A HANDBOOK ON WHOLE-BODY VIBRATION EXPOSURE IN MINING

THE JOINT COAL BOARD HEALTH & SAFETY TRUST
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Acknowledgements

This Handbook is the result of research undertaken by the authors in the NSW coal industry from 1996 to 2000 with funding from the Joint Coal Board Health and Safety Trust (JCB H&ST) and Worksafe Australia. It is the synthesis of research findings as well as information and ideas gleaned from the industry.

We are grateful for the support of a number of people including Ken Cram and Sharon Buckley of the JCB H&ST Secretariat and the Members of the Trust without whose patience and understanding this project would never have been finished.

We are particularly indebted to Jim Knowles for feedback on the text and Oliver Hetherington from Adgroup for his ideas and the design of the Handbook. Cheryl McDonald kindly provided some of the original photographs and Marissa O’Donnell provided the drawings.

Most importantly we would like to thank all those people from the NSW coal mining industry who arranged our site visits, who helped us gather data and information, who showed a genuine interest in the project and who gave us their ideas.

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July 2001
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Purpose of the Handbook

The nature of whole-body vibration (WBV), its sources and prevention are the subject of this Handbook. It aims to assist people in the mining industry to identify and manage the risks associated with vibration exposure. It is for use by people who have responsibility for occupational health and safety (OHS) in the workplace including managers, OHS personnel, engineers, purchasers of equipment, supervisors, operators and drivers, maintenance personnel as well as equipment designers, manufacturers and suppliers.

It is divided into sections with an accompanying checklist and other information to help readers identify, assess and control risks associated with exposure to WBV and to evaluate corrective action.

The Handbook is divided into five sections:

1. A description of WBV and its effects on humans
2. Identification of possible sources of WBV
3. Assessment and evaluation of WBV
4. Control of harmful vibration
   - Monitoring and evaluating solutions
5. Examples of problems
   - Check sheet of steps for reducing vibration exposure
   - Bibliography
Vibration and its effects

What is vibration?

Vibration refers to oscillatory motions of solid bodies. A simple vibrating system is represented by a weight suspended on a spring and set into an up and down motion. The vibrating weight is displaced above and below an average position.

Vibration can be:
- whole-body (WBV) - where the vibration is transmitted to the body as a whole by its supporting surface (i.e. seat or floor);
- segmental - where the vibration is transmitted to a specific segment of the body such as the hand/arm or foot/leg.

Vibration arises from various mechanical sources with which humans have physical contact. Vibration energy can be passed on to operators from vehicles on rough roads; vibrating tools; vibrating machinery; or vibrating work platforms and may give rise to adverse health effects. It can be transmitted through the feet and legs, the hands and arms but most commonly through the buttocks while seated in a vehicle. The magnitude of the effect of vibration depends on the severity and length of exposures.

The vibration discussed in this Handbook is whole-body. This is commonly experienced in mining by drivers, operators and passengers in a variety of vehicles such as bulldozers, dump or haul trucks, graders loaders, personnel and equipment transport and load-haul-dump (LHD) machines used in surface and underground operations. Rides in most of these vehicles include jolts and jars as well as ‘steady state’ vibration. Vibrating tools such as chain saws and jackhammers can produce hand-arm vibration. It can cause a circulatory disorder of the hands known as vibration white finger (Raynaud’s Disease) particularly in colder climates. It has been well researched over many years and there is considerable information available but is not dealt with in this Handbook.

Possible health effects of vibration

The effects on humans of exposure to vibration at best may be discomfort and interference with activities; at worst may be injury or disease. Vibration is believed to cause a range of problems. These include:
- disorders of the joints and muscles and especially the spine (WBV);
- disorders of the circulation (hand-arm vibration);
- cardiovascular, respiratory, endocrine and metabolic changes (WBV);
- problems in the digestive system (WBV);
- reproductive damage in females (WBV);
- impairment of vision and/or balance (WBV);
- interference with activities;
- discomfort.
The most frequently reported problem from all sources of WBV is low-back pain arising from early degeneration of the lumbar system and herniated lumbar disc. Muscular fatigue and stiffness have also been reported. Some studies have associated the degeneration of the lumbar spine with intense long-term exposure to WBV. However, despite this, not a lot is known about the specific effects of exposure WBV on the bones, muscles and joints particularly the spine.

**Back pain and its causes at work**

In the developed world, work-related back disorders are the commonest causes of workers’ compensation claims, sick leave and early retirement. Back disorders are usually accompanied by back pain but no truly effective medical or surgical treatment exists for a large number of cases.

Back disorders are believed to arise from damage to the spine and surrounding structures brought about by an accumulation of strains placed on the back over time. Some heavy occupations such as mining have been associated with earlier, more frequent and more severe symptoms. These disorders are most commonly seen in middle aged and older people (more than 35 years old) although in mining it is not uncommon for workers in their twenties and early thirties to report back pain.

In some cases acute injuries, resulting from trauma such as a car accident, lead to symptoms in people without previous back pain. The one-off severe jolt in a vehicle can be sufficient to do permanent damage to an otherwise good back (see Case Study 1 - Section 2).

However, in most people the damage is cumulative and the precipitating event is unlikely to be the only ‘cause’ of the disorder - it is simply ‘the last straw’ (see Case study 2 - Section 2). Once a person experiences back pain he/she tends to become more sensitive to aggravating factors and is likely to have recurrent problems.

A number of different work-related and individual factors are considered to be risk factors for back disorders but there is no clear understanding of the relative contribution of these. As well there is no general explanation of how back disorders occur, that is, what actually goes wrong in the back which gives rise to symptoms. However, studies indicate that some components of work increase the risk of back disorders and pain. These are:

- heavy physical work;
- fixed (static) work postures;
- sedentary (sitting) work;
- frequent bending and twisting of the trunk;
- lifting and forceful movements;
- increased speed of movements;
- repetitive work;
- vibration.
There has been considerable research carried out in the areas of physical loads and postures and their relationship to back pain but much less is known about the effects on the musculoskeletal system (bones, joints, tendons and muscles) of exposure to WBV.

**Back pain and exposure to vibration in mining**

Mineworkers are exposed to WBV through a number of transport and other mining equipment. For many the immediate effects are no more than discomfort or fatigue. However, increasingly, ‘rough rides’ in a range of vehicles are being reported as the source or aggravation of injuries. The term ‘rough rides’ usually refers to jolting and jarring which occurs while a vehicle is in motion. They are experienced by passengers and drivers alike in both underground and open cut coal mining and are believed to be the main element of vibration responsible for the development of back and neck disorders in mining personnel.

In 1990 analysis of NSW Joint Coal Board figures indicated that jarring and shock were responsible for up to 30% of all back injuries in open-cut mines some of which were severe. As well a number of workers’ compensation claims have been made for back and neck injuries over the last 20 years some of which may have arisen from long-term exposures to rough rides. In 1989 a Canadian study of underground load-haul-dump vehicles (LHDs), found that 20 of 22 tested vehicles exceeded the old International Standard six-hour limit in the z-axis (vertical direction through the body).

In a recent study in NSW coal mines the authors found that some vehicles were unacceptable when assessed for an eight-hour day against the current Australian Standard and many more were unacceptable using the newer International Standard. The study also revealed that back and neck pain are very common in mine workers with nearly 80% reporting back pain within the previous year. However, as there are several major factors that can give rise to these disorders in mining we cannot be precise about the exact contribution of WBV.

There is still much to be learned about the effects of WBV and the current exposure criteria proposed in the recent International Standard (1997) are evolving. Further research is needed, especially in real work situations, to determine workers’ WBV exposures and their effects. Mining personnel undertake work that includes all the factors that are believed to cause back pain (listed on Page 7). Decreasing exposure to any of these should reduce the risks of injury in the short and long term. This Handbook provides information that could be helpful in identifying and controlling harmful vibration exposures.
Effective management of whole-body vibration

Like other hazards at work vibration needs to be identified as a problem and controlled. The approach most usually taken is one of risk management.
Risk Management involves:
- identifying vibration hazards that might exist;
- assessing these to decide if they constitute a risk to health and safety of employees;
- controlling those factors that do pose a risk;
- monitoring and evaluating controls/solutions.
Controls or solutions are usually a combination of measures that reduce the risks to an acceptable level. Rarely is there a one-off ‘quick fix’. It requires a mix of design as well as administrative measures and regular monitoring to ensure that the original risks have been controlled and no new risks have been introduced.

