NOISE AND WHOLE-BODY VIBRATION IN UNDERGROUND LOCOMOTIVE OPERATORS

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DECLARATION

I, Sharon Southon declare that that this research report is my own work. It is being submitted for the degree of Master of Public Health in the field of Occupational Hygiene at the University of the Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination at this or any other university.

……………………………………

S.Southon

This 25th day of October 2010.

In memory of my beloved dad
Ebriahim Southon
(1944 – 2008)

ABSTRACT

Introduction

Locomotive operators in the mining industry are exposed to high levels of noise and vibration. There is currently limited information indicating whole-body vibration exposure levels conducted over an 8-hour time weighted average (TWA) exposure period; most of the available data are based on instantaneous measurements. The 10-Ton New Era locomotive was specifically designed with the focus on areas such as ergonomics, safety, future automation, productivity and flexibility of use. The locomotive has a single cab and can be driven and controlled with maximum visibility in the direction of travel. Most mining houses are converting from the use of the 10 Ton Goodman battery operated locomotive to the 10Ton New Era locomotive, hence the focus of noise and vibration measurements on the latter.

Objectives

This research report documents a project to measure noise and whole-body vibration exposure levels of locomotive operators working in an underground platinum mine. The objectives of the study are:

- to describe the eight hour time weighted average occupational noise exposure levels of locomotive operators operating the 10-Ton New Era locomotive in an underground platinum mine over 2008 and 2009;

- to describe personal whole-body vibration exposure levels of locomotive operators operating the 10-Ton New Era locomotive in an underground platinum mine over 2008 and 2009; and

- to determine whether personal noise and whole-body vibration exposure levels of locomotive operators operating the 10-Ton New Era locomotive in an underground platinum mine over 2008 and 2009 comply with national and international standards.

Methods

Personal noise and whole-body vibration exposure measurements were obtained from 21 underground locomotive operators. Measurements were conducted in accordance with the procedures described in the SANS 10083 standard for personal noise dosimetry and the ISO 2631-1 standard for whole-body vibration. Determination of likely health risks for the operators were based on a comparison of the measured time-weighted noise exposure levels with the South African OEL and the ACGIH threshold limit value; whole-body vibration levels were compared with the HGCZ limits presented in Annex B of the ISO 2631-1 standard and the EU directive daily exposure limits.

Results

The measured noise and whole-body vibration levels taken over an 8-hour TWA exposure period were higher when compared to national and international standards. The mean L_{TWA} levels for noise was 66.5 dB(A) with 12.5% of the measurements exceeding the South African OEL of 85dB(A). 45% of the whole-body vibration measurements fell within the HGCZ indicating that whole-body vibration exposure on locomotive operators presents a moderate probability for an adverse health outcome.

Discussion and Conclusion

Locomotive operators are exposed to potentially harmful levels of noise and whole-body vibration. The Mine Health and Safety Act requires an employer to assess the health and safety risks that hazards pose to their employees, and to take reasonably practicable steps towards eliminating or controlling those risks. Like any other risks at a workplace, noise and whole-body vibration needs to be identified and controlled, and the approach to be taken is one of a risk management.

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NOMENCLATURE

ACGIH	American Conference for Governmental Industrial Hygienists
awx, awy,awz	weighted r.m.s accelerations with respect to the orthogonal axes x, y, z respectively
dB	Decibel
DMR	Department of Mineral Resources
EU	European Union
HGCZ	Health Guidance Caution Zone
Hz	Hertz
IQR	Inter-Quartile Range
ISO	International Organisation for Standards
L_{TWA}	Equivalent continuous A-weighted sound pressure level LAeq,T, normalized to 8 hour as L_{TWA}
NIHL	Noise Induced Hearing Loss
NIOSH	National Institute for Occupational Safety and Health
OSHA	Occupational Safety and Health Administration
PEL	Permissible Exposure Limit
RMS	Root Mean Square
TLV	Threshold Limit Value
TWA	Time Weighted Average
VDV	Vibration Dose Value
WBV	Whole-body vibration

CHAPTER 1 INTRODUCTION

This chapter introduces the study by briefly describing the physics of noise and whole-body vibration (WBV) exposure and the significance of these hazards in the mining industry. It explains the health effects associated with noise and whole-body vibration; it describes the relevant national and international legislation as well as national and international publications related to noise and whole-body vibration measurements particularly on locomotive operators. The chapter concludes by explaining the importance and the purpose of the study and by listing the specific study objectives.

1. BACKGROUND

Mining is one of the most physically demanding occupations worldwide. It is also one of the most dangerous occupations in terms of exposure to noise and whole-body vibration. Although the need for intervention is great, the underground mine environment poses unique barriers to implementing standard noise and vibration `fixes`. The dynamic nature of the mining workplace requires that workers be made aware of risk factors and take early actions to reduce their risk of injury (NIOSH, 1997).

The prevalence of noise and the effects on the health and safety of miners have been extensively studied in the mining and related industries. Mechanical vibration on the other hand, has received far less attention while more and more mineworkers are becoming increasingly exposed to whole-body vibration through a number of transport and other mining equipment (Van Niekerk *et al.*, 2000).

In the mining industry, WBV is of particular relevance for drivers and operators of equipment which may generally be classified as transport equipment, and includes dump and haul trucks, locomotives and utility vehicles (Van Niekerk *et al.*, 1998).

As stated, there is currently limited information indicating whole-body vibration exposure levels conducted over an 8-hour time weighted average (TWA) exposure period; most of the available data are based on instantaneous measurements.

A locomotive is a railbound machine that is used for the purpose of tramming operations (ore, men and material) in or on a mine (DME, 2000). The 10-Ton New Era locomotive was specifically designed with the focus on areas such as ergonomics, safety, future automation, productivity and flexibility of use (Steele, 2007). The locomotive has a single cab and can be driven and controlled with maximum visibility in the direction of travel. Most mining houses are converting from the use of the 10 Ton Goodman battery operated locomotive to the 10Ton New Era locomotive, hence the focus of noise and vibration measurements on the latter to determine degree of exposure to these risks.

Figure 1. 10-Ton New Era locomotive currently used in the mining industry.

Figure 2. 10 Ton Goodman battery operated locomotive previously used in the mining industry.

1.1. Physics of sound and vibration

Sound and vibration both originate in the mechanical movement or excitation of machinery, its sub-assemblies and components. Movement and excitation of these objects causes their repetitive displacements and, thus, the transmission of energy into surrounding air or structures. If the level of energy is sufficient to excite a structure or the ground and the frequency of propagation is relatively low (generally below 20 Hz), the result is vibration perceptible through the tactile sense (touch). When the energy is directly or indirectly transmitted to surrounding air at a propagation frequency of 20 to 20 000 Hz, it is perceptible via the hearing sense as sound. Sound is regarded as noise if it has the potential to interfere with communication or damage people's hearing (Guild *et al.*, 2001).

The previous sentence is problematic since noise is defined in most textbooks as unwanted sound.

1.1.1. Noise

Noise consists of a large number of different frequencies of varying sound pressure levels. The frequency of sound is measured in Hertz (Hz). The frequency of a sound produces its distinctive tone. The normal range of hearing for a healthy young person extends from approximately 20 Hz to 20 000 Hz (or 20 kHz). The pressure variations move through an elastic medium (such as air) from the source of the sound to the listener's ear. Knowing the speed and frequency of sound, one can calculate the wavelength – that is, the distance from one wave top or pressure peak to the next (Bruel and Kjaer, 1999). Another quantity used to describe sound is the size or amplitude of the pressure fluctuations.

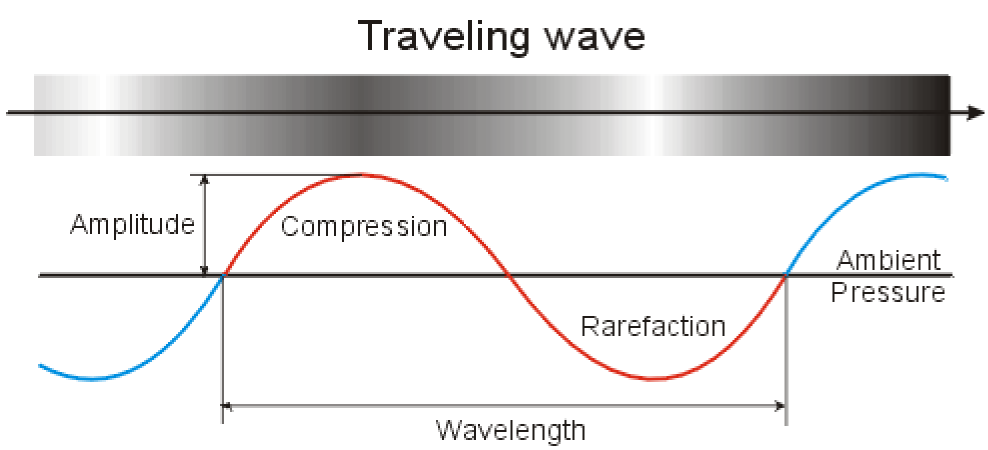

Figure 3. Illustrates the different properties of sound.

To measure sound, the decibel (dB) scale is used. The decibel is not an absolute unit of measurement. It is a ratio between a measured quantity and an agreed reference level. The dB scale is logarithmic and uses the hearing threshold of 20 millionths of a Pascal as the reference level. This is defined as 0 dB (Bruel and Kjaer, 1999).

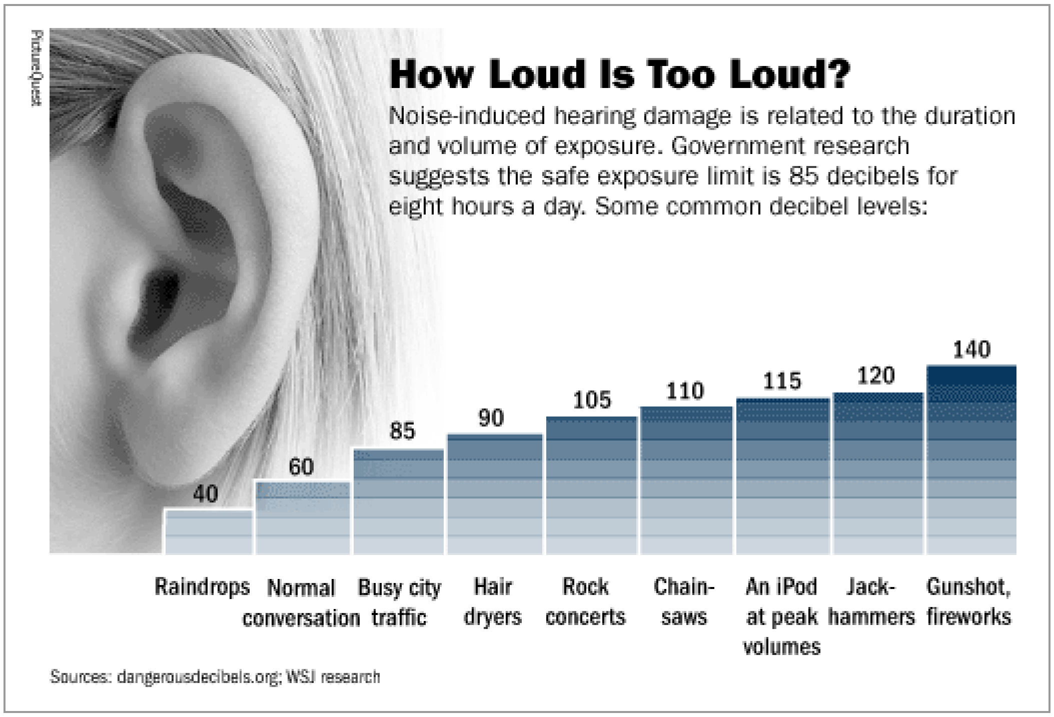

Figure 4. Is an illustration of common decibel levels.

