are some of the additional recommendations made:

* Modify the control layout for both rockbreaker control stations to minimize the requirement for the worker to bend forward and reach to one side.

* Ensure that the monitors and the supporting shelf do not block the operator's view of the grizzly and hammer.

* Ensure that there is sufficient space between the chairs and the door in the new cab.

* As an interim measure to reduce exposure of the operator to the work postures in the period before modifications to the cab, workers can try shifting from a sitting to a standing posture on a regular basis. Changes in posture are beneficial as they distribute task demands throughout the body, aid in blood flow and reduce static

loading. A standing posture would also allow a better view of the hammer and grizzly. If the workers were to try this and find it helpful, consideration should also be given to incorporating this into the new control design.

* Another interim strategy that can be used to reduce worker exposure to the work postures, is the rotation of workers from this task to other tasks. This is already being done on an informal basis by some operators, and should be continued.

The rockbreaker machine cabs have been modified. The two cabs have been combined into one cab with two control stations. By combining the cabs, sufficient space for clearance could be provided without having to fabricate two larger cabs. There may also be psychological and operational advantages to combining the two control cabs. When two workers are operating the rockbreakers they will be less isolated and communication will be far easier so that problem solving and trouble shooting can be done by both workers.

Other changes made include:

* Control console was modified to allow knee room beneath the console. It allows the worker to sit closer to controls and have a better view of the work area, reducing reaching and leaning.

* Seats were moved in-line with controls.

* Control console angled to improve control locations.

* More clearance between door and chairs.

* Fan installed to pressurize cab to keep out dust.

It was reported that the workers were satisfied with the changes and no further concerns have been raised.

UPDATE

These studies were done over a one year period in 1993/94. Since that time the use of ergonomics in Mining in Ontario has expanded. Further work has been done by MOL ergonomists in the northern and other regions regarding seating in vehicles used in both hard rock and gypsum mines, visibility in scooptrams and lighting. In addition to the applications described above ergonomics has been used by the MOL in accident investigations inquests, and before the Mining Legislative review Committee. Activity has also increased outside of the public sector, with ergonomists coming onstream in at least one major mining company and the associated Safe Workplace Association.

Ergonomics as Evidence: Applications of Ergonomics in Accident Investigations

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This case study describes the application of ergonomics knowledge to the investigation of several fatalities and the specific effects of that knowledge on the outcome of the investigations. Anthropometry, workspace design, and lighting/visibility were the focus in three investigations. In two cases related to underground locomotives in mining, the results included a guilty plea for a prosecution, coroners recommendations, and consideration of ergonomics in future locomotive design. In a case in the forestry sector, where operator error appeared to be the overriding factor at the outset, lighting and visibility were found to have played a large role.

1. Introduction

One of the roles of the Ergonomics Consultants at the Ministry of Labour is to provide ergonomics expertise to Occupational Health and Safety Officers in the investigation of complaints, work refusals, and critical and fatal accidents. In the period from 1992 to 1996, the MOL Ergonomics Consultant responsible for the Northern Region was involved in the investigation of six fatalities and one critical injury, in the Mining and Forestry Sectors. Anthropometry, workspace design, and lighting/visibility were the focus in three investigations. This case study will describe these three investigations in terms of the aspect of ergonomics that was applied and the effect of that application on the outcome of the investigation.

2. Areas of Application

2.1 *Anthropometry*

2.1.1 *Investigation:* The operator of an underground locomotive used in mining struck his head on an overhead chute and was fatally injured. He was attempting to re-rail a derailed train car when the train moved backward suddenly. The company was prosecuted under a section of the Mining Regulation that requires sufficient overhead clearance for a seat locomotive operator.

During preparation for the trial, the Ergonomics Consultant was requested to provide information regarding the clearance required. A review of design guidelines (SAE, 1987; Eastman Kodak, 1983) indicated that at least the 95'th percentile of the population should be accommodated. Anthropometric data (Jette, 1983; SAE, 1983) were used to determine the seated height. Required clearance for hard hats (CSA, 1987) and for jolting during vehicle operation (Applied Ergonomics Handbook, 1974) were also considered. When these were added to the seated height the required clearance was 1.8 m. The existing clearance was 1.56 m. Thus it was determined that the clearance was inadequate.

2.1.2 *Outcome:* When the report specifying the required clearance was provided to the company, they opted to plead guilty. They were assessed a $25,000 fine, the maximum under the Occupational Health and Safety Act at the time. In addition, a trial, with its attendant costs, was avoided. The coroner's jury at a subsequent inquest, recommended modifications to avoid the extension of chutes into the passageway.

2.2 *Workspace and Seating*

2.2.1 *Investigation:* In another mine, a locomotive operator was thrown from his cab and crushed between the locomotive and the rock wall when his train derailed due to an uneven section of track. The cabs on underground locomotives are open at the top. Although the rail condition was the main focus of the investigation, a request was made for an assessment of the layout of the cab to determine if it contributed to the operator being ejected.

The operators of this type of locomotive tend to work in a standing position, though there was a wooden seat in the cab. There were several reasons for this. The driver stands to see over the top of the cars in front of him. In addition, the required horizontal range of view was measured to be 165. This required a rotation of the head and trunk if the operator was seated, so the operators would stand to better position themselves. Lastly, the seat was 28 cm wide while the 95'th percentile value for male hip breadth is 41 cm (SAE, 1983). It was reported that the width of the seat combined with the wooden surface made the seat uncomfortable to use for any length of time.

