Bad Vibrations

A HANDBOOK ON WHOLE-BODY VIBRATION EXPOSURE IN MINING

Essential guide to identify, assess and control vibration risks

COAL SERVICES HEALTH & SAFETY TRUST

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Please note:
To assist in identifying
particular issues in
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Contents:

Acknowledgements

The original Handbook (2001) was 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 now Coal Services Health and Safety Trust) and Worksafe Australia. This revised handbook is the synthesis of these research findings as well as information and ideas gleaned from the industry over the intervening years.

The revisions consist of updates of the information on Standards and research data; adding some simple 'tools' for the identification and appraisal of whole-body vibration (WBV) exposure by those who may be affected by it; adding an index and updating the layout and illustrations. Users of the first edition have indicated that the information that it contained was useful and easy to find. Therefore, we have retained all sections that are still applicable.

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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 and other heavy industries 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 accompanying check sheets, survey forms 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 sections:

Section 1: Introduction

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 vibration (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.

Vibration direction and human sensitivity

As described earlier, vibration is an oscillatory movement. It can occur at a number or combination of frequencies. Humans are sensitive to particular frequencies more than others. The direction of the vibration has an effect on how sensitive humans are to specific frequencies. For this and measurement reasons the direction of the vibration should be noted.

Up and down vibration (z-axis) is the most common vibration to which people are exposed. An example of this is the vibration experienced when driving over pot holes or when trotting on a horse. There is also lateral or sideways vibration (y-axis), commonly experienced on rail vehicles. Lastly, there is forward vibration (x-axis), for example in front end loaders and dozers.

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 effect of vibration depends on the severity and length of exposures.

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 to 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 Examples 4 and 5, Section 6 and Case Study 1 Section 2, p13).

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, Section 2, p20). 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 and more now is known about the effects on the musculoskeletal system (bones, joints, tendons and muscles) of exposure to WBV. Evidence is suggesting that, rather than having just an additive effect, WBV exposure is increasing the risk of back pain from other tasks. That is, exposure to vibration increases the chances of people developing back pain from other activities such as lifting or sitting.

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, drivers and operators 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.

A comprehensive picture of the results of exposure to WBV in different occupations worldwide is now emerging in the scientific literature. Exposure is common in machinery operators (both mobile and fixed), vehicle drivers, and pilots of aircraft such as helicopters.

One recent study of 40,000 Swedish workers showed that exposures of more than half a day doubled the likelihood of musculoskeletal symptoms in the low back, neck, shoulders/arms and hands of individuals exposed. Another study of 453 workers from Britain highlighted the significantly increased risks of low back pain arising from 'combined exposures' of WBV, poor working postures and manual handling.

Unfortunately, this is not matched by data currently available for mining from workers' compensation statistics in Australia. One of the problems has been that outcomes such a back pain can be classified as either a work injury or a work-related disease (non-injury health issue) depending on the agency compiling the statistics. This is a problem with work-related musculoskeletal problems generally.

However, an analysis of NSW WorkCover figures for the period 2002 to 2006 indicates that 'exposure to mechanical vibration' and to 'vehicle jarring' were responsible for over 34% of compensable diseases/injuries in coal mine workers and over 4% over non-coal mining workers. Claims mainly involve the trunk and, to a lesser extent, the neck; involved higher compensation payments than other causes of musculoskeletal disorders and the average time off work was higher than for musculoskeletal disorders caused by other agents of injury.

Research indicates that there are significantly increased risks for low back pain arising from 'combined exposures' to WBV, poor working postures and manual handling.

In a study in NSW coal mines the authors found that some vehicles were unacceptable when assessed for an eight-hour or a twelve-hour day against the Australian Standard. The study also revealed that back and neck pain were 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 Australian Standard (2001) are evolving. Much more research is now available, especially in real work situations, to determine workers' WBV exposures and their effects. However, the effects of long term or life-time exposure still need to be clarified.

Mining personnel undertake work that includes all the factors that are believed to cause back pain (listed on Page 8). 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, assessing and controlling harmful vibration exposures.

Section 2: Identification

Effective management of whole-body vibration (WBV)

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 (See Section 4).

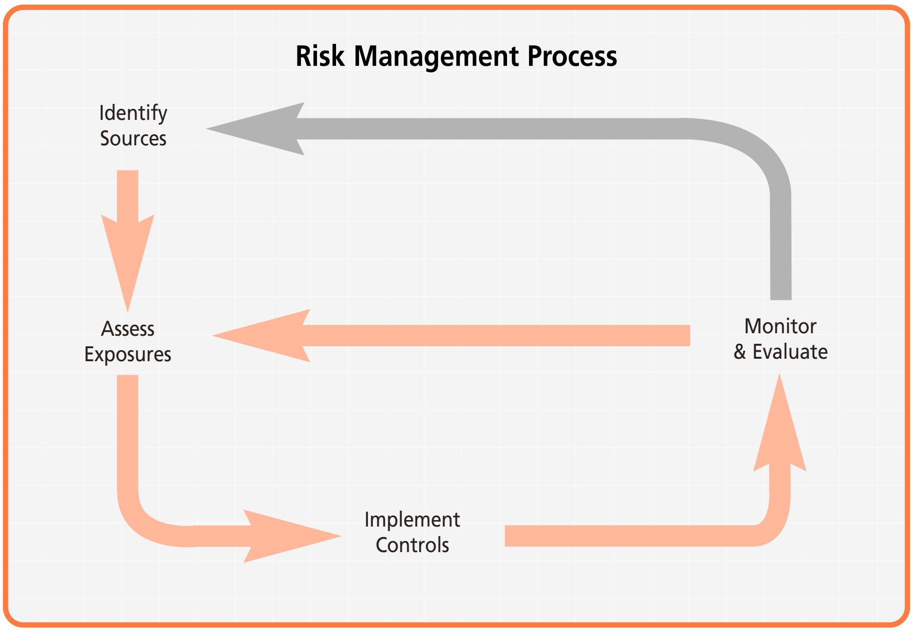


FIGURE 1: The risk management process.

Identification of vibration hazards

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

- Where might people be exposed to whole-body 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, surveys, questionnaires and feedback sheets (see Section 7);
- 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, health surveillance data, 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.

Vibration exposure is substantially increased in vehicles without suspension working on rough ground.

In order to identify possible sources of harmful whole-body 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 or pushing material in a dozer;
- engine vibration to a lesser extent.

Work in a bulldozer is typically rough.

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 e.g. reducing the need for ripping tasks in bulldozers.

The best way to reduce most vibration is to control it at source by making all roads and work surfaces smoother.

Maintaining roads in a satisfactory condition is a common problem in mining.

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 2),

Vibration Exposure Modifiers

FIGURE 2: Sources of vibration exposure and modifiers.

Vibration exposure

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

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.

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 obstacle on or potholes, soft spots and mud in otherwise good roads
- Poor road conditions that are not reported and corrected quickly

CASE STUDY 1: Back injury resulting from jolt in a transport vehicle underground.

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.

Passengers have no warning of sudden jolts.

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.

Bulldozer operators need to twist in the seat when ripping.

Problems with vehicle or machine 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
- Ripping un-shot partings or hard coal in a track dozer
- Activity of the vehicle leading to predominant movement forward (x axis) or sideways (y axis) that is often not dampened by the seat e.g. rubber-tyred dozers, loaders, LHDs mucking out or scaling the roof (see Point 5 in this Section and Section 3 Assessment p25)
- Slewing sideways when travelling or working
- Battering pit walls with excavator in open cut mine

CASE STUDY 2:
Back injury resulting from jolt in a generally rough ride – ripping partings in a bulldozer in an open-cut mine.

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 injury prevention or comfort for drivers. 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. Solid or foam filled tyres also can increase vibration exposure.