1.1.2. Vibration

Vibration refers to oscillatory motions of solid objects. 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 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. Vibration can be segmental where the vibration is transmitted to a specific segment of the body such as the hand/arm or foot/leg, or whole-body (WBV) where the vibration is transmitted to the body as a whole by its supporting surface such as the seat or floor (McPhee *et al.*, 2000).

The motion of any vibrating particle can be charecterised at any time by it’s:

- Displacement from the equilibrium position;

- Velocity, or rate of change of displacement; or
- Acceleration or rate of change of velocity.

For simple harmonic motion, these three characteristics of motion are related mathematically. In an attempt to consolidate the large number of parameters involved in WBV measurement (i.e. mechanical, biological and psychological), the International Organisation for Standardisation (ISO) developed a standard (ISO 2631) in 1997 for defining, measuring and analysing WBV. This standard is applicable to vibration and repeated shock in the frequency range 0,5 Hz to 80 Hz (repeated shock being predominantly of low frequency i.e. 0.5 to 2 Hz) (ISO, 1997b).

1.2. Health Effects

Noise and vibration exposure produces adverse health effects in the mining industry.

1.2.1. Noise

Hearing loss from exposure to noise in the workplace is one of the most common of all industrial diseases. The health effects of noise exposure depend on the level of the noise and the length of the exposure (CCOHS, 2000).

Noise exposure can cause two types of health effects. These effects are non-auditory effects and auditory effects. Non-auditory effects include stress, related physiological and behavioural effects and safety concerns. Auditory effects include hearing impairment resulting from excessive noise exposure. Noise-induced permanent hearing loss is the main concern related to occupational noise exposure.

The main auditory effects include:

- Acoustic trauma which is sudden hearing damage caused by short burst of extremely loud noise such as a gun shot.
- Tinnitus: which is ringing or buzzing sound in the ear, and
- Temporary hearing loss: also known as temporary threshold shift (TSS) which occurs immediately after exposure to a high level of noise. There is gradual recovery when the affected person spends time in a quiet place. Complete recovery may take several hours.

Permanent hearing loss also known as permanent threshold shift (PTS), progresses constantly as noise exposure continues month after month and year after year. The hearing impairment is noticeable only when it is substantial enough to interfere with routine activities. Noise-induced hearing loss cannot be cured by medical treatment and worsens as noise exposure continues.

When noise exposure stops the person does not regain the lost hearing sensitivity. As the employee ages, hearing may worsen as \`age-related hearing loss\` adds to the existing noise-induced hearing loss.

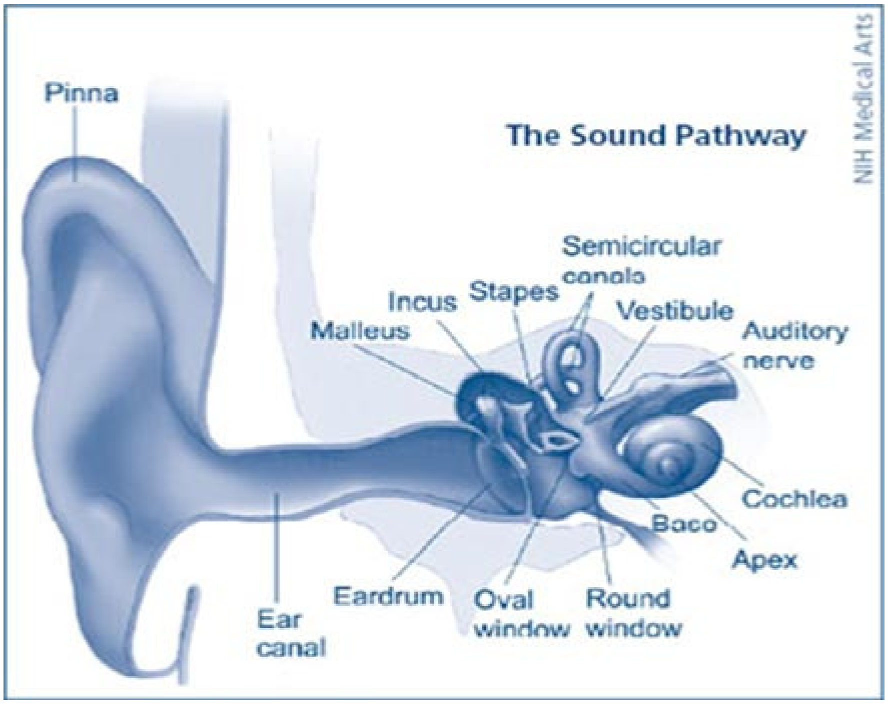

Figure 5. Is an illustration of the sound pathway in the human ear (Source: heartoronto.ca).

In addition to hearing loss, exposure to noise can cause a variety of other problems, including chronic health problems (ILO, 2006):

- Exposure to noise over a long period of time decreases coordination and concentration. This increases the chance of accidents happening.
- Noise increases stress which can lead to a number of health problems including heart, stomach and nervous disorders. Noise is suspected of being one of the causes of heart disease and stomach ulcers.
- Workers exposed to noise may complain of nervousness, sleeping problems or fatigue (feeling tired all the time)
- Excessive exposure to noise can also reduce job performance and may cause high rates of absenteeism.

1.2.2. Vibration

The transmission of vibration to the body is dependent on body posture. Exposure to whole-body vibration causes motions and forces within the human body that may:

- cause discomfort,
- adversely affect performance,
- aggravate pre-existing back injuries, and
- present a health and safety risk.

Low-frequency vibration of the body can cause motion sickness. Epidemiological studies of long-term exposure to whole-body vibration have shown evidence for an elevated risk to health, mainly in the lumbar spine but also in the neck and shoulder (Seidel and Griffin, 2000). Some studies have reported evidence of effects on the digestive system, the female reproductive organs and the peripheral veins (Seidel and Griffin, 2000).

2. LITERATURE REVIEW

In this section, publications relating to noise and whole-body vibration measurements on locomotive operators in the mining industry are considered. There were however not many international and national studies found which considered the time-weighted average personal exposures of noise and whole-body vibration over an 8-hour shift particularly on locomotive operators working in underground mines. From the studies that were published, the following national and international reports and publications (that were more closely related to this study) were selected for review.

At this point, it is important to note, that in 1998, the U.S department of transportation published a `Human Factors Guideline for Locomotive Cabs` document (USDT, 1998). The guideline evaluates working conditions and safety in a locomotive cab by addressing topics such as heating, ventilation, air conditioning, noise, vibration, toilet facilities, general consideration for cab layout, ingress and egress, visibility, seating and workstation design. The guideline describes locomotive cab noise as noise generated by the fans of ventilation systems, open windows which allow all outside noise in and adds wind noise, noise from the background of radio transmissions initiated from the cab, as well as from the horns which impact interior noise especially with open windows.

The engine, irregularities in the track and train slack movement were identified as being responsible for producing vibration and mechanical shocks on the locomotives. According to the guideline, the position of the loco operator (standing versus seated) and the direction of the vibration (vertical versus horizontal) are important factors to consider with exposure; sitting being more stressful than standing, while horizontal vibration being slightly more bothersome than vertical vibration.

2.1. Noise

In the following section, the international literature published on noise exposure and loco operators will be reviewed and discussed.

2.1.1. International perspective

According to the “Human Factors Guideline for Locomotive Cabs” document published by the U.S department of transportation, locomotive noise is low frequency dominant (USDT, 1998). Low frequency noise is identified as a source of fatigue and drowsiness and plays a role in causing noise-induced hearing loss. It also affects work-related effectiveness and health.

In his study, Maguire evaluated the sound measured at all frequencies in the acceptable range of the human ear i.e. 20 Hz to 22 KHz (Maguire, 2004). Measurement was done at the right ear of an engineer operating a 3000HP locomotive under simulated load. The result showed that 50% of the noise exposure was at or below 120Hz and that the peak loudness over the hearing range was a 60Hz component coming from the locomotive’s diesel engine. The noise from the engine that occurred at the 60Hz was almost 7% of the total noise experienced by the worker in the locomotive cab. The other engine tones from the 30Hz to 165Hz contributed to over 46% of the total noise energy present at the engineer’s ear. Maguire concluded that locomotive noise is a combination of various tones from the engine which is primarily low frequency noise. And low frequency noise is noise that is harmful and disruptive to the human ear.

In an in-depth review on Noise-Induced Hearing Loss (NIHL) in Mining, McBride reported that noise exposure and NIHL are still prevalent in the mining industry and that most of the risk comes from the need to use heavy machinery underground (MacBride, 2004). In his study, McBride included noise exposure estimates from various mining equipment used. Noise levels of the electrical locomotives ranged from 85-95dB with the average level of 90dB. The pneumatic drills used emitted the highest noise levels at a range of between 114-120dB; the average level being 117dB. The author concluded that, although hearing protection is so widely used in the mining industry, audiometric monitoring is essential and that pure tone audiometry should still be the method of choice.

Although associated with railways, but not to underground mining, Landon *et al*., summarised noise exposures on rail workers at a chemical facility in North America (Landon *et al.*, 2005). Personal noise measurements were taken from 6 workers over 18 full 12-hour shifts. From the results, 17 of the 18 samples exceeded the Occupational Safety and Health Administration (OSHA) peak impact sound levels of 140dB; with the mean peak sound level being 143.9dB. Full-shift noise exposures were all below the OSHA permissible exposure limit (PEL) and action level for a 12-hour workday. According to the report, the source of peak impact sound levels was the daily exposure from concussion caused by sudden breaks in freight airlines. The study concluded that rail workers at the chemical industry were at risk of NIHL from high impact noise exposures.

Exposure to noise and in turn NIHL continues to be one of the most pervasive problems facing today's workers. In the mining industry, hearing loss is the second most reported injury, representing 20.9% of diseases newly reported to the Mine Health and Safety Act (MHSA) in 2004 (NIOSH, 2007). Furthermore, the National Institute for Occupational Safety and Health (NIOSH) recognizes that NIHL is one of the 10 leading work-related diseases and injuries in the American workforce (Rider, 2002).

2.1.2. National perspective

The South African Department of Mineral Resources (DMR) has made NIHL a priority in the mining industry. The Mine Health and Safety Council (MHSC) has established the following milestone for limiting occupational noise exposure and eliminating noise induced hearing loss (NIHL):

"After December 2008, the Hearing Conservation Program implemented by industry must ensure that there no deterioration in hearing greater than 10% amongst occupationally exposed employees", and

"By December 2013, the total noise emitted by all equipment installed in any workplace must not exceed a sound pressure level of 110bD(A) at any location in that workplace".