The Risk Management Process

[Diagram of the Risk Management Process]
Identification of vibration hazards

The process of Hazard Identification

The first step in controlling vibration hazards is to identify which activities and vehicles might need further investigation.

- Where might people be exposed to vibration?
- Which vehicles or activities are associated with complaints, incidents, injuries or other losses?
- How often do these problems occur?
- How severe are the problems?

The following sources of information could be used:

- consultation with employees such as formal supervisor/safety representative reporting, informal discussions with employees who ride in, drive or operate vehicles, questionnaires;
- direct observation of the workers, tasks and activities, work area inspections, riding in and driving vehicles where permitted;
- statistics and injury records such as medical and health records, records of incidents and accidents, Workers' Compensation records and reports by supervisors/team leaders and employees. However, while these data provide a list of past risks and precipitating events they may not be a true indication of the hazards that currently exist.

In order to identify possible sources of harmful vibration exposure the following information may be useful when observing tasks and talking to workers.

Sources of whole-body vibration in mining vehicles and machines

There are three main sources of harmful vibration in vehicles and machines:

- rough road and poor work surface condition;
- vehicle activity - e.g. ripping versus pushing material in a dozer;
- engine vibration to a lesser extent.

WBV can be transmitted to the driver or operator from a vehicle or machine through the seat and into the driver's body via the legs, buttocks and back. There are many factors that can either increase or decrease the exposure for the driver. These include:

- road construction and maintenance (grading etc);
- vehicle type and design;
- age and condition of the vehicle;
- maintenance of vehicle suspension systems;
- seat design, suspension and maintenance;
- cab layout, design and orientation;
- vehicle or machine speed, driver skills and awareness;
- lighting and visibility;
- task design and work organisation.
Theoretically the best way to reduce most vibration is to control it at source by making all roads and work surfaces smoother. While this should be a goal to aim for, the work carried out by bulldozers, loaders, load-haul-dump machines (LHDs) and face vehicles is, by its nature, rough and may be independent of road or surface conditions. Therefore other factors (modifiers) such as vehicle design and suspension become increasingly important. A combination of these modifying factors is needed to reduce vibration exposures effectively. (Figure 1)

**Vibration sources:**
- Rough roads
- Vehicle activity
- Engine vibration

**Modifying factors:**
- Condition of roads and work surfaces
- Vehicle activity
- Type and design of vehicle
- Vehicle age and condition, suspension and maintenance
- Seat design, suspension and maintenance
- Cab layout, design and orientation
- Vehicle/Machine speed, driver skills and awareness
- Lighting and visibility
- Task design and work organisation

**FIGURE 1:** Vibration exposure modifiers

A combination of modifying factors is needed to reduce vibration exposures effectively.
1. Roads and work surfaces

Poor roads and uneven work areas contribute significantly to rough rides and discomfort but they are not the only cause of acute injuries. A good road with a single, unexpected pothole can cause severe neck and back injuries in passengers if the vehicle is travelling at speed. On the other hand a poor travelling road can slow personnel transport and production and may cause long-term damage to drivers and passengers.

The administrative problems of maintaining roads in a satisfactory condition are common to all mines. However, road maintenance is not always given the same priority and attention as production.

Principal problems with roads or work surfaces
- Rough work areas such as those that are being cleaned up by a bulldozer or an LHD
- Secondary roads that are not maintained to the standard of the main travelling roads but which are used by vehicles such as LHDs underground and fitters’ vehicles in open-cuts
- Excessive water leading to rapid deterioration of road surfaces
- Poor road building and/or maintenance programs
- Unexpected potholes, soft spots or mud in otherwise good roads
- Poor road conditions that are not reported and corrected quickly

A 4WD personnel carrier was travelling out of an underground coal mine at the end of a shift. There was a driver and a passenger in the front and two passengers (a deputy and an operator) were sitting sideways (troop carrier style) directly behind the driver in the back.

The vehicle was going at about 30kph and hit an unexpected rut in the road. The passengers in the back hit the roof and were thrown onto the floor. Neither reported any injuries immediately after the event but several days later both were unable to work because of back pain. After five months neither was back at work doing normal duties.

These injuries occurred when riding in one of the better vehicles used underground. The major elements of the problems were the speed (probably average for a ride out), a deep and unexpected rut and the rougher ride in the back of the vehicle for the two passengers who had had no warning of the rut.

Another important factor is that the driver has little indication of the roughness of the ride for the passengers, who may be sitting sideways and unable to brace themselves.
2. Vehicle activity

The vehicle activity and heavy work undertaken by the machine can have a major effect on vibration exposure for operators. This usually applies to vehicles such as bulldozers and LHDs. For example in open-cut mines ripping coal in a bulldozer can create much higher vibration levels than pushing coal. In underground mines LHDs are used for a range of work some of which exposes personnel to much rougher rides such as mucking out, transporting loads and scaling the roof.

Principal problems with work activities

- Type of load e.g. full or empty; density and weight of the load such as coal or overburden particularly when it influences what roads are used
- Type of activity e.g. ramp making, carrying very heavy loads such as ballast which causes rocking, travelling long distances when loaded or empty
- Activity of vehicle leading to predominant movement forward (x axis) or sideways (y axis) e.g. rubber-tyred dozers, loaders, LHDs mucking out or scaling the roof
- Slewing sideways when travelling or working
- Ripping un-shot partings or hard coal in a track dozer

A bulldozer operator in an open-cut coal mine was ripping a thin layer of hard partings between two thick seams of coal. He was an experienced, middle aged, operator with a history of back pain. His technique involved travelling back and forth over the ripped partings.

Ripping involves using a tine mounted on the rear of the dozer and the operator must twist in the seat to see what is happening behind the machine. In this case ripping continued over two 8-hour shifts with the regular crib breaks. However, due to production demands the operator worked non-stop for three and half hours on fairly rough ground on the third day. Each time he got off the machine he said he felt ‘wrecked’.

At the beginning of the fourth day he reported to the Health Centre complaining that he had had two sleepless nights due to back pain and that it was getting worse so that he felt that he could not continue to work. He was on alternative duties for a week. He likes working on the bulldozer but he can no longer undertake ripping because it always aggravates his back pain.

The major problems in this situation are the severity of the vibration caused from see-sawing over ripped rock and twisting in the seat to see behind the vehicle. Even when using good techniques ripping can precipitate or aggravate back pain in operators and may contribute to future back pain in non-sufferers.
3. Vehicle type and design

In the past, mining equipment has been selected for its suitability for the job, its cost, robustness, power and maintainability but not necessarily for driver comfort. Prolonged, intensive use of these machines may precipitate problems especially in older workers who have back or neck pain or other bone, muscle or joint (musculoskeletal) disorders. This is especially the case where WBV exposures are increased due to inadequate suspension.

Some vehicle types and makes such as bulldozers and LHDs do not have effective suspension systems. Unfortunately it is these that are often exposed to the roughest conditions.

Some underground transport vehicles have no suspension. Passengers are particularly vulnerable to unexpected jolts and jars because they cannot see the road ahead.

Stiff vehicle suspension designed for heavy loads will give a rough ride if used with light loads. Higher tyre pressures can lead to rougher rides and may not always be necessary.

**Principal problems with type and design of the vehicle**

- Unsprung vehicles can be extremely rough
- Underground transport vehicles without suspension can subject drivers and passengers to excessive and harmful vibration
- Unsprung transport vehicles are particularly hazardous for the passengers who cannot see the road ahead and cannot anticipate jolts and jars
- Using suspension designed for heavy loads with light loads
- Lack of visibility or the need to look backwards may increase discomfort and limit the benefits of a good seat
- In some underground machines the driver faces inwards and has to twist to see when travelling forwards or backwards
4. **Age, condition and maintenance of the vehicle**

Many older vehicles have little if any suspension and transmit most of the vibration from road surfaces through to the driver, operator or passenger. Sometimes poor suspension can exaggerate roughness especially if the machine bottoms out.