Some vehicles have no suspension or very stiff suspension that increases vibration exposure significantly.

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
- Vehicles with solid or foam filled tyres transmit road roughness directly into the vehicle
- Using suspension designed for heavy loads with light loads
- Vehicle suspension systems that bottom out transmit jolts to drivers and passengers
- 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 survey of four-wheel drive personnel transport and maintenance vehicles it was found that vehicle suspension and therefore ride roughness deteriorated markedly after 40,000 km. Older vehicles were much rougher than the newer vehicles in terms of their vibration dose values (Figure 3). 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.

Most suspension systems can reduce damaging vibration but they deteriorate over time especially in a rough mining environment.

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

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

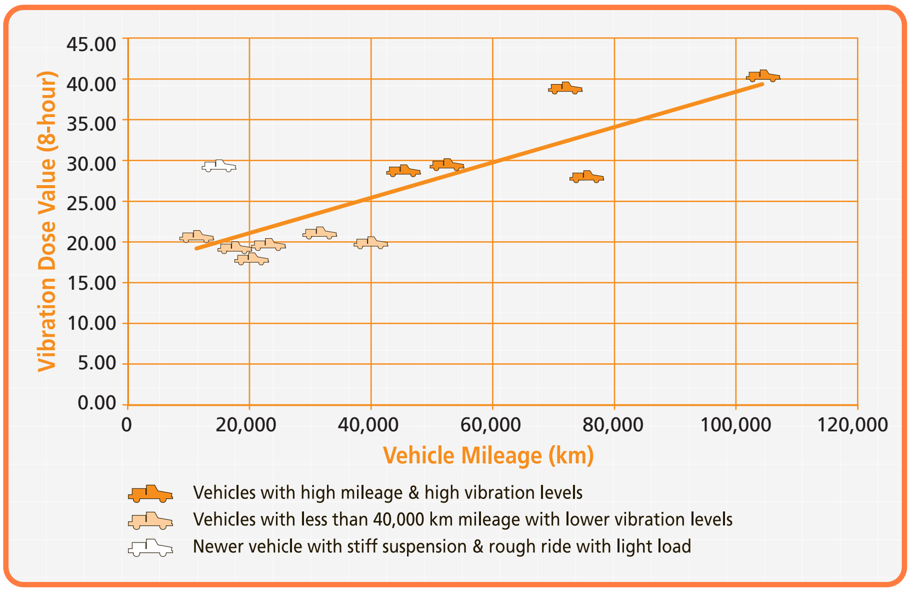


FIGURE 3: Vehicle mileage versus ride roughness. Higher VDV means rougher ride. See Section 3 for an explanation of Vibration Dose Value (VDV).

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; inadequate training 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.

Seats need to be carefully chosen. A poor seat choice can actually increase an operator's exposure to harmful vibration. The seat choice should be governed by the vehicle design, vehicle activity and expected vibration exposure. A suspension seat may not be the best choice.

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 or top out or that cannot be adjusted adequately for all users may cause serious injury.

Seat padding can provide some isolation from vibration and certainly improves comfort but this depends on the age and type of padding. In some cases, certain types of 'shock absorbing' materials can actually increase vibration exposure.

'Troop carrier' style transport vehicles with bench seats for passengers are not recommended. These seats do not provide sideways stability and are often poorly shaped and padded.

Seats need to be carefully chosen. A poor seat choice can increase an operator's exposure to harmful vibration.

Seats must have well-shaped seat pad, backrest and lumbar support. Padding can provide some isolation from vibration.

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 an 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

Poor seat maintenance can contribute to rougher rides.

"Troop carrier" style transport vehicles with bench seats for passengers are not recommended. The seats do not provide sideways stability and are often poorly shaped and padded.

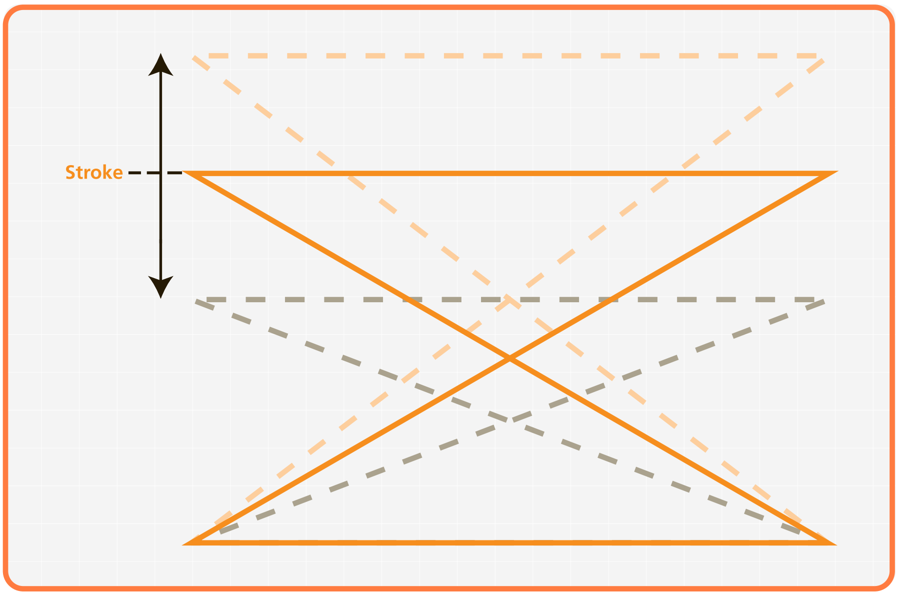
Suspension seats

The purpose of suspensions seats is to reduce the occupant's exposure to vibration and, in particular, shocks. Traditionally, this is done with a mechanical system that moves up and down (z-axis). Figure 4 depicts a simplified mechanism that allows the seat to move and dampen the vibration oscillations. The amount of movement available is called the 'stroke'.

Seat Suspension System

To best protect operators they need to sit in the middle of the stroke. If this is achieved the operator can move up and down the same amount before reaching the end of the mechanism – 'bottoming out' or 'topping out' the seat. Operators vary in weight and to place them in the middle of the stroke the suspension has to be adjusted to the weight on the seat.

***FIGURE 4:** Diagram of a simplified seat suspension system that moves up and down to dampen the vibration being experienced by the operator. The stroke is the amount of movement available in the suspension system.*



Issues with Suspension Seats

Suspension adjustment

Traditionally, suspension seats have required the operator to adjust the suspension correctly. If it is not, he/she is less well protected from the harmful effects of vibration.

Suspension settings

If the suspension is adjusted to the operator's weight then the seat can move an even amount up and down. (B in Figure 5)

If the suspension is adjusted for a lighter person than the operator, say a 70 kg person instead of the 100 kg operator, then the seat will bottom out more easily and the seat will move more freely. The suspension is too soft. (A in Figure 5)

If the suspension is adjusted for a heavier person than the operator, say to 100 kg rather than the 70 kg operator, there is less distance before the seat reaches the top of the stroke and the suspension is stiffer and thus dampens less well. The suspension is too hard. (C in Figure 5)

Self-levelling suspension systems have been developed and these remove the need for operators to adjust the suspension manually. This means that the suspension should be always set appropriately for the weight on the seat.

Seat adjustments

Figure 5 (figure of 3 suspensions) shows that, in some seats, by adjusting the seat suspension the seat height is also changed. Experience indicates that operators often equate the suspension adjustment with seat height and do not appreciate that using it in this way, for height, may reduce their protection from vibration.

This problem can be made worse because the adjustment for the seat suspension is obvious and intuitive while the seat height adjustment is not. In many models to adjust seat height requires using the two controls labelled 'tilt': one for the front of the seat pad and the other for the back of the seat pad.

Self-levelling suspension systems have been developed and these remove the need for operators to adjust the suspension manually.