In a Safety in Mines Research Advisory Committee (SIMRAC) project (GEN 420), Maneylaws *et al.*, conducted a comprehensive literature review on the sources and controls of noise in mining and from mining equipment (Maneylaws *et al.*, 1997). Data obtained in this report (GEN 420) was gathered from within the South African mining industry and in terms of locomotives, refers particularly to a study conducted by Kielblock on `A Review of Hearing Conservation in South African Mining Industry (Kielblock *et al.*, 1991). Kielblock provided a list of unprotected noise exposure levels for a range of job categories in the gold and platinum mining industry. Kielblock reported that within the gold mines, the highest noise exposure measured was from a pneumatic drill operator at 111dB(A), followed by the stoper and shift boss at 103dB(A) and 95dB(A) respectively. The loco driver's noise exposure level was measured at 95dB(A).

To further provide information on noise levels on mining equipment, GEN420, referred to a study conducted by Franz *et al.*, on dealing with the frequency spectra and personal noise exposures in gold and platinum mining (Franz and van Rensburg, 1996). The study showed personal noise exposure levels of Ancillary workers, such as diesel and electric locomotive crews to be the highest and in the range of between 93 to 94dB(A). At the time of the study, there were over 2700 diesel and over 3800 electric locomotives in operation in the industry overall, thus indicating the large number of workers who were affected by this type of equipment.

2.2. Whole-body vibration (WBV)

In the following section, the international literature published on WBV exposure and loco operators will be reviewed and discussed.

2.2.1. International perspective

In a study conducted by Eger *et al.*, the authors concluded that operators of mobile equipment, including transport vehicles, heavy industrial vehicles, mining vehicles, tractors, locomotives, buses and helicopters are exposed to potentially harmful levels of whole-body vibration (Edger *et al.*, 2006). The authors described whole-body vibration exposures experienced by mining equipment operators. In their study, they evaluated exposures of 21 male mine workers while operating mining equipment. The equipment selected included load haul dumpers, bulldozers, graders and locomotives. From the results presented, the mean frequency weighted Root Mean Square (RMS) acceleration value for the locomotive was 0.73 m/s^2 and the axis with the largest acceleration was the z-axis with a mean RMS value of 0.58 m/s^2. The locomotive operator's exposure when compared to the International Standard Organisation (ISO) standard 2631-1 in determining likely health risks was within the health guidance caution zone.

Other equipment found to have acceleration levels above the Health Guidance Caution Zone (HGCZ) limits included the cava loader with a mean RMS value of 3.60 m/s^2 and the underground haul truck at 1.56 m/s^2; both equipment having the z-axis with the largest acceleration levels. The authors conclude that increased mechanization in mining has resulted in a large number of workers exposed to longer durations of whole-body vibration.

Seidel and Heide published a review in 1986 on the long-term health effects of whole-body vibration (Seidel and Heide, 1986). The survey indicated that on average, the health risk associated with exposure to whole-body vibration, increases with higher intensity or duration of exposure. Quantitative exposure-effect relationships, could however not be derived.

Their conclusion was further supported by Wikström *et al.* in an article on the health effects of long-term occupational exposure to whole-body vibration (Wikström *et al.*, 1994). In this study the authors concluded that whole-body vibration may contribute to injuries and other problems of the lower back, however, the exposure-response relationship between vibration levels and the risk for injuries or disorders could not be clarified.

Mandal *et al.* published results on whole-body vibration exposure of heavy earth moving machinery operations in Indian mines (Mandal *et al.*, 2006). The study was conducted in open cast mines on operators exposed to whole-body vibration for over 6-8 hours per day. From the data that was analysed, 13 of the 18 equipment which was monitored had vibration levels beyond the safe limits for 4-hours operating daily as per the ISO 2631-1:1997 standard. The tested mobile equipment (dumpers, locos and dozers) indicated potential for health risk from whole-body vibration.

2.2.2. National perspective

In a SIMRAC project (GEN503) conducted by Van Niekerk *et al.,* whole-body and hand-arm vibration measurements on mining equipment were described to determine the effects on the health of workers and operators in the South African mining industry (Van Niekerk *et al.*, 1998). The study showed higher vibration exposures particularly with equipment which fell in the hand-arm category, such as, rock-drills, pavement breakers and jackhammers. The authors stated that although they experienced difficulty in interpreting whole-body vibration results as most of the measurements were obtained under sever conditions, they concluded that equipment such as front-end loaders, tractor tippers, articulated haul trucks and bull dozers, have the potential to subject the operators to vibration levels of more than 1 m/s^2. Furthermore, from an assessment of the risks associated with the various types of mining equipment, based on the measured levels of vibration, locomotives seemed to pose a moderate risk as compared to what was generally perceived as being safe levels.

Many adverse health effects have also been described in workers exposed to whole-body vibration and the literature has been reviewed in a SIMRAC study, (HEALTH 703) conducted in 2002 (Dias and Phillips, 2002). This report described the health effects of whole-body vibration into easily recognized acute effects such as discomfort, motion sickness and visual disturbances than can impair an operator's ability to control a vehicle; and into more controversial chronic effects which include diseases of the spinal column, muscular and nervous system, gastrointestinal system and urinogenital system. The most consistent association reported in this study was between lower back pain and occupations where there was exposure to whole-body vibration. The study suggested that there were some evidence for a dose-response relationship, although the evidence was relatively weak. The report also mentioned that there were very little known as to whether exposure to whole-body vibration alone was capable of producing lower back pain or if whole-body vibration constituted a risk only in combination with other factors.

3. LEGISLATION AND STANDARDS

The following standards in terms of noise and WBV are applicable internationally and nationally.

3.1. Noise

There are two bodies in the United States, the Occupational Safety and Health Administration (OSHA) and National Institute for Occupational Safety and Health (NIOSH), which set standards for matters relating to occupational health. OSHA is a government department under the Federal Government's Department of Labour and NIOSH is a specialized statutory body that researches, monitors and regulates on occupational health matters in the United States.

3.1.1. International standards

The following international standards related to occupational noise exposures will now be discussed:

3.1.1.1 European Directive 2003/10/EC

The European Parliament and the Council of 6 February 2003 (responsible for the minimum health and safety requirements regarding the exposure of workers to the risks arising from physical agents i.e. noise at work) compiled a directive 2003/10/EC officially known as `Directive 2003/10/EC (EPCEU, 2003). This directive lays down minimum requirements for the protection of workers from risks to their health and safety due to exposure to noise. Where existing European Union (EU) legislation specifies a limit of 90 decibels (dB), the directive reduced this to 87dB calculated over a period of one week. Article 4 of the directive foresees the obligation of the employer to carry out a risk assessment and lists a number of aspects for consideration in that regard.

In the directive, the following limits and action values are defined:

a) Exposure limit values: $L_{EX,8h}$ = 87dB(A) and P_{peak} = 200 Pa respectively;

b) Upper exposure action values: $L_{EX,8h}$ = 85dB(A) and P_{peak} = 140 Pa respectively;

c) Lower exposure action values: $L_{EX,8h}$ = 80dB(A) and P_{peak} = 112 Pa respectively.

Where:

* the daily noise exposure level ($L_{EX,8h}$) is the average noise exposure level for a normal 8-hour working day as defined by ISO 1999

* the peak sound pressure (P_{peak}) is the maximum value of the C-frequency weighted instantaneous noise pressure.

3.1.1.2 American Conference of Governmental Industrial Hygienists (ACGIH)

The ACGIH has established exposure guidelines for occupational exposure to noise in their Threshold Limit Values (TLVs). The following is a summary of these limits:

- Exposures are based on a 3 dB(A) exchange rate.

- The Permissible Exposure Limit (PEL) is 85dB(A). Based on the 3dB(A) exchange rate, allowable TLVs for noise range from 80 dB(A) for a 24-hour period to 139dB(A) for 0.11 seconds.

- No exposure to continuous, intermittent, or impact noise in excess of a peak C-weighted sound level of 140dB is allowed.

- A hearing conservation program is required when workers are exposed to noise above the ACGIH TLV levels.

The OSHA standard for occupational exposure to noise specifies a maximum PEL of 90dB(A) –slow response for a duration of 8-hours a day. The regulation, in calculating the PEL, uses a 5dB time/intensity trading relationship, or exchange rate. This means that for a person to be exposed to noise levels of 95 dB(A), the amount of time allowed at this exposure level must be cut in half in order to be within his OSHA`s PEL. Conversely, a person exposed to 85dB(A) is allowed twice as much time at this level (16 hours) and is within his daily PEL.

3.1.1.3 NIOSH

The National Institute for Occupational Safety and Health (NIOSH) has established guidelines for occupational exposure to noise in their Recommended Exposure Limits (REL). The following is a summary of these limits:

- An eight hour TWA limit of 85dB(A), with a 3dB(A) exchange rate.

- Implementation of a hearing conservation program at an eight hour TWA of 85dB(A).

- Using hearing protection for exposure that equals or exceeds 85dB(A) as an eight hour TWA.

- Reduction of expected performance of hearing protectors (25 percent for muffs, 50 percent for formable plugs, and 70 percent for other plugs).

3.1.2. National standards

The following national standards related to occupational noise exposures will now be discussed:

3.1.2.1 Mine Health and Safety Act

The Mine Health and Safety Act (Act 29 of 1996) and the South African National Standard (SANS) 10083, requires that workers should not be exposed to noise levels equal to or more than 85dB(A) for eight hours per day. In terms of this Act, the employers obligations specific to noise are to conduct a risk assessment, ensure noise control engineering, noise monitoring, demarcation, induction and medical surveillance are conducted. The employer is therefore required in terms of regulation 9.2.(2) of the Act to establish and maintain a system of occupational hygiene measurements (DME, 1996).

Furthermore, in accordance with section 9(2) of the Act, an employer must also prepare and implement a Code of Practice (COP) on any matter affecting the health and safety of employees and other persons who may be directly affected by activities at the mine if the Chief Inspector of Mines requires it. The key elements addressed in the guideline on the compilation of a COP for noise exposure (DME, 2000) are:

- Noise assessment and control
- Personal exposure monitoring
- Education and training
- Hierarchy of controls

- Medical surveillance, and
- Reporting and reviewing

3.1.2.2 SANS 10083

SANS 10083 is a South African standard and was approved by the National Committee STANSA TC 76 (Standards South Africa Technical Committee) Acoustics, electroacoustics and vibration, in accordance with procedures of Standards South Africa, in compliance with annexure 3 of the WTO/TBT (World Trade Organisation/Technical Barriers to Trade) agreement (SANS, 2004). The standard covers the procedures to be followed where hearing conservation measures are to be identified and hearing conservation programmes are to be applied in terms of the relevant legislation. It covers the measurement and rating of a working environment for hearing conservation purposes, the physical demarcation of an area where hearing conservation measures have to be applied and medical surveillance. Annexure D of the standard describes the procedure for the use of personal sound exposure meters which are used to determine noise exposures where employees do not have fixed working positions.