Most suspension systems can reduce damaging vibration but they deteriorate over time especially in a rough mining environment. For instance, in a recent survey of four-wheel drive personnel transport and maintenance vehicles it was found that vehicle suspension and therefore ride roughness deteriorated markedly after 40,000km. Older vehicles were much rougher than the newer vehicles in terms of their vibration dose values (Figure 2). However, one of the newer vehicles gave a ride that was as rough as the older vehicles due to its stiff suspension, which was intended for heavier loads.

Planned vehicle maintenance schedules may not include assessment and/or overhauls of the suspension systems early enough.

**Principal problems with the age and condition of the vehicle and maintenance of suspension systems**

- Inadequately maintained vehicles are rougher
- The rough conditions experienced at mines means that suspension systems are likely to deteriorate quickly
- Maintenance programs need to encompass frequent assessment and overhaul of suspension systems
- Older vehicles tend to be rougher than newer vehicles of the same make and model

**FIGURE 2:** Vehicle mileage versus ride roughness. Higher VDV means a rougher ride. See Section 3 for an explanation of Vibration Dose Value (VDV).
5. Seat design, suspension and maintenance

Much effort has gone into seat design and to reducing vibration exposure in open-cut mines by specialised seating manufacturers. However, complaints about seats are still common. This could be related to incorrect installation and adjustment; inadequate maintenance; poor design; or lack of adjustability for particular individuals especially those with back or neck pain. Sometimes there is inadequate space in the cab, which does not allow correct adjustment of the seat.

If visibility from the cab is restricted operators may not be able to use the seat and especially the backrest as recommended. This is a common problem in underground mining machinery and in surface equipment, such as in a grader, where the operator has to lean forward to see. In bulldozers the operator may need to twist in the seat to see backwards when ripping. In some underground vehicles the driver sits facing the centre of the machine and has to twist to see when driving forward or backwards.

In underground mines severe limitations in cab space often mean that no adjustment is available to the driver or operator. Design guidelines for underground mining vehicles in NSW (MDG1 - Design of Free-Steered Vehicles) specify minimum headroom in cabs of one metre measured from the seat pan to the interior roof of the cab. However, this is often not achievable due to the vehicles’ design or roof height limitations. Risks of neck and back injury for operators are increased significantly under these circumstances.

All conventional vehicle seats resonate in the vertical direction (z-axis) at around 4 Hz and, as a consequence, will amplify vibration at these frequencies. This amplification is significant because the human body is most sensitive to vibration in the range 4-8 Hz in the z-axis. Suspension seats can help but do not completely solve the problem. Seats can also amplify vibration in the x-axis (front to back) and the y-axis (side to side) as illustrated in Figure 3 which shows the transmissibility characteristics of a bulldozer seat. Vibration in the x and y-axes can be significant especially for vehicles operating on uneven terrain.

When seats are not maintained or replaced on a regular basis they can add to vibration problems because seats suspension systems deteriorate over time. Seats that bottom out or that cannot be adjusted adequately for all users may cause serious injury.

Passengers often sit sideways on bench seats in ‘troop carrier’ style transport vehicles. These seats do not provide sideways stability and are often poorly shaped and padded.
Principle problems of seat design, suspension and maintenance

- Vehicle seat design varies and some seats are better designed for the machine and tasks than others
- Many seats lack basic design features such as adequate lumbar support
- Poor cab design or orientation may eliminate or reduce the benefits of good seating
- Lack of visibility or the need to see backwards may limit the benefits of a good seat
- Many seats are not maintained to designers specifications and are not replaced regularly
- Poor seat maintenance can contribute to rougher rides
- ‘Troop carrier’ style personnel transport often has poorly designed bench seats with no lateral stability
6. Cab layout, design and orientation

Poor cab design may increase operators' discomfort and reduce the benefits of good seating and work breaks. In some vehicles the orientation of the cab may mean that operators have to twist to look sideways, to the rear or downwards to see where they are going or what they are doing. This accentuates discomfort arising from the low back or neck.

In many vehicles there is insufficient cab space to adjust the seat for taller drivers, while in some vehicles shorter operators cannot reach the pedals. If cab space is inadequate, or controls are in the wrong location, or if information displays are difficult to read operators/drivers may adopt awkward and potentially damaging postures. They may also be unable to make the best use of the seat.

These awkward postures, particularly if they are adopted repeatedly or over prolonged periods, can lead to back and neck pain and may increase operators' discomfort when working. Older workers are particularly affected under these conditions. It is difficult to separate these factors from the roughness of the ride as the cause of discomfort.

Principal problems of vehicle design and cab layout

- Poor cab design may force drivers into awkward postures, increase their discomfort and reduce the benefits of good seating
- Particular classes of vehicles, especially in underground mines, have inadequate cab space (particularly head and leg room) and layout of controls
- In some underground machines the driver faces inwards and has to twist to see when travelling forwards or backwards

7. Vehicle/machine speed and driver skills and awareness

Operators and drivers of vehicles in rough environments are usually very tolerant of discomfort. However, the long-term damage that could be occurring may show up 10 to 20 years later and the individual makes no link with the exposures that may have contributed over time to the problems.

Increased speeds accentuate ride roughness. There appears to be an optimum speed - neither too slow nor too fast - for different conditions. Drivers' skills and awareness of the conditions are important in establishing this optimum speed, especially when it is coupled with speed limits and safety requirements.

Drivers need to be particularly careful when they are carrying passengers in rear seats. The ride in the back of a vehicle is usually much rougher than in the front, particularly if passengers are sitting behind the rear axles as they do in the typical 'troop carriers'. Also if passengers are sitting sideways they cannot brace themselves.
The term ‘drive to conditions’ tends to be meaningless if it has not been defined or described. In practical terms it does not provide enough guidance to operators and drivers in difficult or abnormal conditions. Operators and drivers are expected to be ‘sensible’ but different people can interpret this differently. Less experienced drivers are particularly at risk in these situations, as many see no link between rough rides and back and neck injuries.

**Principal problems of speed and driver skills and awareness**

- Increased speed makes a significant difference to the roughness of the ride
- Sound driving skills need to be taught and cannot be assumed
- Drivers appear to have little indication of the roughness of the ride for the passengers, particularly when the passengers are sitting sideways at the back of the vehicle and unable to brace themselves.
- ‘Driving to conditions’ is interpreted differently by each person and is insufficient guidance to reduce risks of injury.
- Drivers need feedback on what constitutes a rough ride and information on adverse outcomes of vibration exposure

**8. Lighting and visibility**

Drivers, especially when they are transporting passengers, need to be alert to road conditions and such obstacles as potholes, soft spots, water and materials on the road. Travelling in underground mines or at night in open-cut mines requires good headlights and appropriate speeds. Drivers need to take extra care where there are blind spots from the vehicle or poor visibility of the road.

Locating trucks and other machines for loading or dumping can sometimes create more vehicles movements than is necessary.

**Principal problems with lighting and visibility**

- Hitting potholes and other causes of roughness which cannot be seen due to poor lighting and water
- Passengers cannot anticipate jolts and jars because they cannot see ahead
- Inadequate feedback to operators/drivers when they are positioning vehicles often leads to unnecessary and prolonged vehicle movements

**9. Task design and work organisation**

Long periods of sitting and unvaried work schedules can contribute to back and neck pain. In some cases prolonged sitting and lack of task variety is more likely to cause discomfort and back and neck pain than vibration and is common in truck drivers and operators of excavators and loaders who are working in a paced ‘production line’ situation. It is more of a problem for open-cut mines than underground mines and may account for the very high reporting of back pain and other symptoms in these workers.
Principal problems with task design and work organisation

- Long, unrelieved periods of driving or operating can lead to discomfort and pain even without vibration
- Long periods of driving or travelling can accentuate vibration problems
- Numbers of trips in a work shift, time pressures and work routines all can add to tension, discomfort and even pain

10. Other causes of discomfort while driving, operating and riding

Drivers and operators may be much less tolerant of vibration when it is combined with poor cab design and visibility or if they suffer from back or neck pain. Often these people are the first to alert an organisation to these issues.