The driver's space may be insufficient to allow full adjustment of the seat.

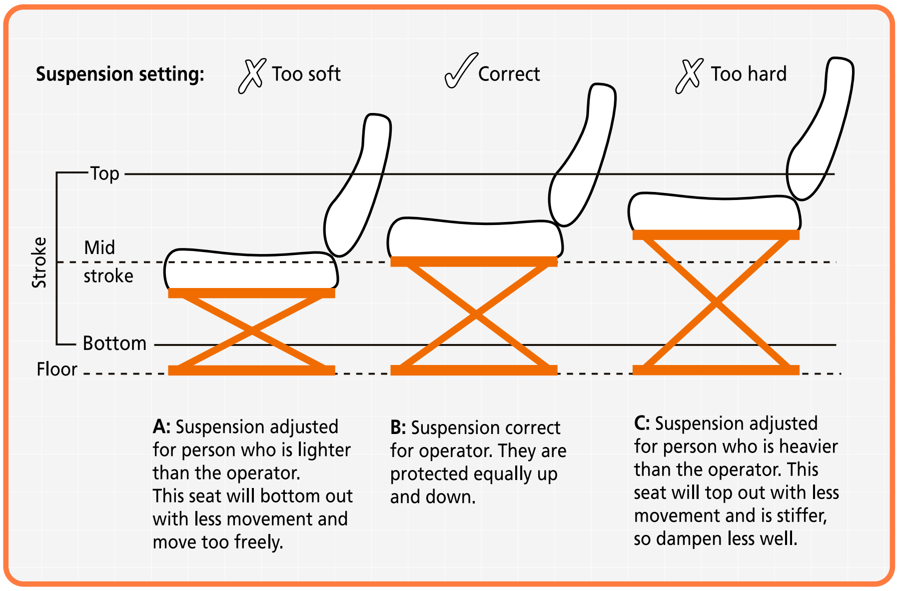


FIGURE 5: Suspension settings for manually adjusted seat suspension systems.

Many other controls allow various parts of the seat such as backrest angle, seat fore-aft position and seat rotation to be adjusted to suit the user's dimensions and requirements. This is desirable. Unfortunately, some operators and drivers find them daunting and difficult to learn. This leads some operators and drivers to making no adjustments although making adjustments would result in a better fit between the person and the seat.

Maintenance

To reduce vibration exposures of users, seats must be well maintained. The suspension is a precise system that needs careful, regular maintenance to work efficiently.

In addition, any adjustments offered on the seat should work easily and over their full range. Coal dust and other mining debris can quickly clog up adjustments making them less effective. Difficult to operate controls can lead to strain injuries.

Principal Points on Suspension Seats

- To best protect the operator the seat suspension needs to be adjusted to the operator's weight. This places the operator in the middle of the stroke.
- Self levelling suspension systems are recommended
- If operator adjustable suspension is supplied it should provide users with feedback about seat's settings, for instance, by displaying a weight
- Height adjustment should be separate, have one control, be obvious and easy to adjust
- Suspension seats usually only dampen vibration in the z axis (up and down) and give minimal protection in the x- and y- axes (front to back and side to side respectively) (See p25).
- The suspension stroke needs to be sufficient for the vibration expected
- Training in seat adjustment and purpose, including the suspension if necessary, needs to provide an operator with an opportunity to practice with the seat

CASE STUDY 3: Dump truck drivers.

An experienced driver was operating a dump truck carrying overburden. He worked 8-hour rotating shifts with some overtime. Without any particular incident occurring he noticed that he was feeling increasing back and neck discomfort and soreness over several weeks. This came and went but gradually got worse until it no longer improved at the weekend.

He found his seat uncomfortable and felt that the condition of the roads from the loading point to the dump were rougher than they should be. He reported his problem to the Health Centre.

The problems here are the prolonged sitting, an intermittently rough ride and a poorly designed and maintained seat. Within a week the roads had been repaired and several weeks later all the older seats were replaced in the dump trucks. The driver's back pain has improved but it recurs from time to time. It probably would improve further with regular breaks out of the cab every hour.

- Seats need to be regularly maintained to manufacturers' specifications.
- Poorly adjusted seats can actually increase vibration exposure levels

Finally, the best seat currently available still only provides limited protection from significant vibration. Seats should be used in combination with other control measures as listed in Section 4.

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 and increases the likelihood of injury.

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 and decrease efficiency 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 or injury.

The best seat currently available still only provides limited protection from significant vibration. Seats should be used in combination with other control measures.

Problems of vehicle design and cab layout

- Poor cab design may force drivers into awkward postures, increase their discomfort and risk of injury 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

In a LHD, the operator sits facing inwards and twists to see forwards and backwards.

7. *Vehicle/machine speed and driver skills and awareness*

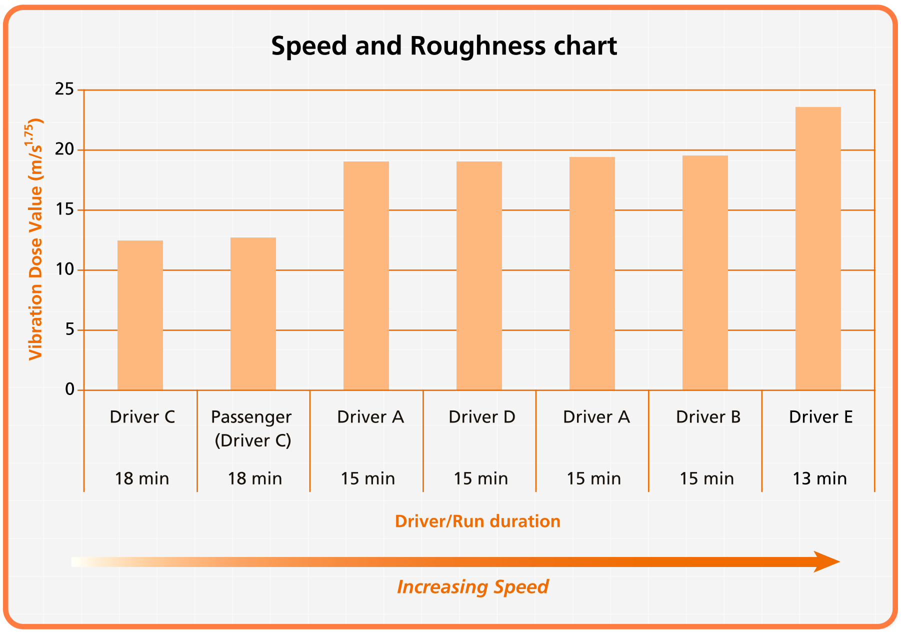
Operators and drivers of vehicles in rough environments are usually very tolerant of discomfort. However, the long-term damage that could be occurring may show up 10 to 20 years later and the individual makes no link with the exposures that may have contributed over time to the problems.

Increased speeds accentuate ride roughness.

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.

Figure 6 illustrates the impact of speed on WBV exposure in comparative recordings of operators and passengers in underground rail personnel carriers. All conditions were the same with the rail carrier being driven from a designated location underground to pit top on the same day. The only difference in these rides were the drivers and the time taken, which varied between 13 minutes (Driver E), 15 minutes (Drivers A, B and D) and 18 minutes (Driver C) on the same route. The fastest run was almost twice as rough as the slowest run.

FIGURE 6: Speed and its effects on whole-body vibration exposures.



Poor operating/driving techniques can also increase vibration levels especially on equipment like dozers e.g. poor positioning of the tine when ripping can significantly increase WBV exposure.

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' is 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.

Problems of speed and driver skills and awareness

- Increased speed makes a significant difference to the roughness of the ride
- Sound driving and operating skills/techniques (taking into account each site's requirements) need to be checked and cannot be assumed because the driver/operator holds a Certificate of Competency
- 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.
- The term 'driving to conditions' is interpreted differently by each person and gives inadequate 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.