3.2. Vibration

Currently there are no regulations in the South African mining industry that place a limit on the vibration to which a worker may be subjected. The DMR is in a process of developing guidelines on evaluation of occupational vibration exposure for the mining industry. This document is currently only available in draft format (DME, 2007). The following legislation and standards on vibration were considered:

3.2.1. International standards

The following international standards related to occupational exposure to whole-body vibration will now be discussed:

3.2.1.1 EU Directive 2002/44/EC

This directive seeks to introduce minimum requirements for workers when they are exposed, in their course of their work, to risks arising from vibration (EPCEU, 2002). The directive gives exposure limit values and action limit values. It specifies the employer's obligations with regard to determining and assessing risks, sets out the measures to be taken to reduce or avoid exposure and details how to provide information and training for the workers.

The vibration directive sets an exposure action value, above which it requires employers to control the whole-body vibration risks of their workforce and an exposure limit value above which workers must not be exposed. The key limits addressed in the EU Good Practice Guide for whole-body vibration (EU, 1997) are:

a) a daily exposure action value of $0.5 m/s^2$

b) a daily exposure limit value of $1.15 m/s^2$

The assessment of the level of exposure to vibration is based on the calculation of daily exposure A(8) expressed as equivalent continuous acceleration over an eight-hour period, calculated as the highest (rms) value or the highest vibration dose value (VDV) of the frequency-weighted accelerations (BSI, 1987).

3.2.1.2 ISO 2631-1: 1997

The primary purpose of ISO 2631-1: Mechanical vibration and shock – Evaluation of human exposure to whole-body vibration (ISO, 1997b), is to define methods of quantifying whole-body vibration in relation to:

- human health and comfort;
- the probability of vibration perception; and
- the incidence of motion sickness

The standard incorporates the assessment methods for both steady state and shock type vibration. It considers vibration in the frequency range of 0.5 Hz to 80 Hz for the evaluation of the effects on health. In terms of the standard, vibration health exposures are classified as being either:

- in the likely health risk zone – (likely health risk)
- in the caution zone – (potential health risk), and
- below the caution zone –(`acceptable` level of vibration)

Vibration exposures in the caution zone indicate potential health effects, while exposures above the caution zone indicate that health risks are likely. For exposures below the caution zone, health effects have not been clearly documented and/or objectively observed.

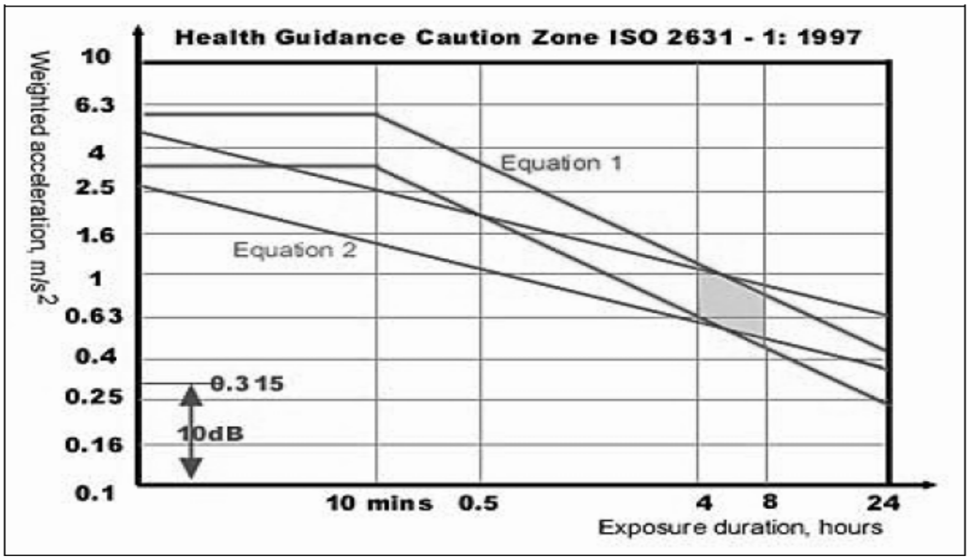

Figure 6. Whole-body vibration health guidance zone (ISO, 1997b).

3.2.1.3 Other standards

The American National Institute (ANSI) and the American Conference of Governmental Industrial Hygienists (ACGIH), have developed standards and threshold limit values (TLV`s) for measuring and quantifying vibration (AS, 2001).

The United States makes use of the ACGIH exposure limits with the frequency weighting based on ISO 5349 standard with a total exposure limit of 4 m/s^2 for between 4 hours and 8 hours exposure. The USA use the ANSI S2.70 – 2007 standard, a revision of the ANSI S3.34 standard of 1986 (Guide for the measurement and evaluation of human exposure to vibration transmitted to the hand standard).

The Australian standard (AS 2670.1 – Evaluation of human exposure to whole-body vibration) was published in 1990 and was a complete adoption of the ISO 2631 – 1, 1985 (DME, 2007).

Guidelines can also be found in BS 6841. WBV is measured by placing accelerometers under the seats of vehicles. The standards for measuring equipment are covered in ISO 8041. Canadian jurisdiction does not have regulations concerning vibration exposures (DME, 2007).

International limit standards are summarized as per Table 1 below.

Table 1. *International Standards on vibration exposure.*

	Whole-body vibration		Hand-arm vibration	
	Exposure limit value	**Exposure action value**	**Exposure limit value**	**Exposure action value**
Europe	1,15m/s^2 (8)	0,5m/s^2 (8)	5m/s^2 (8)	2,5m/s^2 (8)
UK	1,15m/s^2 (8)	0,5m/s^2 (8)	5m/s^2 (8)	2,5m/s^2 (8)
America – ACGIH	-	-	4m/s^2 (8)	-
Canada	-	-	-	-
South Africa	-	-	-	-
Australia			-	-
NIOSH	-	-	-	-

3.2.2. National standards

The following national standard related to occupational exposure to whole-body vibration will now be discussed:

3.2.2.1 SANS 2631

There are currently no South African standards governing the exposure limits to whole-body vibration and there is no defined limit for vibration for vehicle operators. The South African National Standard (SANS) has adopted ISO 2631 as SANS 2631-1 as the standard for measuring whole-body vibration in this country.

4. IMPORTANCE OF THE STUDY

One of the most prevalent occupational injuries in the South African mining industries is Noise Induced Hearing Loss (NIHL). According to the Rand Mutual Assurance Company Limited Guide to Noise-induced Hearing Loss (SANS, 2004), NIHL is responsible for ±15% of all claims submitted to Rand Mutual Assurance (RMA), and accounts for ±45% of costs paid out by the RMA to claimants.

Vibration on the other hand is classified as one of the physical occupational hygiene hazards in the workplace. As a hazard, vibration has not received the required recognition when compared to other occupational hygiene hazards. Apart from whole-body vibration being a difficult hazard to measure and evaluate, there is currently no South African standards governing the exposure limits to whole-body vibration and there is no defined limit for vibration for vehicle operators.

The South African Mine Health and Safety Act, Act 29 of 1996, Section 11 (1) (b) (c) requires that every employer must identify and assess the risks to health and safety to which employees may be exposed while they are at work, hence the reason for conducting the study.

5. PURPOSE OF THE STUDY

A risk assessment process ensures that factors influencing health are fully understood and adequately quantified so that decisions regarding risk control are taken in a consistent and cost effective manner.

The fundamental purpose of this study is therefore to identify whether noise and whole-body vibration exposure may be a health and safety risk to locomotive operators working in an underground mine.

6. OBJECTIVES OF THE STUDY

The specific objectives of the study are:

- to describe the eight hour time weighted average occupational noise exposure levels of locomotive operators operating the 10-Ton New Era locomotive in an underground platinum mine over 2008 and 2009;
- to describe personal whole-body vibration exposure levels of locomotive operators operating the 10-Ton New Era locomotive in an underground platinum mine over 2008 and 2009; and
- to determine whether personal noise and whole-body vibration exposure levels of locomotive operators operating the 10-Ton New Era locomotive in an

underground platinum mine over 2008 and 2009 comply with national and international standards.

CHAPTER 2 METHODS AND MATERIALS

This section describes the study site and considers significant locomotive specifications which may contribute to the exposure levels of noise and whole-body vibration. The noise and whole-body vibration measurement procedure and data analysis technique are also described.

1. STUDY DESIGN

A descriptive study was used to determine the levels of exposure to noise and whole-body vibration experienced by a group of employees whose job required them to drive locomotives in an underground platinum mine. Forty noise and 20 whole-body vibration measurements were taken during the months of July and August 2008 and 2009. At the time of measurement, the mine had a total of 605 locomotive operators appointed. In total, 21 operators were included in the study. They were randomly selected by the mine's SAP software programme in the mornings when the workers reported for work.

The operators were selected randomly from the Mine's Human Resource report and were invited to participate in the study. Measurements were conducted during afternoon shifts as this was when most of the tramming operations took place.

2. STUDY SITE

The Mining Group has five main operating mines in the North- West and Limpopo province. The Platinum Mine selected for this study is situated in the north western limb of the Bushveld Igneous Complex between the towns of Northam and Thabazimbi in the Limpopo Province and comprise some 7 500 hectares.

It is the second largest platinum mine in the world and produces some 655 000 ounces of refined platinum per year. The mine employs approximately 10 000 people, most of whom are housed on the mine and in the town of Thabazimbi.

The two economically payable reefs that are being mined are the Merensky and UG2 Reefs. The Merensky reef, which is considered the primary reef, has been extracted before the UG2 and has subsequently advanced far ahead of the UG2. Mining the Merensky reef takes place with a typical scattered breast, underhand mining layout. Crushing takes place closer to the face as the depth of the working increases.

This site was selected due to easy access to the workings as well as its history of stable ground conditions.

The following section briefly describes the specifications of the locomotives that were operated by the study participants.

2.1. Locomotive specifications

A locomotive is a railbound machine that is used for the purpose of tramming operations (ore, men and material) in or on a mine.

The New Millenium Battery operated locomotive used at the Mine has been specifically designed with the focus on ergonomics, safety and flexibility of use.

The locomotive has a single cab and can be driven and controlled with maximum visibility in the direction of travel. The 750 DC traction motor is incorporated in the design with up to date control and braking features. The locomotive is such that it can be operated as or converted to remote control, tandem operation or full automation as can be seen in figure 7.

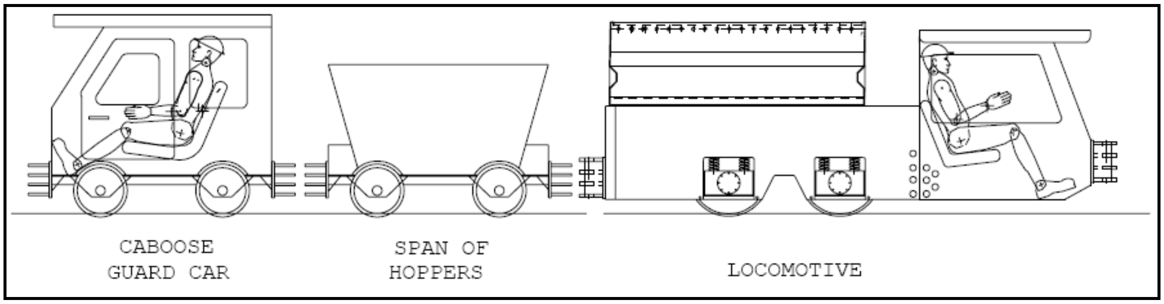

Figure 7. The design of the 10-Ton New Era locomotive.