Drivers/operators who have not had back pain may not be good at estimating the risks of rough rides. Overall, coal miners underestimate ride roughness and so when they report discomfort it needs to be investigated.

Sometimes work in bulldozers and loaders can be made unnecessarily difficult due to poor shot firing. Large rocks that need to be broken up or need careful handling can add substantially to the roughness of a ride.

Other causes of discomfort and complaints

- Most mining personnel underrate the roughness of their rides
- Drivers and operators who have back or neck pain are more likely to complain about ride roughness and they may be the first sign that there is a problem
- Drivers and operators without back or neck pain, especially if they are young, may not be good at judging if a ride is too rough
- Poor shot firing standards that lead to work that is rougher than advisable
Measurement and assessment of vibration exposures

Measurement and assessment of operator's vibration exposure levels is a useful way to:

• Identify those operators who are exposed to potentially damaging vibration levels
• Identify vehicles and specific activities of those vehicles that are producing excessive vibration levels
• Establish a priority list for control of vibration problems
• Check progress on vibration reduction strategies (road maintenance programs, new vehicle suspension etc)

Vibration measurement procedure

A typical measurement system is shown in Figure 4.

A vibration sensor is placed on the seat to pick up the vibration being transmitted through to the driver's body. The sensor detects vibration in three axes; forward to back (x-axis), side to side (y-axis) and up and down (z-axis). The vibration signal is then amplified and recorded for later analysis. The vibration is measured over a sufficient time period to give a realistic sample of the operator's exposure. This could vary between a few minutes if vibration exposure is constant to several hours for exposures that vary throughout the work shift.

After analysis, the resulting vibration exposure can be assessed against health, fatigue or comfort criteria in Standards for whole-body vibration.

The Australian Standard on whole-body vibration was published in 1990 and a newer International Standard was released in 1997. The International Standard provides a different approach to vibration assessment that is more suited to mining vehicles.
Standards for whole-body vibration

The following is an overview of the Australian and International Standards.

**Australian Standard (AS 2670.1, 1990)**

The Australian Standard (AS 2670.1 - Evaluation of human exposure to whole-body vibration) was published in 1990 and was a complete adoption of the now superseded International Standard (ISO 2631 - 1, 1985).

The Australian Standard gives exposure limits for three criteria:

- **Comfort** - concerned with the preservation of comfort (‘reduced comfort boundary’)
- **Fatigue** - relating to impaired working efficiency due to fatigue (fatigue-decreased proficiency boundary).
- **Health** - preservation of health and safety (exposure limit).

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. (Such limit levels have been explored for male human subjects in laboratory research.) The exposure limit is 2 times the fatigue-decreased proficiency limit and the reduced comfort boundary is 3.15 times below the fatigue-decreased proficiency boundary. The reduced comfort boundary is set at a level which does not take into account its subjective nature. For example, a luxury car occupant will expect a higher level of comfort than a bulldozer driver.

The measured vibration level (root mean square value, r.m.s) is compared to a set of criteria curves shown in Figure 5. The Standard prescribes that the one-third octave frequency spectrum is used but also allows the overall r.m.s level to be used as an alternative. As the average vibration increases, the allowable exposure time decreases. The Australian Standard provides vibration exposure limits for periods of 1 minute to 24 hours.
Limitations of the Australian Standard
The assessment methods used in this Standard may underestimate the risks of damaging vibration particularly if they include jolts and jars. This means that potentially damaging vibration exposures could go unrecognised under this Standard.

International Standard (ISO 2631 - 1, 1997)
The International Standard (ISO 2631.1 - Mechanical vibration and shock - Evaluation of human exposure to whole-body vibration) is quite different to the Australian Standard. It incorporates assessment methods for both steady state and shock type vibration. Steady state vibration is assessed using r.m.s. methods while shocks or jolts and jars are assessed using the ‘Vibration Dose Value’ (VDV) which is sensitive to high peaks. An alternative method to the VDV for shocks called the ‘running r.m.s’ method is also recommended in the Standard.

The International Standard is generally more stringent than the Australian Standard and recommends much reduced exposure times for many vehicle operators as shown in the comparison Table 1.

International Standard Health Guidance
Vibration health exposures are classified as either being:
- in the likely health risk zone - (likely health risk);
- in the caution zone - (potential health risk);
- below the caution zone - (‘acceptable’ level of vibration).

Vibration exposures in the caution zone indicate potential health effects while exposures above the caution zone indicate that health risks are likely. For exposures below the caution zone, health effects have not been clearly documented and/or objectively observed.
There are several points to note about the International Standard health guidance zones:

- there are not sufficient data to show a quantitative relationship between vibration exposure and risk of health effects so the recommendations and exposure classifications are intended as guidance rather than strict limits;
- vibration exposure depends on the duration and level of vibration reaching the operator;
- it generally takes many years for the health effects of whole-body vibration to occur with the exception of one-off severe jolts that can cause immediate damage;
- the recommended exposure times do not predict possible immediate damage caused by a one-off jolt;
- in some cases prolonged sitting may be more of a problem than vibration and this could be overlooked when using the Standard;
- vibration is assessed in the worst axis, which is usually the z-axis (up and down). When vibration is high in all axes, (e.g. some dozer rides) the contribution from each axis is added to give the final exposure level.

Ride roughness

The VDV is also a sensitive indicator of ride roughness and was found to correlate very well with driver’s subjective opinion (Figure 7). For example, a driver who complains that the ride is very rough could be exposed to vibration in the likely health risk zone. The ‘caution zone’ begins at a VDV of 8.5 and the ‘likely health risk zone’ at a VDV of 17.

FIGURE 7: Drivers’ subjective road roughness rating versus measured Vibration Dose Value (VDV).
### TABLE 1. Comparison of Australian & International Standards time limits and exposure guidance for average rides.

<table>
<thead>
<tr>
<th>Vehicle Type</th>
<th>Australian Standard</th>
<th>International Standard</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Fatigue limit</td>
<td>Health limit</td>
</tr>
<tr>
<td></td>
<td>Time to reach</td>
<td></td>
</tr>
<tr>
<td><strong>Open-cut Mine Vehicles</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Track dozer - ripping &amp; pushing</td>
<td>4 hours</td>
<td>16 hours</td>
</tr>
<tr>
<td>hard partings</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dump truck - loading overburden</td>
<td>16 hours</td>
<td>24 hours</td>
</tr>
<tr>
<td>Loader - loading coal</td>
<td>8 hours</td>
<td>16 hours</td>
</tr>
<tr>
<td>4 wheel drive personnel carrier</td>
<td>4 hours</td>
<td>16 hours</td>
</tr>
<tr>
<td>- passenger</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Underground Mine Vehicles</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Equipment transport</td>
<td>1 hour</td>
<td>4 hours</td>
</tr>
<tr>
<td>without suspension - driver</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4 wheel drive personnel</td>
<td>4 hours</td>
<td>16 hours</td>
</tr>
<tr>
<td>troop carrier - passenger</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Load haul dump vehicle</td>
<td>4 hours</td>
<td>8 hours</td>
</tr>
<tr>
<td>Personnel rail carrier - passenger</td>
<td>4 hours</td>
<td>16 hours</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Implications of using the International Standard

It may be impractical to reduce exposure times to those recommended in the International Standard so vibration levels will need to be reduced by a combination of other control methods (see Section 4 - Reducing Vibration Exposure)

The following tables give some examples of average vehicle rides and the guidance on exposure times given by the International Standard.