Drivers need feedback on what constitutes a rough ride.

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

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.

Long periods of sitting and unvaried work schedules can contribute to back and neck pain.

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
- Carrying out a task with a vehicle not best suited for the activity
- Poor shot firing can result in rougher work for a dozer driver

10. *Other issues to consider in whole-body vibration assessment*

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 issues

- 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

Section 3: Assessment

Measurement and assessment of whole-body vibration (WBV) exposures

This Section gives a general overview of the Standards and commonly used criteria and terms. It is intended to give background information that is useful for interpreting vibration reports rather than a "do-it-yourself" guide to vibration measurement.

Further reading is recommended in the Bibliography.

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

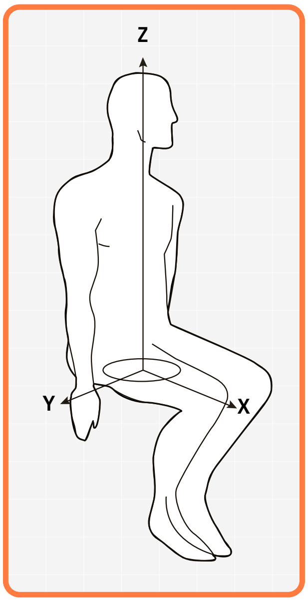
- Identify those operators who are exposed to potentially damaging vibration levels
- Identify vehicles and specific activities of those vehicles that are producing excessive vibration levels
- Establish a priority list for control of vibration problems
- Use vibration characteristics to design and prescribe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

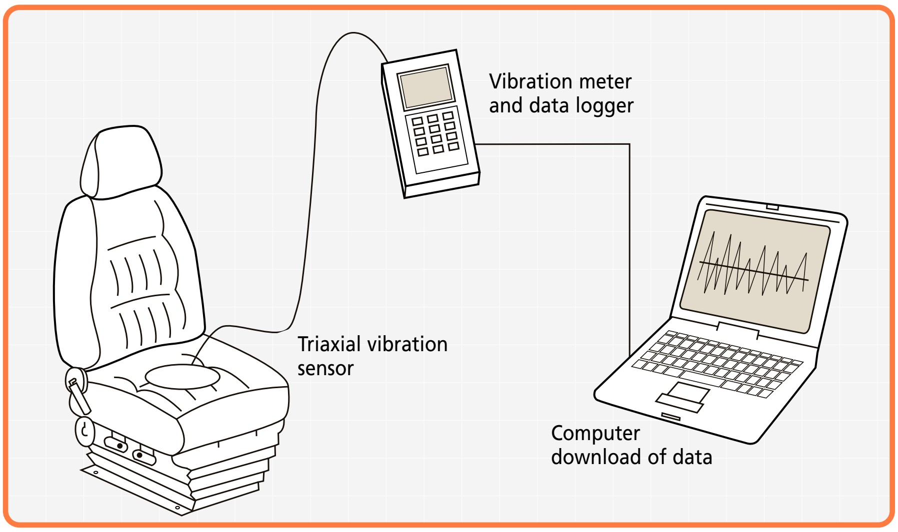
Vibration measurement

Vibration is measured in three axes (see Figure 7); forward to back (x-axis), side to side (y-axis); and up and down (z-axis).

A typical whole-body vibration measurement system is seen in Figure 8.

A vibration sensor is placed on the seat to pick up the vibration being transmitted through to the body – driver, operator or passenger. The sensor detects the vibration in the three axes. The vibration signal is then analysed and logged by a meter. Further analysis can be performed after downloading the data to a computer.





(Above) FIGURE 7: Three vibration axes measured in whole-body vibration (WBV).

(Left) FIGURE 8: The sensor detects vibration in three axes; forward to back, side to side and up and down.

What measurements are taken and recorded

Root mean square (r.m.s.) vibration level - recorded as an average acceleration level over the measurement period. Units are m/s^2;

Vibration Dose Value (VDV) is a cumulative dose measurement which is sensitive to high peak vibration or shocks – increases with time and level of vibration. Units are $m/s^{1.75}$.

Vibration sample time – the time over which the sample is measured. It is important that the vibration is measured over a representative time which is usually 20 minutes or longer.

Jolts and jars can be assessed using the Australian Standard.

Daily Vibration Exposure - is a time weighted average of all the individual vibration exposures to which an operator is exposed over the length of the shift. Operators may be exposed to different levels of vibration during the day, for example, during crib breaks or when using different equipment to carry out a variety of activities.

For example:

If only one vehicle is driven all day the operator is typically exposed to "in the seat" vibration of only 10 hours in the 12-hour shift when crib breaks and other down times are included. In this case the daily average exposure for the 12-hour shift will be lower than the measured average level during a test run.

Operators can often drive several vehicles throughout the day and receive a different vibration exposure from each. The Daily Vibration Exposure is calculated by summing the time weighted average of these exposures which is then compared with the exposure criteria.

Vibration Standards and Exposure Criteria

There are two main criteria currently used in Australia:

Australian Standard AS 2670-2001 *Evaluation of human exposure to whole-body vibration* prescribes methods for the measurement of whole-body vibration. It also includes guidelines for the assessment of whole-body vibration with respect to health in its Annex B.

The Australian Standard was adopted from the International Standard, ISO 2631-1:1997 *Mechanical vibration and shock - Evaluation of human exposure to whole-body vibration*.

European Union Vibration Directive 2002. This document includes an action level and exposure limit values for r.m.s. and VDV vibration. These values take into account the cost and practicality of implementation as well as known health effects. Consequently, the exposure limits are less stringent to those in the Australian Standard guidelines. However, the same frequency weightings, procedures and methods used in the ISO 2631 Standard (and thus AS 2670) are prescribed for measurement and evaluation.

Australian Standard

The Australian Standard (AS2670-2001 *Evaluation of human exposure to whole-body vibration*) on whole-body vibration was published in 2001. It incorporates assessment methods for both steady state (r.m.s.) and shock type vibration (VDV).

The Standard applies to seated persons because the effects of vibration on the health of persons standing, reclining or recumbent are not known.

Vibration exposures are classified as being:

- in the 'Likely Health Risk Zone' - (likely health risk)
- in the 'Caution Zone' - (potential health risk)
- or below the 'Caution Zone' - (health effects not objectively observed).

The criteria use exposure time and level to place the exposure in one of these zones. For exposures in the Caution Zone there is a potential health risk. Health risks are likely above the Likely Health Risk Zone but have not been clearly documented and/or objectively observed below the Caution Zone.

The r.m.s. vibration is assessed against the criteria shown in Figure 9. This is referred to as the Basic Evaluation Method

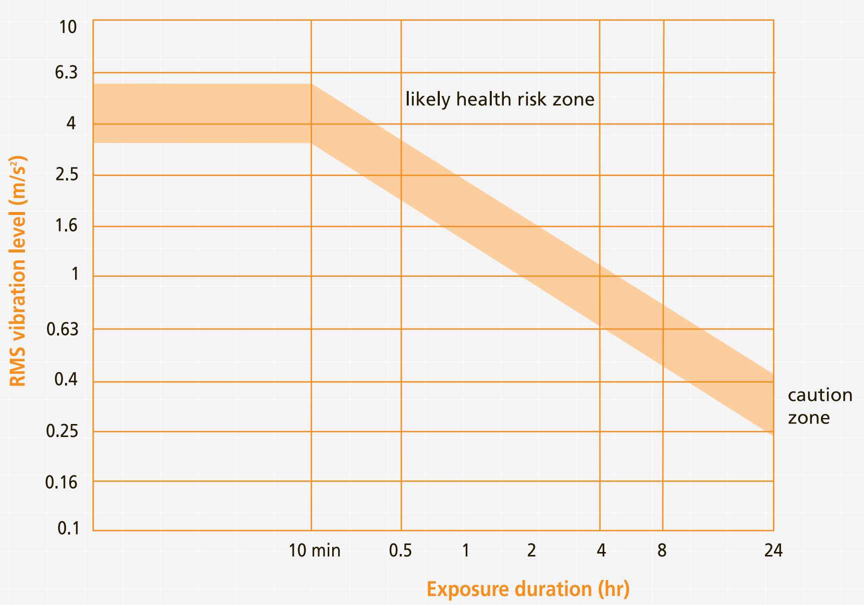


FIGURE 9: Australian Standard Health Guidance Zones.