2.1.1. Driver's compartment

The floor plate dimensions are 1145mm X 1100mm. A pushbutton control and headlight switch is mounted in the controller which is fitted in a suitable position in the driver's compartment. The controller is mounted on a hinged door inside the cab. A roof, which offers adequate protection to the electrics in this compartment against falling stones and dripping water, is fitted. The roof does not hamper the driver in any way.

A rubber-covered seat with backrest is provided to ensure the driver's maximum comfort and visibility as illustrated in figure 8. The seat has built in suspension and is fitted with a lap belt. The T type backrest provides space for a cap lamp battery and rescue pack that may be worn by the driver.

The front window is manufactured from 6 mm shatterproof glass that is laminated and mounted in a removable steel frame with rubber that extends along the full edge. The door slides open along the door of the loco thus avoiding side clearance problems and allows for easy ingress and egress. Natural through ventilation is provided by cut outs and vents.

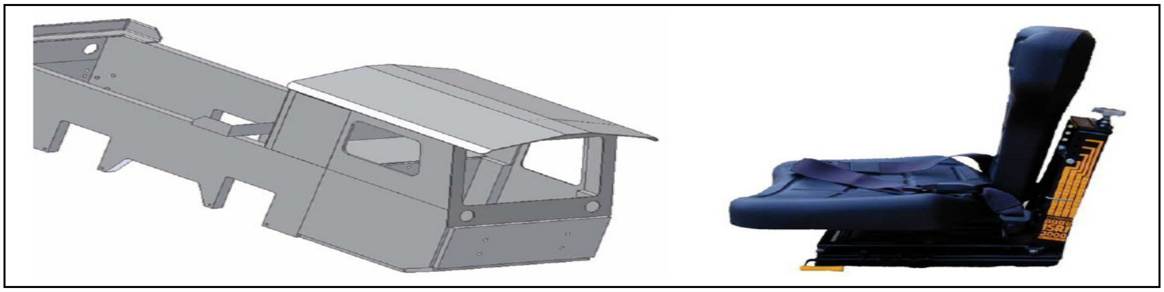

Figure 8. The rubber-covered seat with built in suspension.

2.1.2. Locomotive suspension

Four rubber suspension elements selected for maximum vibration frequency spectrum coverage and maintenance free durability are mounted on the axle box to provide four-point suspension between chassis and axle boxes as can be seen in figure 9 below.

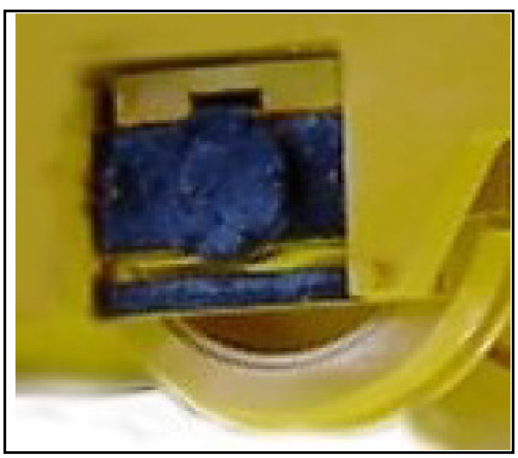

Figure 9. The rubber suspension elements mounted on the axle box.

3. MEASUREMENT METHODOLOGY

The following measurement methodologies were considered for the quantification of occupational noise and whole-body vibration exposures of the locomotive operators:

3.1. Noise measurement methodology

Noise measurements were done according to SANS 10083:2004 standard which stipulates the requirement for an integrated Type 2 precision (SANS 61672-1 & SANS 61672-3) sound level meter to assess occupational exposure.

The manufacture's instruction was used to ensure proper operation.

- The Casella Cel-350 dose badge was used for noise measurements
- The dosimeters were calibrated before and after use in accordance with the SANS standard. Dosimeters were calibrated to 114dB.
- During use, the badge was fitted with a windshield. This was to protect the microphone from any erroneous results from wind, but also help to protect from any dust ingress, moisture or impact damage.
- At the workings, the badges were mounted by clipping them onto the operators` overall collar. According to the standard, this is acceptable as it is within the zone close to the ear.
- The measurement run was started at the beginning of the shift and stopped at the end of the shift. A normal working shift is 8 hours.
- The instrument automatically displayed the results from the completed run as soon as the measurement run was stopped.

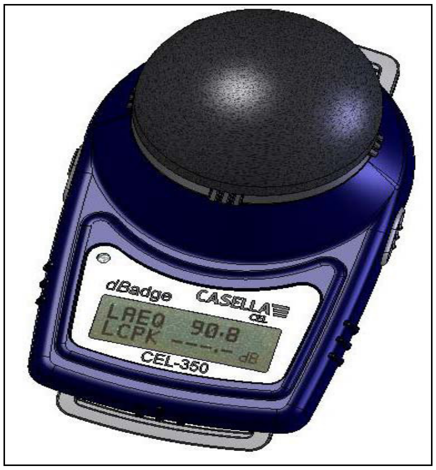

Figure 10. CEL 350 noise dosimeter badge used for the noise measurements.

3.2. Whole-body vibration measurement methodology

Whole-body vibration measurements were conducted in accordance with the ISO 2631-1: Mechanical Vibration and Shock – Evaluation of Human Exposure to Whole-body Vibration – Part 1: General requirements (1997).

The ISO standard provides exposure guidance based on the Health Guidance Caution Zone or equivalent vibration dose values based on exposure duration.

For the purpose of risk management, the EU directive was used to provide guidance to which action should be taken to reduce exposure levels above the daily exposure action value which is set for daily (8-hour) exposure or the daily exposure limit value.

The manufacture's instruction was used to ensure proper operation.

- Whole-body vibration was measured using the Quest HAVPRO vibration meter which was calibrated prior to testing.

- The operators were briefed on the purpose of the measurements.

- The seat pad containing the tri-axial accelerometer, model 356A67, was placed on the seat of the locomotive’s cab. The operator was requested to sit firmly on the pad.

- Placement of the sensors on the seat was according to the ISO 2631 standard; the X-axis (to the front), the Y-axis (to the left) and the Z-axis (to the top). Accelerations were measured along the three axes in order to retrieve the operator’s whole-body exposure.

- A measurement cycle started with the locomotive moving from the tip with the hoppers being empty, to the cross-cut where the hoppers were being filled with ore and back to the tip where the ore was offloaded. This cycle was completed in approximately 60 minutes.

- Data obtained during measurements were downloaded to a PC using the Quest suit Professional II software for whole-body vibration.

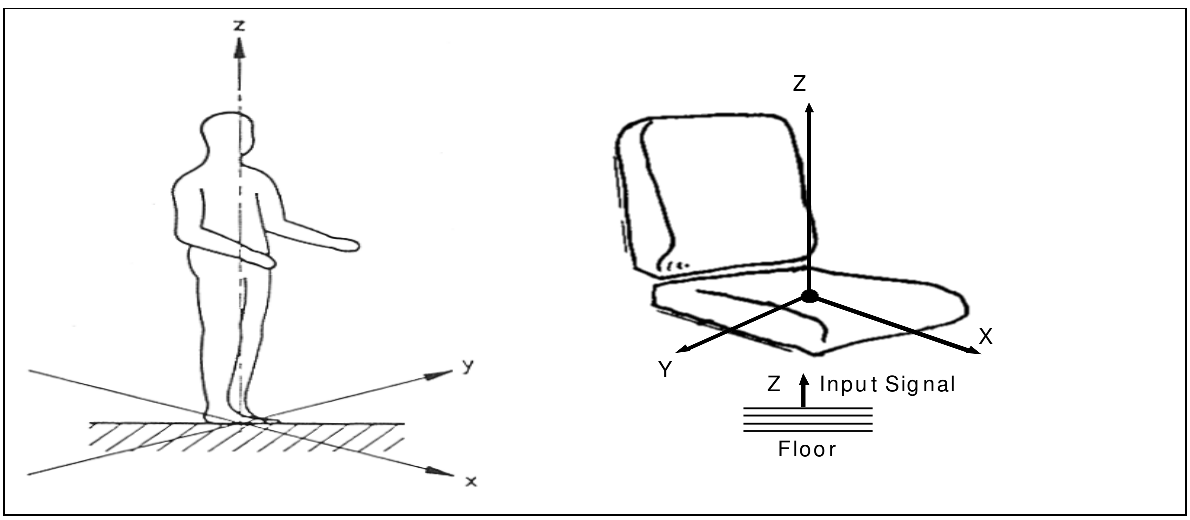

Figure 11. Whole-body vibration measurement co-ordinate system (as described in ISO 2631-1).

4. QUALITY CONTROL

A quality control system was in place for all the noise and whole-body vibration measurements. All measurements were conducted with the assistance of an occupational hygiene assistant and shadowed by an experienced Occupational Hygienist registered with the South African Institute for Occupational Hygiene (SAIOH) for the purpose of quality assurance of the data. Both instruments measuring the noise and whole-body vibration exposures were calibrated as per the specifications of the manufacturers.

5. DATA ANALYSIS AND MANAGEMENT

Descriptive analyses were calculated using the S-PLUS (version 6.2) software package. Both the noise and whole-body vibration measurements could best be described with a lognormal distribution. To describe the average and measures of central tendency for the concentrations, geometric means and geometric standard deviations were used (Tables 3 and 5). As can be seen in Table 2, the noise measurements are presented by sample number, measurement time (in minutes), peak and L_{TWA} exposures (in dB(A)) and were evaluated against reference values of 85dB(A) (South African Occupational Exposure Limit) and 90 dB(A) (American Conference of Governmental Industrial Hygienists Threshold Limit Value).

As can be seen in Table 4, whole-body vibration measurements are presented by sample number, measurement time (in minutes) and frequency-weighted Root Mean Square (RMS) values and were evaluated against reference values of the

ISO 2631-1 health guidance caution zone and the EU Directive for Daily Personal Vibration Exposure of 1.1.5 m/s^2.

6. ETHICS

Ethics approval for this study has been sort and granted by the University of Witwatersrand Human Research Ethics Committee (Medical), ethics approval number R14/49 (see Appendix I). In summary, workers were invited to participate in the study and informed consent was obtained from all study participants. Confidentiality was respected regarding the mining company where the study was conducted as well as to all study participants.

CHAPTER 3 RESULTS

This chapter deals with the presentation and interpretation of the personal noise and whole-body vibration data collected from underground locomotive operators. For the purpose of imparting clarity, the results will be presented in the form of tables and box plots.

1. NOISE EXPOSURE RESULTS

The first objective was to describe the eight hour time weighted average occupational noise exposure levels of locomotive operators operating the 10-Ton New Era locomotive in an underground platinum mine over 2008 and 2009.