Some locomotive cabs have a flip down seat that allows to driver to stand c cab was fixed in position and was located close to the control box which limited where the operator could stand. It resulted in him standing closer to open doorway of the cab. It was determined, therefore, that the layout of the cab and the position and construction of the seat increased the risk of the operator being ejected in two ways: the worker tended to stand, and he was located closer to the opening of the cab.

2.2.1 *Outcome:* The ergonomics report discussed the potential for seated operation, moving the operator away from the opening, and guarding of the opening. The report was submitted as evidence in a inquest, but the Ergonomics Consultant did not testify. The issues of seating and layout were not addressed in the jury's recommendations, but, guarding of the opening was recommended. Information from this investigation and the first one described were used by an occupational physician at another mine when developing a rationale for an ergonomics evaluation of new locomotives being considered for purchase.

2.3 *Lighting and Visibility*

2.3.1 *Investigation:* A mechanic working at a repair station for forestry vehicles was struck by a skidder that was backing up to pick up a tire. The skidder had been modified to act as a service vehicle. A box and hoist had been added. A request for a visibility survey was made to determine the extent of vision obstruction to the rear of the vehicle. The survey was carried out according to a protocol developed by MOL Mining Program staff to evaluate the field of view in underground mining equipment. Measurements were taken to map the contour of the blind zone as projected from the drivers position to horizontal ground level. In addition, the point at which a crouched person could be seen was determined, as the mechanic was crouched beside the tire fastening a chain prior to being struck.

The blind zone contour indicated that the worker would not have been in view as the skidder was backing up. However, the skidder fid direction. The driver claimed he did not see the worker who, according to witnesses, was beside the tire at that time. The accident had occurred in the evening and the area was illuminated by lights in a repair tent and on the skidder. Therefore, a lighting survey was also requested to determine if lighting or glare were factors.

A Hagner Universal Photometer, Model S2, capable of measuring both illumination, and luminance (brightness) was used for the survey. The luminance measurements from the lights within the driver's field of view as he approached the tire indicated that glare was not a factor. Lights with a luminance of less than 3000 candela/m^2 are considered acceptable (CIE, 1979).

The luminance measurements were also used to determine the visibility of a person, dressed and positioned in a similar manner as the accident victim. In order to be visible, an object must differ in luminance or colour from its background (ANSI/IES, 1984). The luminance measurements and direct observation indicated that there was enough contrast to see a person against the snow. However, due to the position and distribution of the lighting in the area, both the person and tire showed up as silhouettes, with no colour and with the same luminance values, even when lit by the skidder lights. Therefore, there was no colour or brightness contrast and the driver may not have been able to see the worker crouched beside the tire.

2.3.2 *Outcome:* The investigation determined that light distribution, the clothing worn, and the obstructions to the rear view may have contributed to the accident. The failure of the driver to see the mechanic was likely due to these factors. There was no inquest into the fatality, but these findings were included in the inspector's report and may have provided some reassurance to the driver of the skidder.

3.0 Conclusion

This case study provides examples of how various areas of ergonomics knowledge can be applied to accident investigation. The material referenced with respect to these three cases indicates that there is human factors/ergonomics information that can be used to aid investigations. There is room for improvement to the investigations however. For example, there is a draft standard (ISO, 1991) on visibility from vehicles describing a measurement protocol that should be considered as it may easier to conduct and evaluate. It uses a light source at the operator's eye position and maps the shadowing due to obstructions. Also, applying a systematic approach to ergonomics investigations, using current accident causation theories to determine root causes related to human factors/ergonomics, would be helpful.

With the exception of lighting surveys which have been carried out in mining accident investigations for some time, ergonomics has not been regularly applied in MOL accident investigations. This paper has illustrated some positive outcomes which can serve as a rationale for expanded and improved application of ergonomics to accident investigations, and recommendations for preventative measures.

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Heat Stress in Mining

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ABSTRACT

Heat stress in the mining industry has been a cause for concern for most of this century. Many of the issues affecting work in hot environments which were first addressed in South Africa in the 1920's are still unresolved. Much of the research has been prompted by the serious and sometimes fatal consequences of heat stroke. Problems also exist with the less serious heat disorders, as these can have a deleterious effect on productivity. There are many techniques for measuring heat stress as each climatic condition needs to be assessed and monitored in the manner which best describes the hot working conditions. The identification of heat tolerant individuals is important in maintaining a healthy workforce and acclimatisation has long been used as a method of assisting the body to cope with heat stress. The type of clothing worn is an important factor in controlling heat exposure. This fact applies particularly to the members of mines rescue teams. In order to successfully control heat stress mining companies must develop overall heat stress management plans designed to control the specific conditions present at the mine site.

The complete text of this literature review is available in Ergonomics Australia On-Line: http://www.uq.edu.au/eaol/apr98/leveritt.pdf

One the same topic, a **Review of Literature on Cooling Garments** has been submitted by Dipak T Chauhan (dipak@laxman.demon.co.uk). The complete review is available in Ergonomics Australia On-Line (http://www.uq.edu.au/eaol/apr98/chauhan.pdf)