The VDV is referred to as the Additional Evaluation Method with the following criteria:

Caution Zone	8.5 $m/s^{1.75}$ to 17 $m/s^{1.75}$
Likely Health Risk Zone	above 17 $m/s^{1.75}$

Note:

The VDV is based on 4th power calculation of acceleration which produces the units of $m/s^{1.75}$. Compared to the r.m.s. this 4th power calculation gives greater emphasis to the shocks or jolts and jars.

These criteria are provided in Annex B of the Standard and are given for guidance rather than as prescribed exposure limits.

The exposure limits in the European Union Vibration Directive 2002 are less stringent than those in the Australian Standard guidelines.

There are several points about the Australian Standard health guidance zones that should be noted:

- 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;
- most guidance in Annex B of the Australian Standard is based upon data available from research on human response to z-axis vibration of seated persons;
- vibration is assessed in the worst axis, which is usually the z-axis (up and down). When vibration is similar in all axes, (e.g. some dozer rides) the contribution from each axis is added to give the final exposure level.

The use of VDV

The VDV is a useful tool in the assessment of vibration exposure. High VDV levels indicate the presence of shocks or jolts and jars in the ride. This can occur even if the r.m.s. level is not high.

It is particularly important to identify and control vibration exposures that have a high proportion of jolts and jars rather than just relying on reducing exposure time. Poor roads are often a source of shocks. Vehicle activities such as dozer ripping or battering pit walls with a digger can also give high VDV levels.

The Australian Standard also provides guidance for using the VDV criteria in addition to the r.m.s. method. It recommends that if the following ratio exceeds 1.75 the VDV method is used as an additional evaluation method.

Ratio $$\frac{VDV}{a_w T^{1/4}} = 1.75$$

Where VDV = Vibration Dose Value in $m/s^{1.75}$

a_w = Weighted acceleration level in m/s^2

T = Duration of measurement in seconds.

Vibration Axes

Typically the assessment of the vibration against exposure criteria is made using the axis with the highest measured level.

Frequency weightings for different axes

The relevant vibration frequencies for health, comfort and perception range from 0.5 Hz to 80 Hz. However, vibration does not have an equal effect on the body across this frequency range. The most important frequencies to be considered for human health are between 1-2 Hz for the x-axis and y-axis while 4-8 Hz is most important for z-axis vibration. These weightings are applied as follows:

x-axis	Wd
y-axis	Wd
z-axis	Wk

The Standard states that the following k factor also be applied:

x-axis	Wd	k=1.4
y-axis	Wd	k=1.4
z-axis	Wk	k=1.0

Obtain feedback from employees on problems and issues.

European Directive 2002 exposure criteria

The European Union adopted a Vibration Directive in 2002. The same frequency weightings, procedures and methods are used as described for the Australian Standard above. The document sets an action level and an exposure limit for whole-body vibration for both r.m.s. and VDV values. These are:

Action level:	r.m.s.	$= 0.5\ m/s^2$
or	VDV	$= 9.1\ m/s^{1.75}$
Exposure limit:	r.m.s.	$= 1.15\ m/s^2$
or	VDV	$= 21\ m/s^{1.75}$

For longer shifts the prescribed levels are reduced by the following equation:

$$a_{\text{r.m.s. action}} = 0.5 \left(\frac{8}{t_h}\right)^{1/2}$$

$$a_{\text{r.m.s. limit}} = 1.15 \left(\frac{8}{t_h}\right)^{1/2}$$

Where: "a" = Measured r.m.s. vibration level in m/s^2

"t_h" = Exposure duration in hours

Health surveillance* is recommended for exposures above the Action Level. Levels should not exceed the Exposure limit. The Directive indicates that individual European states can choose whether to use the r.m.s. or VDV criteria.

The measurement and assessment methods described in ISO 2631-1 (adopted Australian Standard) are prescribed for use.

* *Health surveillance involves monitoring the health of workers to identify health issues at an early stage so that further health problems can be prevented or minimised. It also provides evidence that the control systems in place are properly protecting the health of workers.*

Surveying opinions of ride roughness

The VDV is also a sensitive indicator of ride roughness and was found to correlate very well with drivers' subjective opinions (Figure 10). For example, a driver who complains that the ride is very rough could be exposed to vibration in the upper half of the Caution Zone or into the Likely Health Risk Zone.

FIGURE 10: Drivers' subjective road roughness rating versus measured Vibration Dose Value (VDV).

The VDV is a sensitive indicator of ride roughness and was found to correlate very well with drivers' subjective opinions.

It is interesting to note that operators' opinions appeared to move from 'fair' to 'rough' at about 15 $m/s^{1.75}$. This level has been used as the Action Level in the British Standard BS 6841-1987 *Guide to measurement and evaluation of human exposure to whole-body mechanical vibration and repeated shock*.

This correlation can be used as a tool in an initial subjective survey of vibration exposure and relative roughness of different vehicles and activities. This tool (and several variations) can be found in Section 7, Check sheets and survey forms.

Figure 11 on p31 gives an overview of the typical vibration exposures that have been measured for a range of open cut and underground vehicles. These have been presented as time guidelines (Australian Standard, r.m.s. criteria).

FIGURE 11: Timing for open-cut and underground vehicles

Typical times to reach zones for open-cut and underground vehicles

Vehicle Type		AS 2670-2001 Time to Caution Zone (hours)	AS2670-2001 Time to Likely Health Risk Zone (hours)
Open-cut mines			
Dump truck (transporting material)	Mean Range	9 hours 4-19 hours	24 hours 17 to >24 hours
Loader (loading material)	Mean Range	4 hours 48 minutes to 8 hours	13 hours 4 to >24 hour
Track dozer pushing	Mean Range	5 hours 1-11 hours	11 hours 4 to >24 hours
Tractor dozer ripping & pushing	Mean Range	2 hours 36 minutes to 4 hours	9 hours 13-14 hours
4WD personnel carrier (driver)	Mean Range	3 hours 2-5 hours	14 hours 8 to 19 hours
4WD personnel carrier (passenger)	Mean Range	2 hours 1.5 to 2 hours	7 hours 6 to 8 hours
Grader	Mean Range	4 hours 1 to 8 hours	16.hours 5 to >24 hours
Underground mines			
4WD personnel carrier (driver)	Mean Range	5 hours 3 to 10 hours	18 hours 12 to >24 hours
4WD personnel carrier (passenger)	Mean Range	2 hours 1 to 4 hours	7 hours 4 to 14 hours
Equipment transport without suspension	Mean Range	24 minutes 7 minutes to 2 hours	2 hours 26 minutes to 8 hours
Load hall dump Type 1	Mean Range	2 hours 1 to 4 hours	8 hours 5 to 16 hours
Load hall dump Type 2	Mean Range	46 minutes 17 minutes to 4 hours	3 hours 1 to 9 hours
Rail personnel carrier (driver)	Mean Range	2 hours 1 to 5 hours	9 hours 5 to 20 hours
Rail personnel carrier (passenger)	Mean Range	3 hours 2 to 4 hours	10 hours 7 to 14 hours

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 control'.