### TABLE 2: International Standard Guidance on vibration exposures experienced by mining vehicle operators

<table>
<thead>
<tr>
<th>Vehicle Type</th>
<th>International Standard Exposure Guidance</th>
<th>Typical exposure during 8-hour shift (hours)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Underground mines</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4 wheel drive personnel carrier (driver)</td>
<td>Acceptable</td>
<td>4 hours</td>
</tr>
<tr>
<td>4 wheel drive personnel carrier (passenger)</td>
<td>Acceptable</td>
<td>1.5 hours</td>
</tr>
<tr>
<td>Equipment transport without suspension</td>
<td>Likely health risk</td>
<td>6 hours</td>
</tr>
<tr>
<td>Load haul dump</td>
<td>Likely health risk</td>
<td>6 hours</td>
</tr>
<tr>
<td>Rail personnel carrier (driver)</td>
<td>Caution zone</td>
<td>5 hours</td>
</tr>
<tr>
<td>Rail personnel carrier (passenger)</td>
<td>Acceptable</td>
<td>1 hour</td>
</tr>
<tr>
<td><strong>Open-cut mines</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Track dozer (ripping &amp; pushing partings)</td>
<td>Likely health risk</td>
<td>6 hours</td>
</tr>
<tr>
<td>4 wheel drive personnel carrier (driver)</td>
<td>Caution zone(^1)</td>
<td>5 hours</td>
</tr>
<tr>
<td>4 wheel drive personnel carrier (passenger)</td>
<td>Caution zone(^1)</td>
<td>30 minutes</td>
</tr>
<tr>
<td>Fitter’s vehicle (maintenance run)</td>
<td>Caution zone</td>
<td>3 hours</td>
</tr>
<tr>
<td></td>
<td>Likely health risk</td>
<td>6 hours</td>
</tr>
<tr>
<td>Dump truck (transporting overburden)</td>
<td>Acceptable(^2)</td>
<td>7 hours</td>
</tr>
<tr>
<td>Loader (loading coal)</td>
<td>Likely health risk</td>
<td>7 hours</td>
</tr>
</tbody>
</table>

Notes:
1. A severe jolt within this period could be a likely health risk
2. Prolonged sitting without breaks could be a problem
Reducing harmful vibration exposure

Setting priorities

Once the vibration risks have been identified and assessed resources can be directed to solving the problems. Setting priorities is important and is usually achieved by assessing the severity of a problem and the likelihood of its occurrence. This includes the numbers of people exposed and how frequently they are exposed. The implementation of different solutions or controls will depend to some extent on their feasibility including aspects such as:

- effectiveness/impact on the problem;
- availability (including long-term implications);
- cost;
- maintainability including readily available spares and service.

To be effective it is important to involve the people who do the work in the process of identifying solutions. It is this process that allows flexibility and adaptability when circumstances change and is most important in finding the best solutions.

Type and design of solutions

Controls should be considered according to the ‘hierarchy of controls’. Hazard elimination, process redesign and engineered modifications (‘hard barriers’) are given preference over administrative controls (‘soft barriers’) that rely on people’s adherence to procedures or rules. Nonetheless, successful vibration reduction may need a range of control measures and the contribution of each control option needs to be assessed to determine the most cost-effective approach.

‘Hard’ barriers are usually much more effective in reducing high risks.

These are primarily design solutions such as:

- modifying the process to eliminate the task or the risk e.g. do the job another way or abandon the job;
- redesigning the tasks e.g. change the way tasks are carried out;
- designing machines or vehicles that reduce the vibration transmitted through to the operator;
- improving road and surface conditions.

‘Soft’ barriers are usually less effective as they rely on human behaviour and are subject to error. These include:

- rules such as speed limits;
- safe work procedures (SWP) and standard operating procedures (SOP);
- work breaks or job rotation to reduce exposure on certain vehicles.

Training is necessary to complement a well-designed workplace and efficient systems.
Ensuring worker compliance with rules and procedures is a major problem in any workplace and each individual must be highly motivated if procedures are to work effectively. Usually this occurs when there are significant tangible rewards for them or they face serious consequences such as a fatal injury or punitive measures.

**Implementation of solutions**

In the short term, some design solutions may not be possible but administrative and maintenance controls will be. In the long-term, design solutions will be most effective in controlling harmful vibration. Training is essential to improve driver skills and to raise awareness of vibration issues and its adverse health effects. Such training must always include information on why safety is important and the general principles of risk reduction.

**Sources of information**

Sources of information on solutions can be found from:

- workers who do the job including supervisors and managers;
- company and industry statistics, reports, risk assessments and other documentation;
- manufacturers and suppliers of equipment;
- consultants and experts in particular areas of engineering, ergonomics, occupational hygiene, health and safety etc.;
- professional and research reports and publications (a list of these can be found in the Bibliography).

**Ways to reduce vibration exposure**

As has been explained in Section 3, reducing exposure to harmful vibration cannot rely only on limiting exposure times as this is impractical in many situations where vibration levels are high.

The careful consideration of a number of ‘hard’ and ‘soft’ barriers is usually required. In the long term the improved design of vehicles and machines and the development of reliable systems of road maintenance will significantly reduce WBV exposures.

The following information details the hard and soft barrier techniques that can be used to reduce vibration exposure. Hard barriers are generally listed before soft barriers (see control hierarchy). More detailed information can be found in the publications listed in the Bibliography.

**Driver/operator training**

Training of operators and drivers in ways to avoid potentially harmful vibration could prove useful and cost-effective. Drivers’ need to be aware of the conditions that cause rough rides and what constitutes damaging vibration. They also need the driving/operating skills to avoid or reduce exposure and be given feedback on what constitutes an optimum speed for safety.
Competency training for drivers needs to include information on passenger comfort. Travelling at a speed that is comfortable for the driver may not be comfortable for passengers. Drivers need to be alert to road conditions and obstacles on the road and they need to take extra care where there are blind spots or poor visibility. Instructions such as ‘drive to conditions’ needs to be clearly defined for each person and driver competency testing needs to establish how well each driver can do this in terms of avoiding damaging vibration. Drivers must take particular care when they are carrying passengers especially in the rear seats of ‘troop carriers’.

Training is important in:
- imparting skills and knowledge that can be tested (competencies);
- raising awareness of the link between health and safety and workplace and equipment design;
- reinforcing safe procedures;
- informing employees of changes to policies;
- obtaining feedback from employees on problems and issues;
- teaching people how to identify and solve problems;
- ensuring that operators adjust their seats correctly so that they are comfortable and that they report any problems with seats;
- informing employees of the importance of safety and the general principles of risk reduction.

Training on vibration should be used to:
- raise awareness of what constitutes harmful vibration and its effects;
- improve driver competencies and skills when they are working in rough conditions in a way that will not unnecessarily increase vibration exposure.

Driver training should be linked to practical and enforceable speed limits and driving safety requirements. Most importantly:
- apply and enforce appropriate speed limits;
- it may be feasible to speed limit some vehicles;
- appoint designated drivers with appropriate training who are deemed competent and safe.

Road construction and maintenance programs
Theoretically the best way to reduce most vibration is to control it at source by ensuring that all roads and work surfaces are smooth. This should be the aim especially for transport vehicles such as trucks and light vehicles. Road construction needs to be done correctly and according to established procedures. (See Bibliography – Australian Road Research Board and Coffey & Partners P/L).

The important points to consider are:
- professional road construction methods especially for main roads;
- planned and systematic road maintenance programs that are not regarded as secondary to production demands;
- dedicated vehicles and drivers for road maintenance;
• effective communication of information on road conditions e.g. use of caution markers for pot holes and poor conditions;
• immediate rectification of poor road conditions;
• more effective use of water pumps and drainage techniques;
• immediate removal of materials on the road that are likely to cause jolts and jars e.g. rocks.

Other benefits of well maintained roads include:
• improved travelling times;
• reduced diesel particulate emissions;
• reduced fuel costs;
• less wear and tear on tyres and suspension.

It is not always feasible to keep all roads in a satisfactory condition at all times. Therefore, other methods will be needed to reduce vibration exposure to acceptable levels.

**Appropriate design of vehicles and cabs**

**Vehicle design and suspension**

Vehicle suspension is extremely important in reducing the impact of harmful vibration on the driver or operator. Transport vehicles such as four-wheel drives usually need to be modified so that the suspension is appropriate for the rough conditions found in mining.