The noise exposure data was analysed according to the appropriate SANS 10083 standard and the results compared to both the South African Occupational Exposure Limits and the ACGIH Threshold Limit Values for noise. LAeq,(8h) equals the equivalent continuous A-weighted sound pressure level occurring over the measured time. In this study, the terms LTWA and LAeq,(8h) are used interchangeably.

Table 2 below gives a summary of the time weighted average results of noise. A total of 40 personal noise dosimetry measurements were taken on the operators while operating the locomotives. The average measurement duration was 591 minutes. The mean LTWA value for the operators was 66.5dB(A), with the minimum and maximum LTWA values being 52.2 and 95.4dB(A) respectively.

Table 2. *Summary of L_{TWA} noise exposure results for locomotive operators (unit: dB(A))*

	Sample no	Measurement time (min)	Peak	L_{TWA}
	1	626	127.8	95.4
	2	511	130.6	57.6
	3	514	133.1	86.7
	4	538	114	62.9
	5	550	129.9	55.5
	6	739	116.2	68.7
	7	648	122.7	76.1
	8	588	106.5	57.4
	9	703	111.8	64.1
	10	660	143.5	100.7
	11	581	99.7	54.1
	12	496	133.6	86.1
	13	524	108.4	61
	14	564	140.1	82.1
	15	576	115.5	62.1
	16	668	136.8	92.1
	17	626	106.1	64.1
	18	616	114.3	69.2
	19	633	106.9	56
	20	722	109.4	84.8
	21	647	101.2	57.9
	22	665	106.7	66.1
	23	633	101.5	60.8
	24	641	139.5	60.5
	25	632	112.8	60.7
	26	627	125.6	75.9
	27	641	143.5	59.1
	28	547	119.2	56
	29	551	111.8	53.5
	30	534	125.2	57.7
	31	547	96.8	52.2
	32	504	114.4	56.5
	33	518	105.9	55.3
	34	734	120.4	62.9
	35	541	121.1	69
	36	553	117.2	57.8
	37	548	143.5	77.2
	38	508	111.4	65.4
	39	507	112.8	62.1
	40	461	95.9	56.7
Avg	**n=40**	**591**	**118.3**	**66.5**

Additional statistical information is presented in Table 3 and Figure 12. The data are not normally distributed but has a skew distribution to the right; therefore the geometric mean (GM) as well as the geometric standard deviation (GSD) has been included. The GSD is denoted by the formula:

$$e^{\sqrt{\frac{1}{n}\sum_{i=1}^{n}(\log X_i - \log(GM))^2}}.$$

SD (Mean) stands for Standard error of the Mean, which is a widely used measure of the variability or dispersion; this is not the standard error of the geometric mean. The GSD is demanded as a measure of the accuracy of the geometric mean. The GM indicates the central tendency of the data.

Table 3. *Statistical representation of personal noise exposure data (dB(A))*

N	Mean ± SD (Mean)	Median± SD (Med)	GM± GSD	Min	Max	IQR
40	66.5 ± 1.99	62.1 ± 1.10	65.46 ± 1.19	52.2	100.7	70.88 -57.55 =13.3

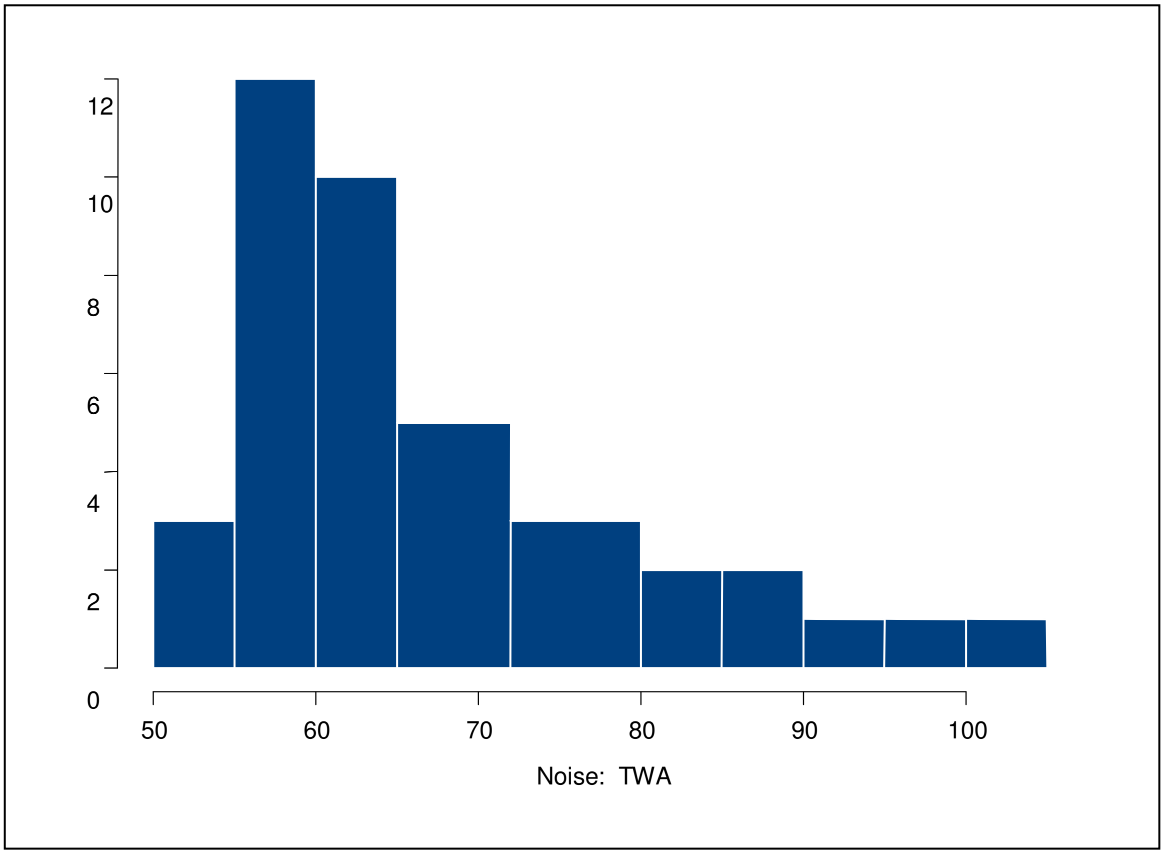

Figure 12. Illustrates the asymmetrical distribution of TWA noise data

Figure 13 below represents the statistical data in the form of a box plot. From below, the following lines are indicated on the box plot:

- The Lower Extreme (excluding the outliers – there are not any outliers indicated on the lower side). Note that any value further than 1.5 times the Inter- Quartile Range (IRQ) is considered an outlier.

- The Lower Quartile, i.e. the beginning of the red section below.

- The Lower Confidence bound for the Median (95%), i.e. the beginning of the blue section below.

- The Median, which is the white line.

- The Upper Confidence bound for the Median (95%), i.e. the end of the upper blue section.
- The Upper Quartile, i.e. the end of the red upper section.
- The Upper Extreme excluding the outliers.
- The Outliers indicated with lines marked with a small geometric figure (the noise data has 2 outliers).

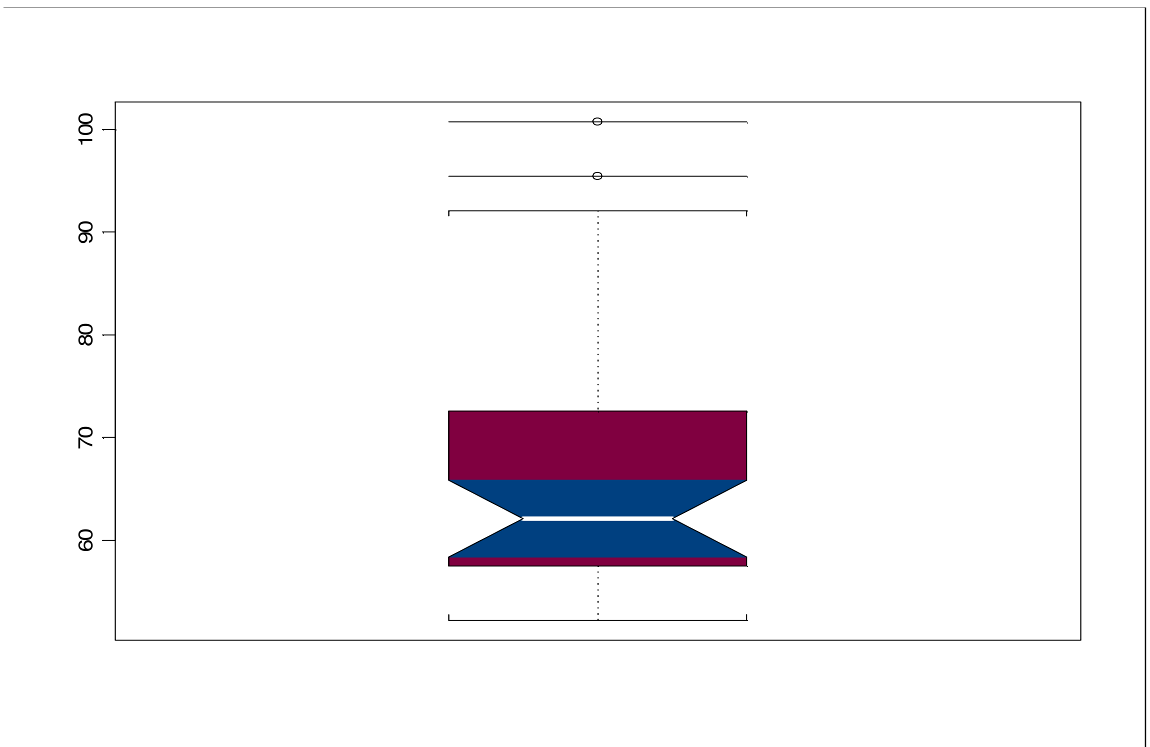

Figure 13. Box plot of L_{TWA} noise exposure of locomotive operators

2. WHOLE-BODY VIBRATION EXPOSURE RESULTS

The second study objective was to describe personal whole-body vibration exposure levels of locomotive operators operating the 10-Ton New Era locomotive in an underground platinum mine over 2008 and 2009

ISO standard 2631-1 provides guidance to interpret the possible health effects of vibration exposure.