Hazard elimination, process redesign and engineered modifications ('hard barriers') are more effective than administrative controls ('soft barriers') that rely on people's adherence to procedures or rules. 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	Elimination Substitution	e.g. use another method	**Most effective**
A number of hard and soft options may be considered and applied individually or in combination	Redesign Separation	e.g. reduction through design such as machinery design, adequate maintenance, improved roads, improved seating e.g. remote control	
	Administrative	e.g. provision of policies and procedures (speed limits), appropriate training, work breaks. job rotation and/or warning signs (known as soft barriers)	
Soft barriers	Personal Protective Equipment (PPE)	Not applicable for Whole-body Vibration	**Least effective**

FIGURE 12: Hierarchy of control

'Hard' barriers are usually much more effective in reducing high risks. These are primarily design solutions such as:

- improving road and surface conditions;
- 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.

'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 to achieve sound driving/operating skills.

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. Procedures are more effective when there are significant tangible rewards for employees or they face serious consequences such as a fatal injury or punitive measures e.g. speed limits that are monitored or enforced.

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

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 helps 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.

Training is essential to improve driver skills and to raise awareness.

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

Reducing exposure to harmful vibration cannot rely only on limiting exposure times as this may be impractical 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 whole-body vibration exposure. Hard barriers are generally listed before soft barriers (see Figure 12 on 'hierarchy of control').

Road construction and maintenance programs

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.

The best way to reduce most vibration is to control it at source by ensuring that all roads and work surfaces are smooth.

The important points to consider for roads 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:

- reduced 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 for vehicle design and suspension 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' safety and 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; solid and foam filled tyres provide little isolation of the vehicle from the road roughness.**

Cab design and layout

Good posture is extremely important for comfortable operation. Cabs should be designed so that the operator can sit in an efficient and safe posture to operate controls and can see without having to adopt awkward and potentially damaging postures. In particular, tasks that require the operators to twist in their seats to see either behind (ripping in a bulldozer) or to the side or down (grading a road) are considered poor.

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.

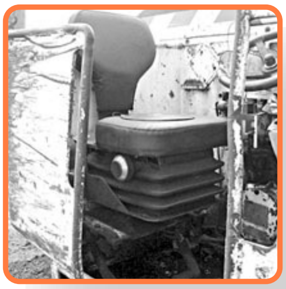
Space should be sufficient to accommodate the tallest and biggest operators in reasonable comfort while seat and control adjustments should allow the shortest operator to reach hand and foot controls.

The 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 1400 mm);**
- **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.**

The driver's space may be insufficient to allow full adjustment of the seat.

Vibration sensor on seat.



Seats must have well-shaped seat pad, backrest and lumbar support.

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. This training needs to be hands-on and provide an understanding of why the adjustments are required.

Features of a well-designed seat include seat profiles that support the back and legs but do not restrict movement; and suspension systems that do not magnify exposures and do not bottom or top out. 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, ideally, would 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.

However, no seat no matter how well designed will solve all the problems that lead to excessive vibration exposure. Appropriate seats can lessen the impact of jolts and jars and decrease discomfort but if used incorrectly they can accentuate the effects of vibration.

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 need to be simple and intuitive; easy to locate and maintain**
- **adjustment controls need to be maintained regularly;**
- **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 (180 mm minimum to 300 mm 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.

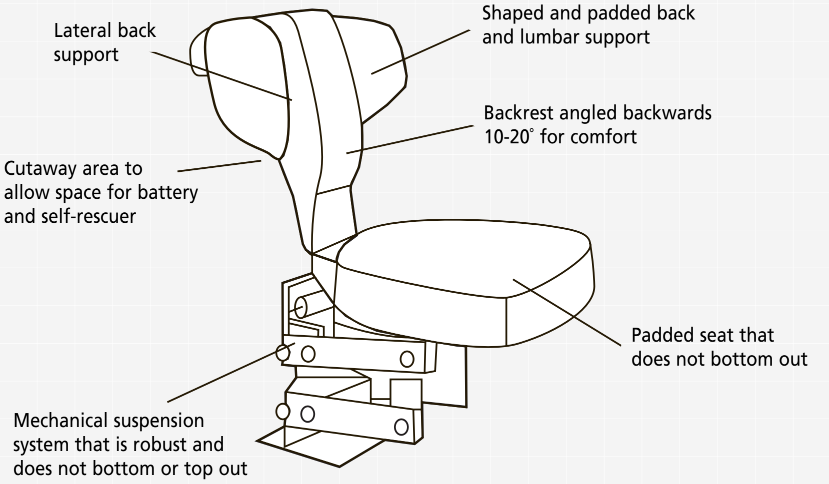
In tender documents manufacturers should be asked to supply information on the suspension systems and their specifications. This should include overhaul and parts replacement schedules and special requirements for maintaining the system in rough conditions.

Include suspension systems in planned maintenance programs.

Important points to consider in maintenance of seats suspensions 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.**

Typical seat for underground vehicle



Typical seat for open-cut vehicle

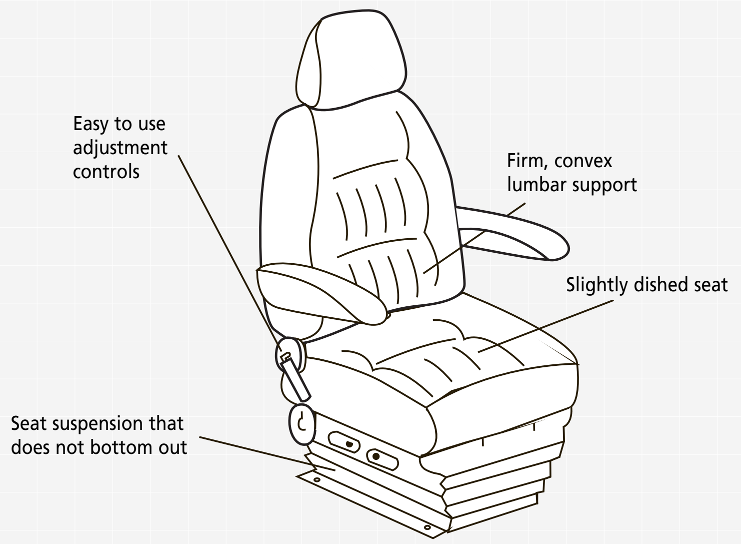
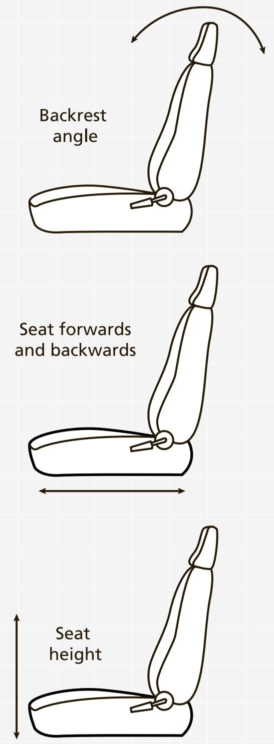


FIGURE 13: Operators' seats for mine vehicles designed using ergonomics guidelines and operational feedback.



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.**

Driver/operator training

Training of operators and drivers in ways to avoid potentially harmful vibration could prove useful and cost-effective. Drivers' and operators' 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' need to be clearly defined for each person and driver competency testing should 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.**

Instructions such as 'drive to conditions' need to be clearly defined for each person and driver competency testing should establish how well each driver can do this in terms of avoiding damaging vibration.

Where adjustable seats are provided, and suspension seats in particular, training should include:

- the purpose of the design and the controls
- how controls should be used with opportunities to practice including feedback from the trainer
- the benefits of making adjustments in terms of injury, discomfort, fatigue and efficiency
- a chart showing the controls and explaining what they do is useful as a memory aid but should not be the only instruction that the user receives.