Many underground mining machines and some surface machinery have little or no vibration damping for the operator. These include bulldozers, loaders, load-haul-dump machines (LHDs) and face vehicles. In addition the work carried out by these machines, by its nature, is rough and may be independent of road or surface conditions. In these circumstances other factors (modifiers) such as vehicle design and suspension become increasingly important.

Important points to consider are:
• operators must be isolated from the frame of the machine in some way so that exposure to WBV is reduced to an acceptable level especially when the vehicle is doing rough work that is intensive and prolonged;
• vehicle suspension must be appropriate for operators’/drivers’ comfort as well as loads and must not bottom out;
• suspension systems in four-wheel drive passenger transport vehicles may need redesign to ensure that they are effective and robust;
• riding between the axles is smoother than in front of or behind the wheel-base;
• using appropriate tyres and tyre pressures.

**Cab design and layout**

Good posture is extremely important for comfortable operation. Cabs should be designed so that the operator can sit in a comfortable posture to operate controls and can see without having to adopt awkward and potentially damaging postures.
Space should be sufficient to accommodate the tallest and biggest operators in reasonable comfort while seat and control adjustments should allow the shortest operator to reach hand and foot controls. The driver’s space envelope, including the placement and design of displays and controls, should be sufficient to allow comfortable working postures and adequate visibility from the cab for all sizes of operators. The following requirements should be met:

- there should be sufficient head space for the driver (a minimum of one metre clearance from seat to roof, preferably a minimum of 1400mm);
- there should be sufficient leg space for drivers to operate the steering wheel, pedals and other controls;
- space should allow room for an adjustable operators/drivers seat;
- there should be adequate visibility from the cab (headlights, line-of-sight);
- the location and design of controls should be consistent with conventions and standards;
- the location and visibility of displays should be consistent with conventions and standards;
- if the operator has to look behind (e.g. bulldozers) or down to the front (e.g. graders) while operating consider ways to reduce bending or twisting in the seat such as by providing a forward tilt or swivel mechanism on the seat.

**Seat design, suspension and maintenance**

Well-designed seats are important in reducing exposures to damaging vibration. Problems with seats can be rectified with a systematic and informed program of seat purchasing, installation, maintenance and repair. Training of drivers in the importance of seat adjustment is essential.

Features of a well-designed seat include suspension systems that do not magnify exposures and do not bottom out; and seat profiles that support the back and legs but do not restrict movement. Seats for drivers and passengers must have a well-shaped seat pad and backrest (particularly the lumbar support), as these are important in reducing vibration transmitted to the operator.

Different sized operators and drivers need to be able to adjust the seat height and distance from the controls. Often this is limited by the cab size. Seat suspension must be separate to seat height adjustment. This allows short and taller drivers to adjust both independently regardless of their weight.

Seats need to be maintained to the manufacturers’ specifications and maintenance periods and hours of use need to be specified and logged. Major overhaul or replacement schedules should be nominated and specified by the manufacturer. If mining personnel are to carry out the maintenance they will need specific competency training by the manufacturer.
Important design features of a drivers/operators’ seat:

• it should be well contoured; an appropriate size and shape; and should have adequate padding and suspension;
• it should be adjustable and the range of adjustment should be sufficient to accommodate all potential users;
• adjustment controls should be easy to locate, use and maintain;
• there must be sufficient headroom to allow for seat height adjustment;
• cab space should allow full fore/aft adjustment of the seat;
• there should be sufficient fore/aft adjustment (180mm minimum to 300mm optimum) to allow small and large operators to sit comfortably behind the controls;
• seat height adjustments should be separate from suspension adjustments;
• drivers and passengers seats should face forwards;
• seat maintenance programs should be in accordance with manufacturers’ instructions and sufficient to maintain the seat in an acceptable condition. This applies particularly to the suspension system, the adjustment levers and the seat stability.
**Maintenance of vehicle suspension systems**

Vehicle suspension should be included in planned maintenance programs. The age and condition of the vehicle can be used as an indicator of the need to overhaul or replace suspension. In tender documents manufacturers should be asked to supply information on the suspension systems and their specifications. This should include overhaul and parts replacement schedules and special requirements for maintaining the system in rough conditions. Important points to consider are:

- include requirements for information on the vehicle suspension systems in the tender documents;
- include suspensions systems in the planned maintenance program;
- ensure that maintenance personnel are appropriately trained to assess and maintain vehicle suspension systems.

**Lighting and visibility**

**Lighting of road ways**

The drivers’ line of sight from the cab should be optimised while blind spots should be minimised. Adequate lighting of roadways either by headlights and/or road lights can help to reduce the risks of hitting objects, potholes or other unexpected rough road conditions at night or in underground mines. Therefore ensure that:

- visibility from the cab is adequate;
- blind spots for the drivers are identified and minimised;
- area/road lighting is adequate;
- headlights are adequate;
- windscreen washers are operating and water reservoirs are full.

**Positioning vehicles**

Visibility of the area and the vehicles in the vicinity as well as feedback to the driver on his/her location are important in reducing unnecessary vehicle movements and accidental contact with other vehicles. Drivers of trucks, especially when they are inexperienced, need adequate feedback when positioning for filling (service vehicles), loading or dumping. Sight indicators or audible warnings are useful and may take various forms depending on the conditions and the needs of the driver and the mine. Therefore consider providing:

- Visual and/or audible feedback for drivers to help locate vehicles quickly and accurately e.g. trucks in relation to shovels; service trucks in relation to the vehicles they are refuelling.
Miscellaneous

Task design and work organisation

Operators are less likely to experience symptoms of discomfort when they have varied work routines. In open-cut mines, prolonged sitting in vehicles such as dump trucks can be alleviated to some extent through regular breaks out of the cab and job rotation. Operators/drivers should take regular short breaks out of their seats and move around during a working day. Five minutes every half hour or so is probably sufficient to reduce discomfort to a tolerable level during an eight-hour shift. Longer shifts will require longer breaks. Rotating between vehicle types may provide variation especially during longer shifts. It also may help to reduce exposure to vibration from rougher vehicles doing heavy work.

In contrast, work in underground mines tends to be more varied but nevertheless operators should be encouraged to break up long periods of sitting with other tasks. For jobs that require prolonged sitting ensure that operators:

- take regular breaks out of the seat/cab and/or;
- regularly rotate on different types of vehicles;
- consider different ways of doing rough jobs that may reduce vibration exposure.

Shot firing standards

Operations personnel need guidance on how to determine acceptable levels of vibration for bulldozer and loader operators. Open-cut mines should consider developing a policy on how to limit rough work undertaken in bulldozers and loaders when a shot fails to meet expected standards or when shot firing is not feasible. Ripping is one of the roughest jobs in an open-cut mine and the bulldozer is not designed to protect the operators from the harmful vibration that can be generated.

Therefore:

- Ensure adequate shot firing standards.
- Consider using alternative methods to break up and transfer large rocks or partings.
- Develop a policy on limits to rough work for operators of bulldozers and other machines.
- Ensure that ripping is done to minimise travelling over rough areas.
**Evaluation of solutions**

Evaluation of solutions is important if the benefits - or the lack of them - are to be determined. Different forms of evaluation can be used according to the needs and limitations of each situation. They need not be complicated. It may be as simple as asking a range of users what they think. However, more extensive evaluation might be required when usable information is to be fed back to manufacturers and suppliers or if the solution is critical in terms of injury control.

The following questions need to be asked about the solution or control measure:

- Was the vibration exposure to workers reduced to acceptable levels?
- Was it a total or partial success?
- What, if any, aspects did not work?
- Did any aspects work better than expected?
- Was the solution acceptable to the workers involved? If not, why not?
- Does it need modification to make it work better?
- If it needs modification do the workers/users or others have any ideas on how it might work better?

It is important to repeat the hazard identification and risk assessment process at regular intervals and to keep checking that the solutions are working. If not, make appropriate changes. Improvement must be continually monitored and ongoing.