Table 4. *Summary of whole-body vibration results*

			Frequency-weighted RMS						
Sample no.	**Measurement time (min)**	**Axis**	**RMS**	**∑RMS**	**Amin**	**Amax**	**A(8)**	**∑A(8)**	**Classification according to the ISO 2631 HGCZ**
1	105	x	0.344				0.36		
		y	0.338				0.35		
		z	0.521	0.709	0.003	4.104	0.39	**0.64**	Caution with respect to health risks - vibration shock
2	142	x	0.267				0.28		
		y	0.357				0.37		
		z	0.438	0.624	0.006	2.866	0.33	**0.53**	Caution with respect to health risks.
3	39	x	0.751				0.78		
		y	0.8				0.84		
		z	0.913	1.785	0.001	60.54	0.68	**1.95**	Likely damage to body - huge vibration shock
4	96	x	0.256				0.26		
		y	0.269				0.28		
		z	0.374	0.527	0.004	1.897	0.28	0.42	Acceptable
5	101	x	0.383				0.4		
		y	0.408				0.42		
		z	0.467	0.727	0.002	1.938	0.35	**0.7**	Caution with respect to health risks
6	190	x	0.36				0.37		
		y	0.39				0.4		
		z	0.477	0.712	0.002	1.938	0.35	**0.65**	Caution with respect to health risks
7	141	x	0.422				0.44		
		y	0.375				0.39		
		z	0.512	0.76	0.003	2.953	0.38	**0.74**	Caution with respect to health risks - some vibration shock
8	67	x	0.181				0.18		
		y	0.191	0.375	0.002	2.013	0.2	0.26	Acceptable

			z	0.268				0.2		
	9	114	x	0.256				0.26		
			y	0.221				0.23		
			z	0.4	0.523	0.003	1.816	0.3	0.41	Acceptable
	10	150	x	0.288				0.3		
			y	0.263				0.27		
			z	0.459	0.601	0.003	2.314	0.34	0.49	Acceptable
	11	65	x	0.019				0.02		Caution with respect to health risks - vibration shock
			y	0.024				0.02		
			z	0.06	0.074	0.002	0.415	0.05	0.02	
	12	180	x	0.229				0.24		
			y	0.229				0.24		
			z	0.341	0.47	0.001	2.005	0.25	0.36	Acceptable
	13	177	x	0.164				0.17		
			y	0.148				0.15		
			z	0.298	0.371	0	1.328	0.22	0.24	Acceptable
	14	150	x	0.234				0.24		
			y	0.228				0.23		
			z	0.357	0.484	0.001	2.013	0.26	0.36	Acceptable
	15	48	x	0.269				0.28		
			y	0.252				0.26		
			z	0.363	0.517	0.005	2.302	0.27	0.42	Acceptable
	16	129	x	0.341				0.35		Caution with respect to health risks
			y	0.444				0.46		
			z	0.534	0.772	0.006	2.44	0.4	**0.72**	
	17	76	x	0.282				0.29		
			y	0.328				0.34		
			z	0.438	0.614	0.003	2.34	0.32	**0.51**	Acceptable
	18	126	x	0.307				0.32		Caution with respect to health risks - shock
			y	0.402				0.42		
			z	0.49	0.702	0.001	3.409	0.36	**0.63**	
	19	67	x	0.291				0.3		Caution with respect to health risks
			y	0.373				0.39		
			z	0.457	0.655	0.006	2.423	0.34	**0.57**	
	20	77	x	0.256				0.26		
			y	0.23				0.24		
			z	0.466	0.592	0.004	1.787	0.34	0.43	Acceptable
Average			**Overall mean**					**Overall mean**		
			x	**0.3**				**0.31**		
			y	**0.31**				**0.325**		
	N= 20	**112**	z	**0.431**	**0.63**	**0.003**	5.142	**0.321**	**0.55**	

Table 4 gives a summary of the whole-body vibration exposure measurements. Vibration exposure was dominant in the z-axis, and the average frequency-weighted RMS acceleration for the z-axis was 0.431m/s2. It is important to note that in an entire 8-hour work shift, operators spent approximately 1hour 30 minutes travelling from the Tip to the Cross-cut boxes and back to the Tip to load and off-load ore. The total daily duration of vibration exposure from the locomotives was 4.5 hours.

In order to predict the health risk associated with the operating of the locomotive, the 8-hour equivalent frequency-weighted RMS acceleration value A(8) was calculated.

The whole-body vibration data are further presented statistically in Table 5 and Figure 14.

Table 5. *Statistical representation of whole-body vibration exposure data*

N	Mean ± SD (Mean)	Median± SD (Med)	GM± GSD	Min	Max	IQR
20	0.55 ± 0.084	0.50 ± 0.055	0.44 ± 2.29	0.02	1.95	0.64 -0.40 =0.24

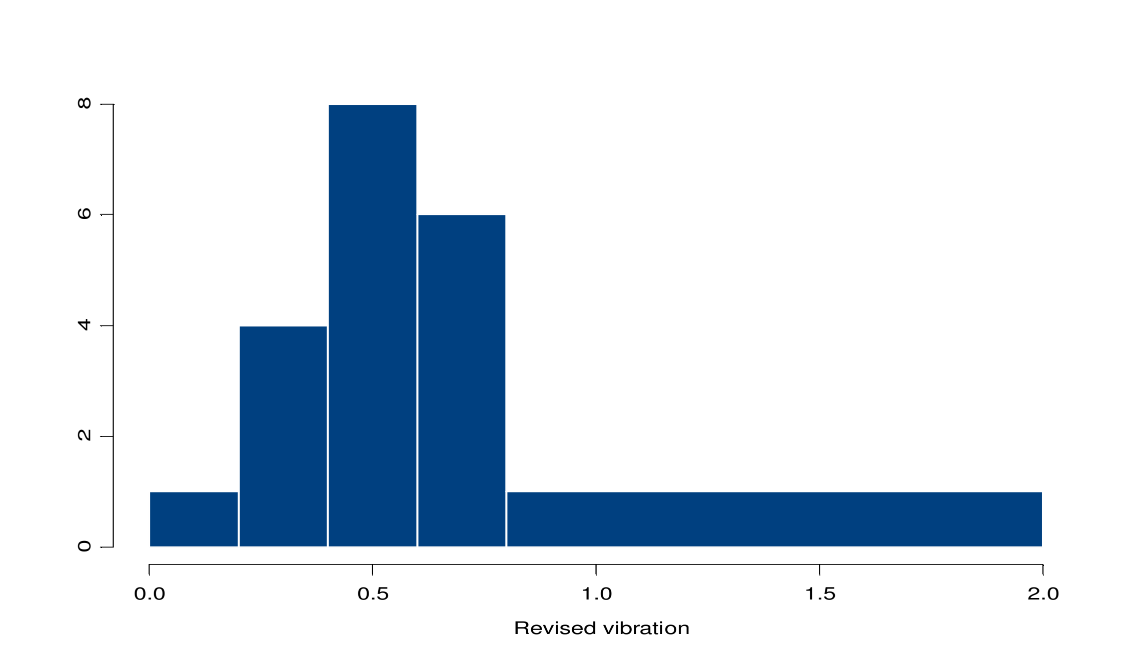

Figure 14. Histogram representing 20 whole-body vibration observations

As with the noise measurement data described above, the data are not normally distributed but has a skew distribution to the right; therefore the geometric mean (GM) as well as the geometric standard deviation (GSD) has been included. The GSD is denoted by the formula:

$$e^{\sqrt{\frac{1}{n}\sum_{i=1}^{n}(\log X_i - \log(GM))^2}}.$$

SD (Mean) stands for Standard error of the Mean, which is a widely used measure of the variability or dispersion; this is not the standard error of the geometric mean. The GSD is demanded as a measure of the accuracy of the geometric mean. The GM indicates the central tendency of the data.

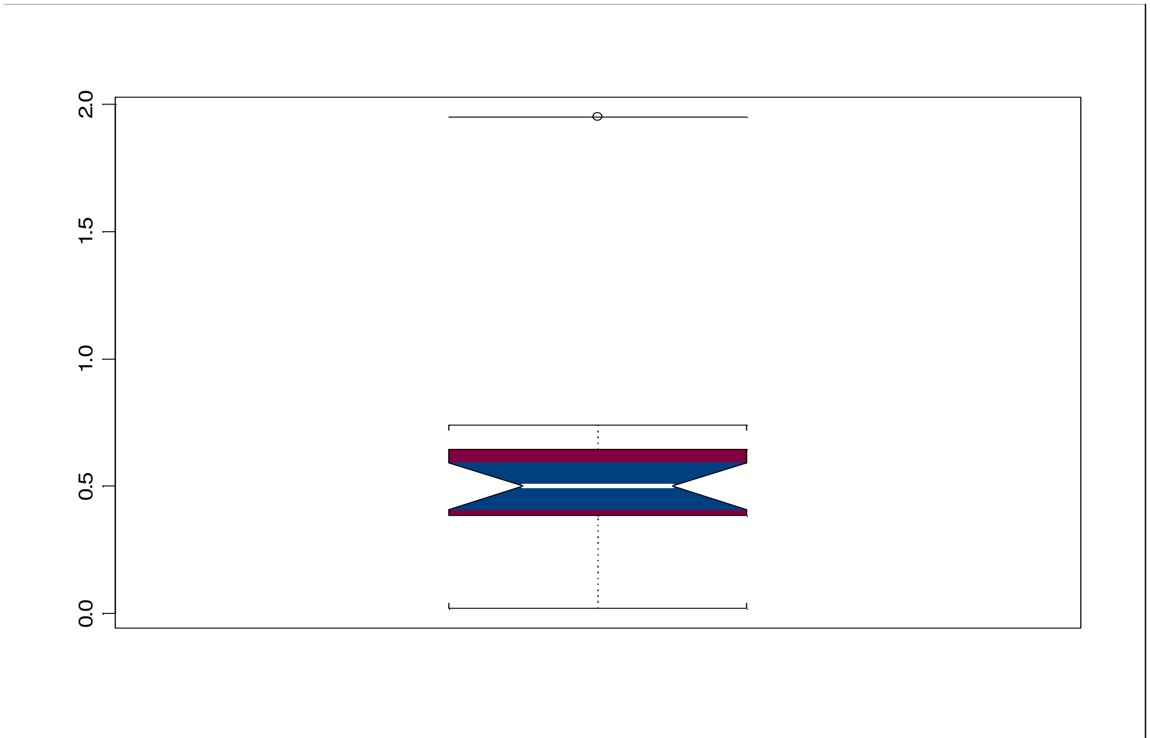

Figure 15. Box plot for the whole-body vibration observations

Figure 15 represents the statistical data in the form of a box plot. From below, the following lines are indicated on the box plot:

- The Lower Extreme (excluding outliers – there are not any outliers indicated on the lower side). Note that any value further than 1.5 times the Inter-Quartile Range is considered an outlier.
- The Lower Quartile, i.e. the beginning of the red section below.
- The Lower Confidence bound for the median (95%), i.e. the beginning of the blue section below.
- The Median which is the white line.
- The Upper Confidence bound for the median (95%) i.e. the end of the upper blue section.
- The Upper Quartile, i.e. the end of the red upper section.
- The Upper Extreme excluding outliers.

- The outliers indicated with lines marked with a small geometric figure (there is only 1 large outlier in the vibration data).

3. COMPARISON OF NOISE AND WHOLE-BODY VIBRATION RESULTS TO NATIONAL AND INTERNATION STANDARDS

The third study objective was to determine whether personal noise and whole-body vibration exposure levels of locomotive operators operating the 10-Ton New Era locomotive in an underground platinum mine over 2008 and 2009 comply with national and international standards.