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;
- emphasise the impact of speeding has on exposure to WBV.

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.**

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 recommended. However, just getting out of the seat for a shorter period may be sufficient to reduce discomfort and fatigue 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.

Therefore for jobs that require prolonged sitting ensure that operators:

- **take regular breaks out of the seat/cab (these can be brief but they need to be regular) and/or;**
- **regularly rotate on different types of vehicles;**
- **consider different ways of doing rough jobs that may reduce vibration exposure.**

Drivers need regular breaks out of the seat.

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.**

Section 5: Evaluation

Monitoring and evaluation

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.

Repeating tasks carried out to identify and assess the vibration exposure are often used to evaluate the success of a control.

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

- Was the vibration exposure to workers reduced? Was it to an acceptable level?
- 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?

Evaluation may be as simple as asking a range of users what they think.

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

Example 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 exposure guidelines indicated that the Caution Zone was 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 regular short breaks out of the seat and implementing job rotation.

Engineering design

- Maintain roads and work areas including areas around shovel and dump
- 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 shift.
- Regular, frequent breaks out of the seat (preferably a minimum of a few minutes within each hour. Longer and more frequent breaks are needed in 12-hour shifts).
- Training in appropriate seat adjustment
- Training and adherence to proper operating techniques

Example 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 assessed 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 track adjustment, balance etc
- 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 (preferably a minimum of a few minutes within each hour. Longer and more frequent breaks are needed in 12-hour shifts)
- Training in appropriate seat adjustment
- Training in proper and smooth operating technique

Example 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 assessed 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

- Isolate the cab from the frame of the machine
- Install effective seating
- 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 loader operator training especially in how to load and move smoothly
- Use job rotation to limit periods of loading for operators
- Ensure that operators take regular, frequent breaks out of the seat (preferably a minimum of a few minutes within each hour. Longer and more frequent breaks are needed in 12-hour shifts).
- Training in appropriate seat adjustment
- Ensure regular maintenance is carried out on vehicle, and seat if applicable, suspension systems

Example 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 40,000 km.

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 assessed 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, suspension and seat maintenance
- Ensure that passenger seats face forward and that they are properly designed to provide support and some shock absorption. Some shaping and padding can provide extra stability.
- 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.
- Ensure the vehicle has a clean windscreen and that the washer reservoir is full

Example 5: Hitting 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 indicators 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 or top out).
- Appropriate vehicle maintenance including appropriate seat maintenance and timely seat replacement.

Administrative

- Specific operator competency training for the shovel operator and truck driver
- Verbal feedback to truck driver by shovel operator on the correct positioning of the truck.

Example 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.

The roughness of the conditions and the activity of the vehicle contribute substantially to the ride roughness.

Standards assessment

The Australian Standard assessed the ride as reaching the caution zone after 1 hour and the likely health risk zone in 4 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 (preferably a minimum of a few minutes within each hour. Longer and more frequent breaks are needed in 12-hour shifts)
- Training in appropriate seat adjustment
- Training in and adherence to proper operating techniques

Section 7: Survey forms

Check sheet for vibration exposure reduction

This check sheet is to help you identify and manage vibration problems at your mine. Photocopy the check sheet, date it and use it to provide an overview of the current situation. Progressive check sheets 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.

The survey forms on p53-55 are designed to help you identify specific rides, vehicles and tasks that are rough; or to compare vehicles/machines and tasks for roughness. (See p30 for an explanation of how responses can be managed.)

Check Sheet for vibration exposure reduction

Name(s): ....

....

Mine .... Date ....:

1. Identification of vibration sources

☐ 1.1 Consult with operators, drivers, passengers and safety representatives
Action ....:

☐ 1.2 Seek operators', drivers' or passengers' ratings/opinions of vehicle roughness
Action ....:

☐ 1.3 Check road conditions and work areas
Action ....:

☐ 1.4 Take a ride in or drive 'rough' vehicles if feasible
Action ....:

☐ 1.5 Examine injury records, incident and accident records, complaints of back pain
Action ....:

☐ 1.6 Assess the severity and frequency of occurrence of injuries, discomfort or complaints
Action ....:

1.7 Confirm that problems are arising from exposure to vibration
☐ Action ....:

1.8 Determine the general nature of the problems
☐ Action ....:

1.9 Determine which vehicles/work situations might lead to excessive vibration
☐ Action ....:

2. Measurement, assessment and recording of vibration levels

☐ 2.1 Measure vibration levels in vehicles where there appear to be problems
Action ....:

☐ 2.2 Rank vehicles in terms of operator exposure levels
Action ....:

☐ 2.3 For each vehicle, rank each activity in terms of operator exposure levels
Action ....:

☐ 2.4 Assess injury risk by comparing exposure levels with health criteria in the relevant Standards
Action ....:

☐ 2.5 Establish a database of vibration levels for future reference
Action ....:

☐ 2.6 Write a priority list for vibration reduction including risks to drivers, operators and passengers
Action ....:

3. Reducing vibration exposures

Operator training

3.1 Raise awareness of the possible harmful effects of vibration amongst workers
☐ Action ....:

3.2 Train operators in what constitutes harmful vibration
☐ Action ....:

3.3 Include ways to minimise harmful vibration in competency training of drivers/operators
Action ....:

☐ 3.4 Appoint drivers/operators who are deemed competent and safe (appropriate training) especially if they are carrying passengers

Action:..:

☐ 3.5 Seek feedback from operators on problems and solutions

Action: ....:

☐ 3.6 Train operators in correct seat adjustment and their purpose

Action: ....:

☐ 3.7 Train operators in the purpose of seat suspensions where applicable. If the suspension is user adjustable include the importance of setting the suspension for the operator's weight.

Action: ....:

Road maintenance programs

☐ 3.8 Use professional road construction techniques especially for main roadways

Action: ....:

☐ 3.9 Implement road maintenance programs that are planned and systematic and not regarded as secondary to production demands

Action: ....:

☐ 3.10 Ensure dedicated vehicles and drivers for timely road maintenance

Action: ....:

☐ 3.11 Implement systems that enable rapid feedback of information on road conditions and potential problems to other drivers and operators e.g. caution markers for potholes or poor conditions

Action: ....:

☐ 3.12 Rectify problems immediately e.g. filling of pot holes, removal of materials on the road

Action: ....:

☐ 3.13 Use effective water pumps and drainage techniques

Action: ....:

Restricting speed

☐ 3.14 Apply appropriate speed limits

Action: ....:

☐ 3.15 Enforce speed limits

Action: ....:

☐ 3.16 Use speed limited vehicles in specific situations (allowing for safety constraints)

Action: ....:

Design of vehicles and suspension

☐ 3.17 Consider modifying or replacing vehicle suspension to improve ride

Action: ....:

☐ 3.18 Check that suspension systems are appropriate for loads typically carried by the vehicle

Action: ....:

☐ 3.19 Consider lowering tyre pressures on vehicles, where feasible, to improve the ride

Action: ....:

☐ 3.20 Consider replacing solid or foam filled tyres, where feasible, to improve the ride

Action: ....:

☐ 3.21 The design of vehicle suspension system must ensure that it never bottoms or tops out

Action: ....:

☐ 3.22 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

☐ 3.23 Layout of controls should be comfortable for all drivers/operators

Action: ....:

☐ 3.24 Ensure that the driver/operator does not need to adopt awkward postures to operate the vehicle or machine

Action: ....:

☐ 3.25 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: ....

☐ 3.26 Locate displays and controls consistent with conventions and standards

Action: ....

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

Action: ....

Seat design, suspension and maintenance

☐ 3.28 Seat height adjustment should be separate from suspension adjustment

Action: ....

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

Action: ....

☐ 3.30 All drivers and passengers seats should face forwards

Action: ....