Therefore:

- Regularly monitor and re-assess vibration for operators of machines/vehicles that have problems.
- Check if solutions that have been implemented are fully effective and, if not, make appropriate changes.
- Use engineering in preference to administrative solutions where feasible.
Examples of typical problems and solutions

Problem 1: Operating a dump truck in an open-cut mine

Although the ride is relatively smooth, drivers of dump trucks and similar vehicles in open-cut mines frequently complain about back and neck pain that develops through the working day.

Standards assessment

The Australian Standard fatigue limit for a typical dump truck ride is 16 hours with a health exposure limit of 24 hours. The International Standard exposure guidelines indicate that the caution zone is reached in 6 hours and the likely health risk zone after 24 hours exposure.

Possible solutions

Prolonged exposure to low-grade vibration may contribute to the driver’s discomfort. However, the main issue is likely to be the prolonged sitting which is, in itself, a risk factor for back pain. Other factors that could also contribute to discomfort could be:

- poor cab layout;
- inappropriate seat design;
- inadequate maintenance;
- tension and fatigue.

The underlying causes of the back pain are not obvious to drivers but could be addressed through such strategies as encouraging them to take breaks out of the seat and implementing job rotation.

Engineering design

- Adequate cab space especially leg and headroom
- Appropriate layout of controls and displays
- Good visibility from the cab
- Appropriate seat design and maintenance

Administrative

- Job rotation – operation of perhaps two or three different vehicle types each eight-hour shift.
- Regular, frequent breaks out of the seat (a minimum of 5 minutes within each hour preferably 10 minutes within each hour and longer where 12-hour shifts are worked).
Problem 2: Pushing and ripping partings in a bulldozer in an open-cut mine

The roughness of the conditions and the activity of the vehicle contribute substantially to the ride roughness in a bulldozer. The vehicle is usually unsprung, is of extremely robust construction and is very heavy. Every movement is transmitted to the cab and, if the seat does not damp the vibration effectively, it is also transmitted to the operator. The machine may see-saw over large rocks and the operator also needs to twist to look behind the vehicle. Most operators complain of discomfort or pain after an hour or two of this activity.

Standards assessment

The Australian Standard fatigue limit is typically 4 hours for this ride, while the health exposure limit is 16 hours. The International Standard assesses the ride as reaching the caution zone after only 10 minutes and the likely health risk zone in 2 hours.

Possible solutions

Engineering design

- Effective vehicle suspension
- Install seats with effective suspension (seat must not bottom out)
- Isolate of the cab from the frame of the machine
- Develop appropriate vehicle maintenance systems including appropriate seat maintenance and timely seat replacement

Administrative

- Ensure adequate shot firing standards
- Consider using alternative methods to break up and transfer large rocks or partings
- Develop a policy on limits of rough work for bulldozers and other machines
- Define harmful vibration for operators and give them feedback on what ‘driving to conditions’ means in practice.
- Provide specific vehicle operator training concentrating on technique and minimising travelling over ripped or rough ground
- Enable job rotation and limiting ripping periods for operators
- Ensure that operators take regular, frequent breaks out of the seat (a minimum of 5 minutes within each hour preferably 10 minutes within each hour and longer where 12-hour shifts are worked).
Problem 3: **Filling, travelling and dumping coal from a loader in an open-cut mine**

The nature of the conditions, the filling and the travelling contribute substantially to the ride roughness in the loader. The vehicle has suspension and rubber tyres and is large and heavy. It tends to lurch and bounce fore to aft when filling especially with an inexperienced or unskilled operator, and there is side-to-side movement when turning and travelling. Many operators complain of discomfort and back pain after loading for extended periods.

**Standards assessment**

The Australian Standard fatigue limit is typically 8 hours for this ride, while the health exposure limit is 16 hours. The International Standard assesses the ride as reaching the caution zone after 1.5 hours and the likely health risk zone in 5.5 hours.

**Possible solutions**

**Engineering design**

- Maintain roads and work areas at an optimum level
- Install effective seat suspension (seat must not bottom out)
- Isolate the cab from the frame of the machine
- Develop appropriate vehicle maintenance systems including appropriate seat maintenance and timely seat replacement

**Administrative**

- Define harmful vibration for operators and give them feedback on what ‘driving to conditions’ means in practice
- Provide specific vehicle operator training especially in how to load and move smoothly
- Ensure that the position of the truck allows room for easy access by the loader
- Use job rotation to limit periods of loading for operators
- Ensure that operators take regular, frequent breaks out of the seat (a minimum of 5 minutes within each hour preferably 10 minutes within each hour and longer where 12-hour shifts are worked).
Problem 4: Hitting a pothole in a passenger transport vehicle when driving at higher speeds

The one-off jolt usually occurs without warning and all personnel particularly the passengers in the back are unprepared. Speed of travel accentuates the impact. Less skilled or inexperienced drivers may be less able to avoid rough patches. As well, in troop carriers, passengers are sitting sideways and have no way of bracing themselves. Seats do not have suspension and sitting behind the rear axle can be particularly rough. When there are only a few passengers the ride can be rougher than when it is fully loaded. In open-cut mines some light vehicle suspension systems deteriorate quickly in rough mining conditions and need to be overhauled. This has been found to occur after about 40,000km.

Standards assessment

It is difficult to capture one-off severe jolts because they occur infrequently. A rough ride in a passenger vehicle gives an indication of the effect. The Australian Standard assesses the fatigue and health limits for a rough passenger ride as 4 hours and 16 hours, similar to those of the track dozer. However, the International Standard is much more stringent assessing the ride as reaching the caution zone in only 6 minutes and the likely health risk zone in 1.5 hours (under the Vibration Dose Value criteria). Although the 6-minute caution zone is very limiting it still does not protect against a one-off jolt which could occur in the first few seconds or minutes of the ride.

Possible solutions

Engineering design

- Ensure that vehicle suspension is effective and appropriate for the type of vehicle and its activity
- Appropriate vehicle and suspension maintenance
- Ensure that passenger seats face forward and that they are properly designed to provide support and some shock absorption
- Provide adequate roadway lighting at night or in underground mines – road lights or headlights (must not dazzle)
- Ensure that the vehicle has appropriate tyres and tyre pressures
Administrative

- Develop appropriate and effective road maintenance systems.
- Define harmful vibration for operators and give them feedback on what ‘driving to conditions’ means in practice.
- Specific driver competency training for drivers of personnel carriers
- Enforce speed limits
- Advisory speed limits for particular areas and caution markers for rough spots
- Effective and timely communication of information on road conditions and potential problems for drivers.

Problem 5. Bashing the body of a truck with a shovel or dumping large rocks in the body of a truck in an open-cut mine

These one-off jolts occur without warning. The truck driver cannot see what is happening and is unprepared. The speed of movement when swinging the shovel, accentuates the impact. Less skilled or inexperienced shovel operators may have more problems. If a truck is not located correctly the shovel operator may have more difficulty loading safely.

Standards assessment

Exposure limits as outlined in the Standards are not helpful in this situation as they are expressed in terms of recommended periods of time. These are events that should never occur so improving visibility and operator skills (shovel operation and truck location) are important controls.

Possible solutions

Engineering design

- Feedback for the truck driver when positioning next to the shovel
- Adequate visibility of the truck by the shovel operator including adequate lighting at night (must not dazzle).
- Effective truck suspension or isolation of the cab from the frame of the machine
- Effective seat suspension (seat must not bottom out).
- Appropriate vehicle maintenance including appropriate seat maintenance and timely seat replacement.

Administrative

- Specific operator competency training for the shovel operator and truck driver
Problem 6. Carrying ballast for long distances over secondary roads and mucking out in a load-haul-dump (LHD) machine in an underground mine

The roughness of the conditions and the activity of the vehicle contribute substantially to the ride roughness. The vehicle is unsprung, is of extremely robust construction and is very heavy. Every movement is transmitted to the cab and the seat, which has no suspension. Some activities can set up a pitching motion in the cab and all vibration is transmitted directly to the operator. In addition the operator sits sideways facing inwards and twists to see forward and back. Cab space is cramped with inadequate leg and headroom and the layout is poor.