Table 6. *Summary of the number of L_{TWA} noise exposure results exceeding national and international occupational exposure limits*

Total Sample No.	Total Measurement time (min)	No. & % of Measurements Exceeding the OEL		
		Min	SA OEL ≥ 85dB(A)	OSHA ≥ 90dB(A)
40	23633	52.2	5/40 = 12.5 %	3/40 =7.5%

Five of the 40 measurements were equal to or exceeded the South African Occupational Exposure Limit of 85dB(A), i.e. 12.5% of the total number of measurements. Three of the measurements exceeded the ACGIH threshold limit value of 90dB(A) i.e. 7.5% of the total number of measurements.

Table 7 below, provides a summary of the whole-body vibration exposure results compared with both the ISO 2631-1 standard and the EU Directive 2002/44/EC. The axis with the highest mean RMS acceleration level was selected for comparison to the ISO 2631-1 Health Guidance Caution Zone (HGCZ).

In order to predict the health risk associated with the operating of the locomotive, the 8-hour equivalent frequency-weighted RMS acceleration value A (8) was calculated and compared to the EU limits.

Table 7. *Summary of whole-body vibration results compared to international standards*

		ISO 2631 Health Guidance Caution Zone			EU Directive for Daily Personal Vibration Exposure	
Total No. Samples	**Total Measurement Time (min)**	**No. of samples & % within Acceptable Zone**	**No. of Samples & % in Caution Zone**	**No. of & % Samples likely to Cause Damage**	**No. of samples & %≥Action Limit (0.5m/s/s)**	**No. of samples & % ≥ OEL (1.15m/s/s)**
20	2240	11/20 = 55%	9/20 = 45%	1/20 = 5%	10/20 = 50%	1/20 = 5%

Twenty measurements were taken in total with a total measurement time of 2240 minutes. When evaluating the measurements to the ISO 2631 Health Guidance Caution Zone 55, 45 and 5 % of the measurements were within the acceptable, caution zone and likely to cause damage zone respectively. When evaluating the measurements against the EU Directive for Daily Personal Vibration Exposure 50 and 5% of the measurements exceeded the action limit of 0.5 m/s2and OEL of 1.15 m/s2 respectively.

CHAPTER 4 DISCUSSION AND CONCLUSION

In this chapter, a discussion is included on personal exposure to noise and whole-body vibration from underground locomotives. Specifically, this study quantified personal occupational noise and whole-body exposures to 21 locomotive operators in a Platinum Mine over 2008-2009. The objectives of this study were:

- to describe the eight hour time weighted average occupational noise exposure levels of locomotive operators operating the 10-Ton New Era locomotive in an underground platinum mine over 2008 and 2009;
- to describe personal whole-body vibration exposure levels of locomotive operators operating the 10-Ton New Era locomotive in an underground platinum mine over 2008 and 2009; and
- to determine whether personal noise and whole-body vibration exposure levels of locomotive operators operating the 10-Ton New Era locomotive in an underground platinum mine over 2008 and 2009 comply with national and international standards.

Quantification of employees` exposure, particularly to estimate the risk of hearing loss, is best done by determining the A-weighted sound exposure for a stated time interval; for a representative 8-hour working day, this parameter becomes the LTWA, and is numerically equivalent to the noise exposure level normalised to a nominal 8-hour working day.

In this study, the time weighted average (TWA) noise exposure levels of 40 measurements were calculated. The mean TWA noise exposure calculated was 66.5dB(A) and was lower than the mean TWA value of 90dB(A) reported by Maneylaws et al. (Maneylaws A, 1997). A possible explanation for the lower mean TWA value of 66.5dB(A) obtained in my study could be that whilst the noise surveys were conducted, locomotives were in most cases only operating for 4 hours out of the 8-hour working shift. During the remaining 3 hours, operators were not active in any other task and the only noise they were exposed too was the background noise from the compressed air pipes (70dB(A)).

Additionally, when the locomotives were in operation, higher noise levels (85 – 100dB(A)) were recorded which is similar to results reported by McBride (85–95 dB(A)) (MacBride, 2004). According to McBride, most of the transport and mechanical noise came from diesel powered load handlers, materials and man carrying haulage equipment. The primary noise sources identified were those from the engine, transmission and exhaust. He described that additional noise sources on locomotives and man-handling cars included wheel-track impulse noise and structural vibration (MacBride, 2004).

The mean TWA value reported in my study was relatively low at 66.5dB(A). Nevertheless, this study showed that 12.5% of the total measurements reported exceeded the South African Occupational Exposure Limit (OEL) of 85dB(A) and 7.5% of the total measurements reported exceeded the Occupational Safety and Health Administration (OSHA) Permissible Exposure Limit (PEL) of 90dB(A).

The ISO 2631-1 provides guidance for the assessment of whole-body vibration with respect to health. The standard states that the assessment of whole-body vibration should be made independently along the x -, y – and z-axis of the human body. It identifies exposure guidance based on the Health Guidance Caution Zone (HGCZ), which provides limits for frequency-weighted r.m.s. acceleration levels based on exposure duration. Documentation in ISO 2631-1 states, *`For exposures below the zone, health effects have not been clearly documented and/or objectively observed; in the zone, caution with respect to potential health risks is indicated and above the zone health risks are likely` (ISO, 1997a).*

In my study, the highest vibration magnitudes observed were in the z-axis; the average frequency-weighted r.m.s acceleration for the z-axis was 0.431 m/s2 (Table 4). From the 20 measurement samples that were conducted, 9 samples fell within the `caution zone`, indicating potential health risks, while only 1 sample revealed `a likely cause of damage`.

Results from my study are similar as findings reported in the SIMRAC GEN 503 project (Van Niekerk *et al.*, 1998). Van Niekerk et al. reported moderate predicted health risks from the underground locomotives, when compared to the ISO 2631-1 HGCZ. According to their findings, frequency-weighted r.m.s. acceleration values for the locomotives were below 1m/s2, as compared to the other mining equipment evaluated, such as the front-end loaders and bulldozers, which presented high vibration levels; the z-axis acceleration values were between 2 – 4.2 m/s2.

Eger et al. also predicted `moderate health risks` for the locomotive operators (Edger *et al.*, 2006). The mean frequency-weighted r.m.s. acceleration value was 0.73 m/s2 compared to the 0.63 m/s2 obtained in my study. The locomotives evaluated by Eger et al., could be operated from both a seated and standing position. The measured whole-body vibration exposure was however lower at the operator/seat interface (z- axis acceleration was 0.58 m/s2 compared to the 0.431 m/s2 measured in my study), than at the floor/feet interface (0.76 m/s2). Both of these values still placed the operators within the HGCZ limit for the 8-hours of exposure.

In terms of the ISO standard, vibration health exposures are classified as being either:

- in the likely health risk zone – (likely health risk)
- in the caution zone – (potential health risk), and
- below the caution zone –(`acceptable` level of vibration)

In my study 55, 45 and 5 % of the measurements were within the acceptable, caution zone and the likely to cause damage zone, respectively. Although the majority of the measurements were within acceptable levels of exposure, alarmingly, 45% of the measurements were within the caution zone which may result in potential health effects. Therefore the mine under investigation should take reasonable steps to prevent this proportion of the workforce to fall into the likely health zone category.

In terms of whole-body vibration, the EU Directive gives clear direction for measured vibration levels. Vibration above the exposure value referred to as the `daily exposure action value`, which is set for a daily (8-hour) exposure, at a frequency-weighted r.m.s. acceleration of 0.5m/s2 (when considering the dominant axis of exposure, 1.4awx, 1.4awy, 1.0awz), means that the employer should take action to reduce exposure. In my study, 50 % percent of the measurements exceeded the action limit of 0.5 m/s2 indicating that the mine under investigation should take immediate action to reduce whole-body vibration exposures to locomotive operators to as far below the action limit as reasonably practicable.

A second critical evaluation level, termed the `daily exposure limit value` , set at 1.15m/s2, indicates to the employer that employees must stop performing the tasks that expose them to high vibration levels until such time the situation is rectified. In my study, only one measurement (5%) exceeded the daily exposure limit of 1.15m/s2. Although this may indicate that the locomotive operator workforce of the mine is unlikely to be over exposed to the daily exposure limit, caution must be taken to prevent exposures above this limit and therefore be measured and monitored robustly and frequently.

LIMITATIONS OF STUDY

The following challenges and limitations were presented during the field surveys:

- The number of measurements in my study is limited. Therefore, one should be cautious when interpreting the results.
- When conducting the whole-body vibration measurements, the initial challenge was that data had to be downloaded to a PC situated in a lab 115km away from the test site. This led to delays in conducting the whole-body vibration measurements.
- When issuing noise dosimeters, employees who were paraded by the Mine's access control system, in most cases did not report to the control room. This also led to delays in the sampling schedule.

CONCLUSION

The following conclusion may be drawn from the results presented in this study:

- Evaluation of the noise dosimetry data according to the South African occupational noise exposure limit of 85dB(A) and the OSHA threshold limit value of 90dB(A), indicate that there is a potential of locomotive operators being over exposed to significantly harmful levels of noise; also
- For the whole-body vibration measurements presented here, evaluation against the ISO 2631-1 health guidance zone and the EU Directive exposure limits for 8-hour shift, indicate that whole-body vibration exposure on locomotive operators presents a moderate probability for an adverse health outcome.

Like any other risks at a workplace, noise and whole-body vibration needs to be identified and controlled. Since operators of transport machinery and equipment are exposed to a variety of risk factors such as ergonomics, noise, vibration and temperature extremes that may lead to health problems, the approach to be taken is one of risk management, and this involves identifying the hazards that might exist, assessing them, and relating the findings to employee exposure levels which should be linked or incorporated into the records for medical surveillance.

CHAPTER 5 RECCOMMENDATIONS

Locomotive operators are exposed to potentially harmful levels of noise and whole-body vibration. Interventions to reduce the risk for the occurrence of NIHL and whole-body vibration exposure are therefore recommended and must be based on:

- A quantitative risk assessment which involves the selection of the most appropriate strategy to reduce the noise and whole-body vibration emission to the levels required, and to limit the probability of harmful effects.
- As the noise exposure levels of some of the operators were above the 85 dB(A) criteria, these drivers should be involved in a Hearing Conservation Program. The program must establish a noise-monitoring system that evaluates each locomotive operator's noise exposure sufficiently to determine continuing compliance to noise standards.
- As an early preventative measure, hearing protective devices to prevent further NIHL is advised.
- The extent to which mine workers are exposed to whole-body vibration is not known. There is an urgent need to investigate the importance of workers suffering from lower back injury. It is suggested that whole-body vibration monitoring be made mandatory for all mechanized mines.
- There is also a lack of awareness about vibration hazards and its ill effects. It is recommended that the mine launch and participate in awareness campaigns regarding vibration and the health effects thereof.
- Periodic medical examinations which include recording any change in the locomotive operator's exposure to noise and whole-body vibration should be conducted.
- Generally, more women are introduced in underground operations. Therefore it is recommended that the mine takes special precautionary measures in appointing women as locomotive operators particularly in their child bearing age.

- Finally, based on the results of this investigation, future research to assist the mining industry in making decisions regarding appropriate engineering and administrative controls required to reduce locomotive operators` whole-body vibration exposure levels below the HGCZ limits set out in ISO 2631-1, is warranted.

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APPENDIX I ETHICS APPROVAL