☐ 3.31 All drivers'/operators' seats should be fully adjustable

Action: ....

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

Action: ....

☐ 3.33 Drivers'/operators' seats should be supportive especially in the lumbar region.

Action: ....

☐ 3.34 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: ....

☐ 3.35 Seats must never bottom or top out

Action: ....

☐ 3.36 Seats should be appropriately designed for the vehicle, the usage and the tasks

Action: ....

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

Action: ....

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

Action: ....

Maintenance of vehicle suspension systems

☐ 3.39 Implement planned maintenance programs for vehicle suspension systems

Action: ....

☐ 3.40 according to manufacturers' specifications

Action: ....

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

Action: ....

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

Action: ....

Lighting and visibility

☐ 3.43 Ensure that visibility from the cab is adequate

Action: ....

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

Action: ....

☐ 3.45 Ensure that blind spots are identified and drivers/operators trained accordingly

Action: ....

☐ 3.46 Ensure vehicle headlights are adequate

Action: ....

- [ ] 3.47 Ensure that the area/road lighting is adequate
  Action: ....
- [ ] 3.48 Consider aids (visual or audio) for drivers when positioning a vehicle in loading or filling areas
  Action: ....

Task design and work organisation

- [ ] 3.49 Consider different ways of doing a job that reduces vibration exposure
  Action: ....
- [ ] 3.50 Develop a policy on limits of rough work for bulldozers and other machines
  Action: ....
- [ ] 3.51 Encourage drivers take short, regular breaks out of the seat. These can be as short as a minute although 5 minutes in each hour and more with 12 hour shifts is recommended
  Action: ....
- [ ] 3.52 Consider a job and vehicle rotation system
  Action: ....

Shot firing standards

- [ ] 3.53 Ensure that shot firing standards are adequate
  Action: ....
- [ ] 3.54 Consider alternative methods to break up and transfer large rocks or partings when shot firing is not feasible
  Action: ....
- [ ] 3.55 Ensure that ripping is done in a way that minimises travelling over rough areas
  Action: ....

4. Monitoring and evaluation

- [ ] 4.1 Regularly re-assess vibration levels in machines and vehicles that are identified as having problems
  Action: ....
- [ ] 4.2 Ensure that vibration exposure levels are being reduced to an acceptable level
  Action: ....
- [ ] 4.3 Ensure wherever possible that 'hard barriers' are used as solutions in preference to 'soft barriers'
  Action: ....
- [ ] 4.4 Check if solutions implemented were fully effective
  Action: ....
- [ ] 4.5 If the solutions implemented were not fully effective determine which aspects did not work and why
  Action: ....
- [ ] 4.6 If the solutions worked ensure that they are durable and sustainable and recorded
  Action: ....
- [ ] 4.7 Consider the feasibility and cost of different solutions and their impact on vibration exposure
  Action: ....
- [ ] 4.8 Implement any necessary modifications
  Action: ....
- [ ] 4.9 Implement a continuous monitoring program
  Action: ....

General comments:

....
....
....
....
....

Survey Forms for rating individual rides, vehicles and tasks for roughness

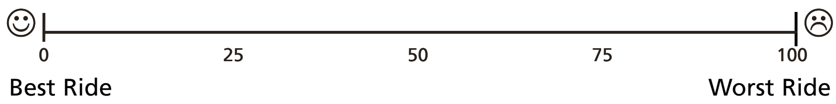
Option 1 –

Compare this ride to all other rides you have ever experienced

Instruction to Driver/Operator:

You have just finished driving/operating a vehicle/machine.

Please place a X mark on the black line to indicate where you believe that your last ride ranks in terms of roughness in comparison with the roughest and smoothest rides that you can remember.



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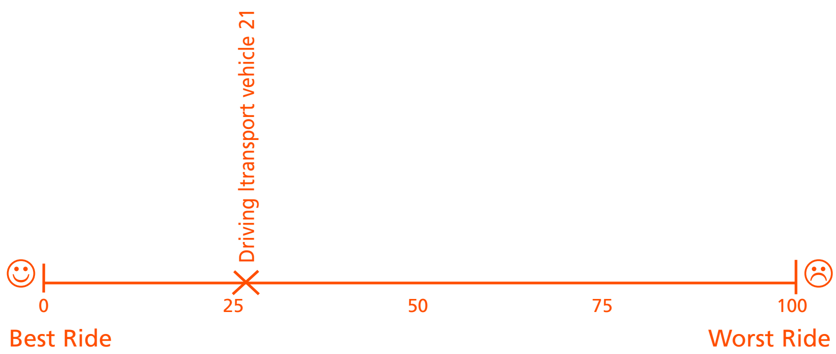

Comments: ....

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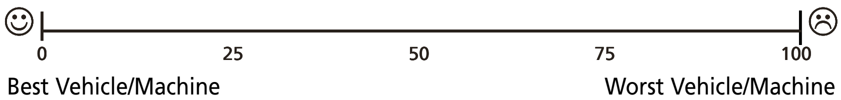
Option 2 –

Compare vehicles that you operate regularly with each other (use the vehicle name, types and/or numbers to identify each vehicle or machine e.g. dozer 261, haul truck 548, grader 6, transport vehicle 3)

Instruction to interviewee:

Please place a X mark on the black line to indicate where you believe that the ride in this vehicle ranks in terms of roughness compared with other rides that you have experienced at work in the last week. Rank all the rides on this line.



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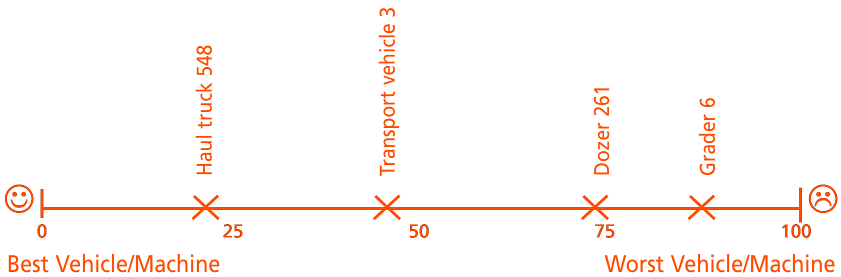

Comments: ....

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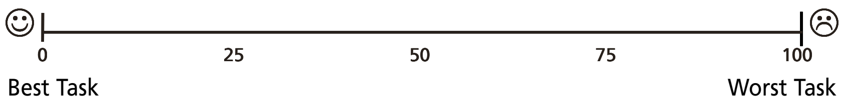
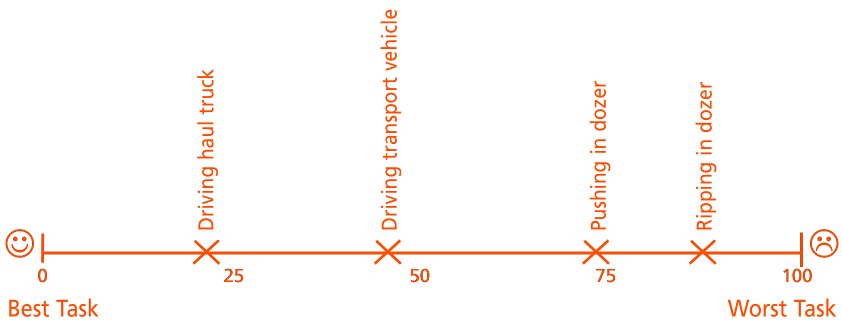
Option 3 –

Compare jobs that you do regularly (e.g. ripping, pushing, road making, light vehicle driving, haul truck driving)

Instruction to interviewee:
Please place a X mark on the black line to indicate where you believe that each driving, operating or riding task that you do ranks in terms of roughness compared with other tasks that you have done at work in the last week. Rank all the tasks on this line.



Example:



Comments:...
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