Standards assessment

The Australian Standard fatigue limit is typically 4 hours for this ride, while the health exposure limit is 8 hours. The International Standard assesses the ride as reaching the caution zone after 12 minutes and the likely health risk zone in 2.5 hours.

Possible solutions

Engineering design

• Maintain road and work area conditions at an optimum level
• Design the cab so that the operator faces forwards (or with a swivelling seat with dual controls) with enough leg and head space for a large operator
• Ensure effective vehicle suspension
• Install a well-designed seat with effective seat suspension (seat must not bottom out)
• Appropriate vehicle maintenance including appropriate seat maintenance and timely seat replacement.
• Isolate the cab from the frame of the machine

Administrative

• Define harmful vibration for operators and give them feedback on what ‘driving to conditions’ means in practice.
• Specific vehicle operator training especially in how to load and move smoothly
• Job rotation – operation of perhaps two or three different vehicles each shift.
• Regular, frequent breaks out of the seat (a minimum of 5 minutes within each hour preferably 10 minutes within each hour and longer where 12-hour shifts are worked).
Checklist for vibration exposure reduction

This checklist is to help you identify and manage vibration problems at your mine. Photocopy the checklist, date it and use it to provide an overview of the current situation. Progressive checklists can be completed as problems are identified and solutions implemented.

Always involve drivers, operators and passengers in identifying problems and devising and evaluating solutions/controls.

Name(s): ____________________________
Mine: ____________________________ Date: ____________

Identification of vibration sources

• Consult with operators, drivers, passengers and safety representatives

  Action: ____________________________

• Seek operators’, drivers’ or passengers’ ratings/opinions of vehicle roughness

  Action: ____________________________

• Check road conditions and work areas

  Action: ____________________________

• Take a ride in or drive ‘rough’ vehicles if feasible

  Action: ____________________________

• Examine injury records, incident and accident records, complaints of back pain

  Action: ____________________________

• Assess the severity and frequency of occurrence of injuries, discomfort or complaints

  Action: ____________________________

• Confirm that problems are arising from exposure to vibration

  Action: ____________________________

• Determine the general nature of the problems

  Action: ____________________________

• Determine which vehicles/work situations might lead to excessive vibration

  Action: ____________________________

Measurement, assessment and recording of vibration levels

• Measure vibration levels in vehicles where there appear to be problems

  Action: ____________________________

• Rank vehicles in terms of operator exposure levels

  Action: ____________________________

• Assess injury risk by comparing exposure levels with health criteria in the relevant Standards

  Action: ____________________________

• Establish a database of vibration levels for future reference

  Action: ____________________________

• Write a priority list for vibration reduction including risks to drivers, operators and passengers

  Action: ____________________________

Reducing vibration exposures

Operator training

• Raise awareness of the possible harmful effects of vibration amongst workers

  Action: ____________________________

• Train operators in what constitutes harmful vibration

  Action: ____________________________
• Include ways to minimize harmful vibration in competency training of drivers
  
  Action: 

• Appoint drivers/operators who are deemed competent and safe (appropriate training) especially if they are carrying passengers
  
  Action: 

• Seek feedback from operators on problems and solutions
  
  Action: 

• Train operators in correct seat adjustment
  
  Action: 

**Road maintenance programs**

• Use professional road construction techniques especially for main roadways
  
  Action: 

• Implement road maintenance programs that are planned and systematic and not regarded as secondary to production demands
  
  Action: 

• Ensure dedicated vehicles and drivers for timely road maintenance
  
  Action: 

• Implement systems that enable fast communication of information on road conditions and potential problems to other drivers and operators e.g. caution markers for potholes or poor conditions
  
  Action: 

• Rectify problems immediately e.g. filling of pot holes, removal of materials on the road
  
  Action: 

• Use effective water pumps and drainage techniques
  
  Action: 

**Restricting speed**

• Apply appropriate speed limits
  
  Action: 

• Enforce speed limits
  
  Action: 

• Use speed limited vehicles in specific situations (allowing for safety constraints)
  
  Action: 

**Design of vehicles and suspension**

• Consider modifying or replacing vehicle suspension to improve ride
  
  Action: 

• Check that suspension systems are appropriate for loads typically carried by the vehicle
  
  Action: 

• Consider lowering tyre pressures on vehicles where feasible to improve the ride
  
  Action: 

• The design of vehicle suspension system must ensure that it never bottoms out
  
  Action: 

• Consider ways to isolate the cabin from the frame of machines that undertake rough work to reduce WBV exposure to an acceptable level
  
  Action: 

**Cab design and layout**

• Layout of controls should be comfortable for all drivers/operators
  
  Action: 

• Ensure that the driver/operator does not need to adopt awkward postures to operate the vehicle or machine
  
  Action:
Ensure that there is sufficient headroom and legroom to accommodate all sized operators and to allow full adjustment of the seat (seat height, backrest angle and fore/aft travel)

Action:

Locate displays and controls consistent with conventions and standards

Action:

Consider ways to avoid the need for an operator to bend, turn or twist in the seat

Action:

Seat design, suspension and maintenance

Train drivers/operators in correct seat adjustment and the advantages of a well-adjusted seat

Action:

Ensure that seats do not bottom out

Action:

Seat height adjustment should be separate from suspension adjustment

Action:

Seat adjustment controls should be easy to locate, use and maintain

Action:

All drivers and passengers seats should face forwards

Action:

All drivers/operators’ seats should be fully adjustable

Action:

Seats should be well contoured; an appropriate size and shape; and should have adequate padding and suspension

Action:

Drivers/operators’ seats should be supportive especially in the lumbar region.

Action:

There should be no protruding parts (other than the lumbar support) that might cause pressure or could prevent even contact with the surface of the seat or the backrest

Action:

Seats must never bottom out

Action:

Seat maintenance programs should be in accordance with manufacturers’ instructions and sufficient to maintain the seat in an acceptable condition

Action:

Maintenance of vehicle suspension systems

Implement planned maintenance programs for vehicle suspension systems

Action:

Ensure specialist maintenance for seating and suspension systems

Action:

Ensure maintenance personnel are appropriately trained to assess and maintain vehicle suspension systems

Action:

Ask manufacturers to supply information on the suspension systems and their specifications

Action:

Lighting and visibility

Ensure that visibility from the cab is adequate

Action:

Ensure that windscreen washers and wipers are operating and water reservoirs are full

Action:
• Ensure that blind spots are identified and drivers/operators trained accordingly
  Action:

• Ensure vehicle headlights are adequate
  Action:

• Ensure that the area/road lighting is adequate
  Action:

• Consider aids (visual or audio) for drivers when positioning a vehicle in loading or filling areas
  Action:

**Task design and work organisation**

• Consider different ways of doing a job that reduces vibration exposure
  Action:

• Develop a policy on limits of rough work for bulldozers and other machines
  Action:

• Encourage drivers take regular breaks out of the seat (a minimum of 5 minutes per hour)
  Action:

• Consider a job and vehicle rotation system
  Action:

**Shot firing standards**

• Ensure that shot firing standards are adequate
  Action:

• Consider alternative methods to break up and transfer large rocks or partings when shot firing is not feasible
  Action:

• Ensure that ripping is done in a way that minimises travelling over rough areas
  Action:

**Monitoring and evaluation**

• Regularly re-assess vibration levels in machines and vehicles that are identified as having problems
  Action:

• Ensure that vibration exposure levels are being reduced to an acceptable level
  Action:

• Ensure wherever possible that ‘hard barriers’ are used as solutions in preference to ‘soft barriers’
  Action:

• Check if solutions implemented were fully effective
  Action:

• If the solutions implemented were not fully effective determine which aspects did not work and why
  Action:

• If the solutions worked ensure that they are durable and sustainable
  Action:

• Consider the feasibility and cost of different solutions and their impact on vibration exposure
  Action:

• Implement any necessary modifications
  Action:

• Implement a continuous monitoring program
  Action:

**General comments:**
Bibliography


